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A CIRCULAR ECONOMY-BASED MODEL FOR ASSESSING THE SUSTAINABILITY OF CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT

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MODEL ZA PROCENU ODRŽIVOSTI UPRAVLJANJA OTPADOM OD GRAĐENJA I RUŠENJA ZASNOVAN NA PRINCIPIMA CIRKULARNE EKONOMIJE

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Abbreviations

UN	**U**nited **N**ations
EU	**E**uropean **U**nion
GDP	**G**ross **D**omestic **P**roduct
CDW	**C**onstruction and **D**emolition **W**aste
BIM	**B**uilding **I**nformation **M**odelling
GIS	**G**eographic **I**nformation **S**ystem
CE	**C**ircular **E**conomy
SDG	**S**ustainable **D**evelopment **G**oals
RU	Preparing for **R**e**u**se
RC	**R**e**c**ycling
CRCA	**C**oarse **R**ecycled **C**oncrete **A**ggregate
RAC	**R**ecycled **A**ggregate **C**oncrete
FRCA	**F**ine **R**ecycled **C**oncrete **A**ggregate
SS	**S**ieve **s**and
DC	**D**own**c**ycling
RE	**Re**covery
ER	**E**nergy **R**ecovery
D	**D**isposal
ID	**I**llegal **D**umping
EWC	**E**uropean **W**aste **C**atalogue
ELW	**E**uropean **L**ist of **W**aste
Eurostat	**Euro**pean **Stat**istical Office
LCA	**L**ife **C**ycle **A**ssessment
ISO	**I**nternational **O**rganization for **S**tandardisation
PEF	**P**roduct **E**nvironmental **F**ootprint
GHG	**G**reen**h**ouse **G**asses
LCC	**L**ife **C**ycle **C**osting
CBA	**C**ost **B**enefit **A**nalysis
DCF	**D**iscounted **C**ash **F**low
FNPV	**F**inancial **N**et **P**resent **V**alue

FRR	**F**inancial **R**ate of **R**eturn
ENPV	**E**conomic **N**et **P**resent **V**alue
ERR	**E**conomic **R**ate of **R**eturn
B/C	**B**enefit-**C**ost
HPM	**H**edonic **P**rice **M**ethod
BREEAM	**B**uilding **R**esearch **E**stablishment **E**nvironmental **A**ssessment **M**ethodology
LEED	**L**eadership in **E**nergy and **E**nvironmental **D**esign
WFD	**W**aste **F**ramework **D**irective
EC	**E**uropean **C**ommission
MFA	**M**aterial **F**low **A**nalysis
WGR	**W**aste **G**eneration **R**ate
WPC	**W**aste **p**er **C**apita
WPA	**W**aste **p**er **A**rea
WPGDP	**W**aste **p**er **GDP**
WPCT	**W**aste **p**er **C**onstruction **T**urnover
MS	**M**aterial **S**tock
MIC	**M**aterial **I**ntensity **C**oefficient
MCI	**M**aterial **C**omposition **I**ndicator
BS	**B**uilding **S**tock
RFID	**R**adio **F**requency **I**dentification
ANN	**A**rtificial **N**eural **N**etworks
MCDM	**M**ulti-**C**riteria **D**ecision-**M**aking
AHP	**A**nalytical **H**ierarchy **P**rocess
SFH	**S**ingle-**f**amily **H**ouse
MFH	**M**ulti-**f**amily **H**ouse
FDR	**F**inancial **D**iscount **R**ate
SDR	**S**ocial **D**iscount **R**ate
CAPEX	**Ca**pital **Ex**penditure
OPEX	**O**perational **Ex**penditure
RWEX	**R**eplacement **W**orks **Ex**penditure
CDEX	**C**learance and **D**econtamination **Ex**penditure
RV	**R**esidual **V**alue

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A Circular Economy-Based Model for Assessing the Sustainability of Construction and Demolition Waste Management

Abstract

In an effort to tackle climate change and decrease the consumption of natural resources, more and more industries worldwide are adopting circular economy principles. The construction industry is no exception; however, the implementation of these principles is beyond satisfactory levels. As a consumer of more than half of the extracted materials and a contributor to more than a third of waste, the construction industry hides great circular economy potential.

In recent years, the scientific community has devoted a great effort to investigate different aspects of construction and demolition waste (CDW) management. The assessment of key aspects of sustainability, such as the economic, environmental and social aspects, were particularly studied, mainly to find the optimal management alternative that would be the least detrimental to the environment and the society. However, the available studies rarely included all three pillars of sustainability. Moreover, management alternatives that were assessed included only recycling, backfilling and disposal in most cases, leaving the treatment options that support circular economy principles such as reuse and high-quality recycling unexplored. Additionally, most of the studies performed sustainability assessments on statistical data of CDW quantities that are often unreliable and may significantly underestimate the sustainability performance.

The main objective of this research was to propose a new model for the sustainability assessment of CDW management and the selection of the optimal CDW management alternative. To achieve this objective, the following specific goals were addressed: 1) setting up a unique material stock database that includes the types and quantities of materials embedded in buildings; 2) proposing possible CDW management alternatives; 3) proposing a model for estimating future quantities and composition of CDW; 4) proposing a model for assessing the sustainability performance of the proposed alternatives; 5) comparing and ranking of CDW management alternatives; 6) analysis of the ranking results and selecting the optimal CDW alternative.

The model was tested in a case study for the management of CDW from residential buildings in Serbia. In this case study, three alternatives: the current CDW management (BAU), the alternative that aims to achieve the EU average CDW recovery rates (EU28(2018)) and the alternative that implements circular economy principles in CDW management practices (CE) were evaluated and ranked. Each alternative was ranked against four different decision-makers scenarios: economic, environmental, social and holistic.

The model includes the integration of the existing and widely used methods: bottom-up inventory analysis and dynamic stock modelling for the estimation of the material stock and CDW quantities and composition, Cost-Benefit Analysis for sustainability assessment and Multi-Criteria Decision-Making Analysis (Analytical Hierarchy Process - AHP) for ranking of the CDW alternatives and choosing the optimal CDW management alternative.

The implementation of the model in the case study for CDW management in Serbia yielded three sets of results. The first set of results was related to the creation of a unique material stock database that included the list of materials embedded in residential buildings built between 1946 and 1990 with detailed specifics (geometry and physical characteristics). Based on this,

the total weight and the composition of the materials embedded in these buildings were calculated. The total weight of material embedded was estimated to be 714.6 million tonnes, out of which 601.1 million tonnes were embedded in single-family house (SFH) buildings and 113.5 million tonnes of materials were embedded in multi-family house (MFH) buildings. The materials with a share of over 80% belong to the mineral fraction (concrete, bricks, tiles, ceramics).

The second set of results included the potential waste quantities and composition when these buildings in Serbia are renovated or demolished. Depending on the renovation alternative, the total amount of waste in the period 2021—2046 ranged between 40.2 and 41.1 million tonnes, with an average annual contribution between 1.5 and 1.6 million tonnes. The sensitivity analysis of the waste quantities showed that these quantities might range between 0.89 and 2.5 million tonnes if the demolition rate changes up to 30%, while the renovation rates do not bring significant changes to the amount of waste. The highest share of the waste stream (67%) is made up of clay and concrete-based materials. Consequently, the waste composition (waste streams) and the possible treatments of these waste streams determine the sustainability performance of three proposed CDW management alternatives for Serbia.

The third set of results was related to the sustainability performance and the ranking of CDW management alternatives. The direct outputs of the Cost-Benefit Analysis (financial and economic net present value) identified cash flow balance and potential economic, environmental and social benefits to the waste operators and the society for each alternative for Serbia. The current CDW management alternative in Serbia was the worst option. The financial and the economic net present values were negative in this alternative, which implies that managing waste under this alternative will not benefit the waste operator or society. On the other hand, the CE alternative was identified as the best option, with both of these indicators positive.

The ranking of alternatives with the Multi-Criteria Decision-Making Analysis resulted in the optimal CDW management alternative under different decision-making preferences. In the environmental and holistic decision-making scenarios, the CE alternative was ranked as the optimal, while the current waste management alternative was ranked as the optimal solution under the economic and social preferences.

In addition, the sensitivity analysis applied to the sustainability performance revealed several critical variables such as the demolition rate, discount rates, capital and operational costs and unit prices of recovered bricks and aggregates. These are the variables that should be carefully considered when waste management strategies are planned.

The case study showed that efficient CDW management practice depends on active participation and partnership of all stakeholders, from policymakers to researchers and practitioners. All these stakeholders may find the proposed model useful from different management aspects. The policymakers may use this model to evaluate the effects of the stricter implementation of the existing regulations and the promotion of new regulations such as the carbon and landfill taxes or even landfill bans for recyclable waste fractions. More advanced instruments would include reusing and recycling subsidies and the implementation of green procurement provisions in public contracts. And finally, in lack of financing for better waste management practices, carefully planned and contracted public-private partnerships may be the right answer that will, in the end, benefit all partners, the environment and the society.

Key words: circular economy, construction and demolition waste, material stock, waste quantification, waste management, reuse, recycling, multi-criteria decision-making

Scientific field: Civil Engineering

Scientific sub-field: Management, Technologies and Project Management in Construction

Model za procenu održivosti upravljanja otpadom od građenja i rušenja zasnovan na principima cirkularne ekonomije

Rezime

Kao odgovor na klimatske promene i smanjenje potrošnje prirodnih resursa sve više industrija širom sveta usvaja principe cirkularne ekonomije. Građevinska industrija nije izuzetak, međutim primena ovih principa je daleko ispod zadovoljavajućeg nivoa. Zahvaljujući činjenici da troši više od polovine iskopanog materijala i da generiše više od trećine otpada, građevinska industrija ima veliki potencijal za primenu principa cirkularne ekonomije.

Naučna zajednica je u skorije vreme, posvetila mnogo napora istraživanju različitih aspekata upravljanja otpadom od građenja i rušenja, posebno procenama aspekata održivosti, kao što su ekonomski, ekološki i društveni aspekt, kako bi pronašla optimalnu alternativu za upravljanje ovim otpadom koja bi bila najmanje štetna po životnu sredinu i društvo. Međutim, dostupne studije retko uključuju sva tri stuba održivosti. Štaviše, alternative za upravljanje koje su procenjivane u studijama su u većini slučajeva uključivale samo recikliranje, nasipanje i odlaganje na deponiju, zanemarujući pri tome opcije tretmana otpada koje podržavaju principe cirkularne ekonomije, kao što su ponovna upotreba i recikliranje koje rezultira kvalitetnim recikliranim agregatom. Dodatno, većina studija je analizirala održivost opcija za upravljanje otpadom od građenja i rušenja na osnovu statističkih podataka o količinama koji su često nepouzdani i mogu značajno potceniti rezultate.

Glavni cilj ovog istraživanja je predlaganje modela za procenu održivosti alternativa za upravljanje otpadom od građenja i rušenja i izbor optimalne alternative. Kako bi se postigao ovaj cilj, postavljeno je nekoliko pojedinačnih ciljeva: 1) formiranje jedinstvenog fonda građevinskog materijala, baze podataka o tipu i količini materijala ugrađenih u zgrade; 2) predlaganje mogućih alternativa za upravljanje otpadom od građenja i rušenja; 3) predlaganje modela za procenu budućih količina i sastava otpada od građenja i rušenja; 4) predlaganje modela za procenu održivosti alternativa za upravljanje otpadom od građenja i rušenja; 5) poređenje i rangiranje alternativa za upravljanje otpadom od građenja i rušenja; 6) analiza rezultata rangiranja i izbor optimalne alternative za upravljanje otpadom od građenja i rušenja.

U tu svrhu, ovaj model je testiran na stambene zgrade u Srbiji. Alternative koje su procenjivane i rangirane su: alternativa sa sadašnjim načinom upravljanja otpadom od građenja i rušenja (BAU), alternativa koji teži da dostigne prosečne evropske procente iskorišćenja ovog otpada (EU28(2018)) i alternativa koji primenjuje principe cirkularne ekonomije u upravljanju otpadom od građenja i rušenja (CE). Svaka od ovih alternativa je rangirana u skladu sa različitim prioritetima donosioca odluka: ekonomskim, ekološkim, društvenim i sveobuhvatnim.

Model koje je predložen integriše postojeće metode koje su široko u upotrebi. Za procenu fonda građevinskog materijala i količinu i sastav otpada od građenja i rušenja korišćena je analiza inventara zgrada i dinamičko modeliranje fonda zgrada, dok je za procenu održivosti i rangiranje alternativa korišćena analiza troškova i koristi i višekriterijumska optimizacija.

Primena modela na izabranu studiju slučaja je dala tri grupe rezultata. Prva grupa rezultata predstavlja kreiranje jedinstvene baze podataka koja sadrži listu materijala ugrađenih u stambene zgrade u periodu od 1946. do 1990. godine sa detaljnom specifikacijom geometrije i fizičkih karakteristika zgrada. Na osnovu ovoga izračunata je ukupna količina i sastav materijala ugrađenog u stambene zgrade. Ukupna težina materijala koji je ugrađen u stambene zgrade iznosi 714.6 miliona tona, od čega se 601.1 milion tona odnosi na zgrade namenjene porodičnom stanovanju, a 113.5 miliona tona na zgrade namenjene višeporodičnom stanovanju. Materijali koji u ovom fondu materijala učestvuju sa preko 80% pripadaju materijalima mineralnog porekla (beton, opeka, keramika).

Druga grupa podataka se odnosi na moguće količine otpada kada se ove zgrade renoviraju ili sruše. U zavisnosti od alternative renoviranja, ukupna količina otpada u periodu 2021—2046 varira između 40.2 i 41.1 miliona tona, sa prosečnim godišnjim prinosom od 1.5 do 1.6 miliona tona. Analiza osetljivosti ovih rezultata je pokazala da se ove količine mogu kretati u opsegu od 0.89 do 2.5 miliona tona ukoliko se stopa rušenja promeni za 30%, dok stope renoviranja nemaju značajniji uticaj na količine otpada. Najveći udeo u količini otpada (67%) imaju materijali na bazi opeke i betona. Shodno tome, sastav i mogući tretmani ovog otpada određuju troškove i prihode tri predložene alternative za upravljanje otpadom od građenja i rušenja u Srbiji.

Treća grupa rezultata se odnosi na analizu troškova i koristi i rangiranje alternativa za upravljanje otpadom od građenja i rušenja. Rezultati analize troškova i koristi su identifikovali alternativu sa sadašnjim načinom upravljanja kao najlošiju opciju. Negativna vrednost finansijske i ekonomske neto sadašnje vrednosti impliciraju da upravljanje otpadom od građenja i rušenja u ovoj alternativi ne donose korist ni operatoru otpada ni društvu. Sa druge strane, CE alternativa se pokazala kao najbolja opcija u kojoj su obe neto sadašnje vrednosti pozitivne.

Rangiranje alternativa pomoću višekriterijumske optimizacije je rezultiralo izborom optimalna alternative u različitim scenarijima odlučivanja. U ekološkom i sveobuhvatnom scenariju odlučivanja CE alternativa je rangirana kao optimalna, dok se u ekonomskom i socijalnom scenariju odlučivanja, sadašnji način upravljanja otpadom od građenja i rušenja pokazao kao optimalna opcija.

Dodatno, analiza osetljivosti procene održivosti je otkrila nekoliko kritičnih parametara kao što su stopa rušenja, diskontne stope, kapitalni i operativni troškovi i jedinične cene opeke za ponovnu upotrebu i recikliranog agregata, koji se moraju pažljivo razmotriti kada se planiraju strategije za upravljanje otpadom od građenja i rušenja.

Studija slučaja je pokazala da efikasno upravljanje otpadom od građenja i rušenja zavisi od aktivnog učešća i partnerstva svih zainteresovanih strana, od istraživača do političara i praktičara. Model predložen u ovom istraživanju bi mogao da bude koristan svima. Političari bi mogli da ga koriste prilikom razmatranja strožijih kontrole i bolje primene postojeće regulative kao i promovisanja novih zakonskih instrumenata kao što su porez na emisiju ugljen-dioksida i porez na odlaganje na deponiju ili čak zabrana odlaganja na deponiju otpada koji se može reciklirati. Napredniji instrumenti bi mogli da uključe podsticaje za ponovnu upotrebu i recikliranje kao i primenu zelenih nabavki u javnim ugovorima. I konačno, u nedostatku finansiranja boljih opcija za upravljanje otpadom, pažljivo planirana i ugovorena javno-privatna partnerstva bi mogla da budu odgovor koji bi koristio svim partnerima, kao i životnoj sredini i društvu.

Ključne reči: cirkularna ekonomija, otpad od građenja i rušenja, fond građevinskog materijala, kvantifikacija otpada, upravljanje otpadom, ponovna upotreba, recikliranje, višekriterijumsko odlučivanje

Naučna oblast: Građevinarstvo

Uža naučna oblast: Menadžment, tehnologije i upravljanje projektima u građevinarstvu

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1 Introduction to the Thesis

1.1 Introduction

This chapter serves as the blueprint for the research and the guideline for future readers. It describes the research context and the research process from the problem that gained the author's attention to the approach chosen to address it. In the beginning, the chapter sets up the research background, justifies the need for the research and outlines the research questions. It also highlights the main objectives of the research and the methodological approach used to reach them. Finally, the chapter ends with an overall review of the following chapters of the thesis.

1.2 Research Background

Ever since the United Nations' (UN) Conference on the Human Environment, held in 1972, the unique race to preserve the planet has started. Back then, the focus was on the cooperation on environmental issues between the countries and the need for environmental research and education. Therefore, the attendees agreed on 26 principles concerning the environment and development (United Nations 1973). Fifty years later, with almost the same focus, we know this is a marathon, but the reward is still promising: a better future for our children. Depending on their starting point, countries had more or less success in adopting these principles. However, the need for environmental research and education remained international. The research you are about to read covers this domain, particularly the sustainability aspects of the construction industry.

Why is the construction industry in the spotlight of this research? Most of the time, when the world (world economy, global governments) speaks about development, it refers to the construction industry. The forecast shows that despite the Covid-19 pandemic, the global construction industry will grow 30% up to 2030, reaching 15.2 trillion dollars (Robinson, Leonard, and Whitington 2021). In 2020, the construction industry in the European Union (EU) had a share of 10.6% of gross domestic product (GDP) and 6.2% of total employment, while investment reached 1,402 billion euros (European Construction Industry Federation 2022). Whether is it the urban renewal, the major transport infrastructure or the complex industrial project in question, it boosts economic growth and creates new jobs. On the other hand, it is held accountable for the severe environmental impact, mainly owing to CO_2 emissions and natural resource consumption (Goubran 2019; Lima et al. 2021). The construction industry, particularly concrete production, is one of the major consumers of raw materials, i.e., limestone, sand, gravel, and crushed stone. These consumption business models are mainly linear, and they generate large amounts of waste worldwide (approximately 3 billion tonnes annually) (Akhtar and Sarmah 2018).

The latest data for 2018 for Europe shows that the construction industry has contributed with almost a billion tonnes of construction and demolition waste (CDW), which represents 35% of the total waste. The records for Albania and Turkey were not available; thus, it is reasonable to expect these numbers to be higher (Eurostat 2021a). Nevertheless, the reported weight of the construction and demolition waste in Europe for 2018 is approximately three times the weight of the entire adult population on Earth (in 2005) (Walpole et al. 2012). Although labelled as an inert and benign type of waste, it became one of the priority wastes streams in the EU (Gálvez-Martos et al. 2018) mostly due to its weight and volume and the vast potential for waste treatment and the use of secondary materials. However, the construction and demolition waste management maturity levels differ across Europe (Deloitte et al. 2017). High rates of recycling are still hard to reach for most European countries. Exceptions are the Netherlands, Italy, Luxembourg, Belgium, United Kingdom of Great Britain and Northern Ireland (United Kingdom) and the Czech Republic, which reported more than 95% of construction and demolition waste's mineral fraction recycled (Eurostat 2021b). However, there is no statistical data on how much of recovered (recycled) material is used in a high-grade application, and this high percentage is mainly attributable to backfilling (C. Zhang et al. 2022). Some of the significant obstacles to higher levels of reusing and recycling that researchers have identified are the lack of regulatory frameworks, incentives and charges, inappropriate recycling technologies, poor quality of recycled products and an immature recycling market (Kabirifar et al. 2020; Z. Wu, Yu, and Poon 2020; C. Zhang et al. 2022).

In addition to barriers, researchers have primarily focused on one of the aspects of construction and demolition waste management: recycling as a treatment method, technical properties of recycled products, different approaches to quantification or different aspects of waste management. Lately, the integration of emerging technologies such as Big Data, Building Information Modelling (BIM), Geographic Information System (GIS) and Circular Economy (CE) principles in construction and demolition waste management were also considered in research studies (C. Z. Li et al. 2020). However, there is a limited number of research studies on the holistic approach to the sustainability performance of construction and demolition waste management, especially through the circular economy lens. There are multiple reasons for this. First, while there is an abundance of studies concerning one or two aspects of sustainability in construction and demolition waste management, the integration of all three aspects is rarely evaluated. Most of the studies investigated construction and demolition waste management scenarios only from the economic or the environmental aspect or even integration of both aspects, while the social aspect was often left out (H. Wu, Zuo, Yuan, et al. 2019). Presently, researchers criticize this partial approach stating that it induces misleading decisions of policy and decision-makers (Iacovidou, Velis, et al. 2017; Ghisellini, Ripa, and Ulgiati 2018; H. Wu, Zuo, Yuan, et al. 2019). Consequently, the need to investigate the effects of all sustainable aspects on different waste management scenarios and to choose the optimal one is emphasized (Jin, Yuan, and Chen 2019; H. Wu, Zuo, Zillante, et al. 2019). This formulates the fundamental question of this research. In response, an integrated decision-support model appropriate for the sustainability assessment of construction and demolition waste management scenarios was designed.

Secondly, the great disparity between the CDW estimation and sustainability assessment results worldwide explains why countries need their estimations and assessments. Particularly, developing countries such as Serbia cannot simply transfer sustainable waste management practices from developed countries due to cultural, economical and practical differences. When it comes to CDW estimation, the studies dealing with the comparison of construction and demolition waste management practices only highlighted the need to bridge this gap by placing construction and demolition waste management comparison in the country or a regional context (Jin, Yuan, and Chen 2019; Kabirifar et al. 2020). This formulates the second research question. This research will answer this question by examining and evaluating the current best practices from Europe, choosing the appropriate ones, and assessing how their application contributes to the sustainability and circularity of construction and demolition waste in Serbia.

And finally, there is a growing interest in the scientific community in the circular economy concepts in construction and demolition waste management. The existing body of literature has identified that most studies analyse only the environmental impact of circular economy principles compared to the economic and the social impacts, while the most investigated waste treatment option is recycling compared to reusing and reducing (Ghisellini, Ripa, and Ulgiati 2018). This calls for further research on circular economy implementation coupled with the integration of environmental and economical, and social impacts. Although holistic, this concept is also location-specific. Its performance depends on the type of construction and the material embedded in it, the availability of treatment facilities when this material becomes waste and the market for salvaged goods. And then, there is the need to ensure that developing countries will meet the circular economy targets. This formulates the final research question: How much can the adoption of circular economy principles enhance the sustainability of construction and demolition waste management? In response to this question, the decision-support model created in this research will place the circular economy principles into the appropriate geographic context (Serbian) and consider the economic, environmental and social impacts on the sustainability of construction and demolition waste management.

1.3 Research Hypothesis and Research Objectives

To overcome the research problem identified above and obtain the answers to the research questions raised, the following research objectives were proposed.

As mentioned in the previous chapter, the core objective of this research was to carry out the sustainability assessment of different construction waste management alternatives, i.e., to propose a decision-support model for integrating the concept of sustainable development and circular economy into a construction and demolition waste management system.

This research hypothesises that a CDW management decision-support model may be created through the integration of bottom-up inventory analysis and dynamic building stock modelling for the estimation of the material stock and CDW quantities and composition, Cost-Benefit Analysis for the sustainability assessment and Multi-Criteria Decision-Making analysis for ranking of the CDW alternatives.

To achieve the main research objective and validate the research hypothesis, several more specific objectives of this research were set:

1. To identify sustainable development goals and circular economy principles and investigate their possible application in the construction and demolition waste management industry;
2. To analyse the origins, composition and physical and chemical characteristics of construction and demolition waste streams and their possible treatment options;
3. To analyse construction and demolition waste management eco-system: the stakeholders, their goals and mutual relations, the legislative and regulatory framework and the economic, environmental and social factors that contribute to management practices;
4. To critically review and evaluate current construction and demolition waste management practices worldwide and choose the appropriate ones to incorporate into the model;
5. To examine existing methodologies for the estimation of construction and demolition waste quantities and for sustainability assessments of construction and demolition waste management;
6. To create an integrated decision-support model for the estimation of quantities and

evaluation of sustainability performance of different construction and demolition waste management options;

7. To validate the decision-support model using the Republic of Serbia as the case study by:
    a) Setting up a database of material incorporated in typical residential buildings (Material Stock database) in the Republic of Serbia and calculating material intensity coefficients;
    b) Designing three case study alternatives for renovation and construction and demolition waste management alternatives (one of which is a baseline) for the Republic of Serbia, which reflect the best current practice in Europe;
    c) Estimating and forecasting the construction and demolition waste generation and benchmark these figures with generation rates in other countries;
    d) Quantifying the economic, environmental and social performances of each construction and demolition waste management alternative;
    e) Comparing and ranking the construction and demolition waste management alternatives and identifying the optimal alternative;
    f) Formulating recommendations to researchers, policymakers and practitioners to ensure the effective and efficient application of circular economy principles and sustainable decision making in construction and demolition waste management.

These research objectives will be achieved with the help of the research methodology that is elaborated in the next chapter.

1.4 Research Methodology

To answer the research questions and meet the research objectives, a broad multidisciplinary approach was adopted. The analysis of all three sustainability pillars of different construction and demolition waste alternatives requested several knowledge areas to be better understood and connected. As one may assume, the domain of possible solutions to the research problem was at the intersection of economic, environmental and social sciences and construction and project management sciences.

The research process followed in this thesis was divided into five logical and chronological stages, which comprise six chapters in total. The first step was to describe the research background, identify the knowledge gap and highlight the research problem that will be addressed. This formed the first introductory chapter of the thesis. The second step was to identify state of the art and place this problem into the appropriate context. This was covered in the literature review chapter, which is the second chapter of the thesis. The third step was to propose a methodology that provides a solution to the problem. The solution was proposed in the third chapter of the thesis. The fourth and fifth steps were to apply and validate the proposed methodology for the case study in Serbia and draw satisfactory conclusions. These correspond to chapters four, five and six, which are the final three chapters of the thesis. An outline of the research process and a brief description of the research activities are described below.

The research problem and the research objectives framed in the introduction were placed into the appropriate context with the help of the available literature review. The literature review helped to create a theoretical foundation and to develop the research framework for this thesis. A comprehensive literature review was conducted on sustainable development goals, circular economy principles and construction and demolition waste management, particularly available models for quantification and sustainability assessment. The search for relevant literature was limited to scientific publications, technical reports and working papers from relevant organizations (i.e., statistical offices, World Bank, United Nations, etc.) and relevant policy documents. The aforementioned terminology was run through the scientific publication databases such as Scopus, Science Direct, and Google Scholar. Most of the scientific publications were published between 2000 and 2021 in the following top tier journals: "Journal of Cleaner Production", "Resources Conservation, and Recycling", "Waste Management", "Building and Environment", "Construction and Building Materials", "Waste Management and Research", "Sustainability" etc. Other types of literature were found on the websites of the corresponding organizations. Both the literature in English and Serbian were included in the review.

The literature review had three goals. The first goal of the literature review was to identify the circular economy principles and current best practices in construction and demolition waste management that can contribute to sustainable development. The second goal was to obtain a deeper understanding of the construction and demolition waste management eco-system, its key stakeholders and their goals and relations, and the nature of construction and demolition waste, its origin, composition, possible treatment, and factors that may contribute to effective waste management practices. And the third goal was to identify, analyse and evaluate the approaches to the possible problem and methods, tools and techniques that can be used for its solution in this research.

The synthesis of major findings from the literature review yielded various research methods to be considered to solve this multidisciplinary research problem. In the end, the proposed solution utilizes several main research methods from different areas of expertise: Inventory, Bottom-up material stock, Cost-Benefit and Multi-Criteria Decision-Making Analysis. These methods are accompanied by a Case study approach and a Scenario Analysis and form a decision-support model developed for assessing the sustainability of construction and demolition waste management alternatives. A brief description of the main methods will follow, while a fully detailed description will be available in Chapter 3. A case study approach to research is used when there is a need to put a research topic in a particular context (Williamson et al. 2002). It is often used in combination with other research methods. In this thesis, it is used with a Scenario Analysis, as future implications of different waste management treatment options need to be considered. These implications considered the cost and revenues of different options from a sustainability perspective. For this purpose, a Cost-Benefit Analysis was used, which is a widely accepted quantitative method for the evaluation of different alternatives based on their associated costs and benefits to society. The method proposed here will follow the guidelines from the European Commission (European Commission 2014a) for the analysis of the economic, environmental and social impacts of the entire life cycle of investment projects.

The next step was to develop three alternatives within a case study that reflect the real-world context and that will give a holistic approach to the research problem. The proposed decision-support model was then exercised on each alternative, and the results of each alternative were recorded. Finally, a Multi-Criteria Decision-Making Analysis was employed to find the optimal alternative for construction and demolition waste management treatment in the context of the observed case study. This method is often used to facilitate different and often conflicting and complex criteria in decision making.

Building from the key findings from previous steps, the conclusion was drawn, and the contribution to knowledge and the limitations of the research were given. Together with the recommendations to researchers, policymakers and practitioners, these formed the final step in the research process.

1.5 Thesis Structure

The thesis is organized into six chapters that follow the hierarchical structure of the research process framework depicted in Figure 1: Introduction, Literature Review, Methodology, Case Study Results, Discussion and Implications of the Case Study Results, and Closing Remarks.

Chapter 1 gives an overall introduction and justification for the research. Additionally, it discusses the research background and sets up the research problem. The chapter also highlights the research questions and research objectives. Subsequently, it provides an overview of the methodological approach to the problem solution. And finally, the first chapter ends with a general review of the thesis.

Chapter 2 builds a state of knowledge and provides a theoretical foundation for the research. It investigates the available literature comprised of several important issues. It starts with an overview of sustainable development goals and circular economy principles and their application in the construction industry. Then it describes the nature of construction and demolition waste, its origins, its possible composition, characteristics and possible treatments of different waste streams. The chapter then focuses on the construction and demolition waste eco-system and its key stakeholders, the economic, environmental and social impacts of waste management practices, the legal and institutional framework and the best management practices. The chapter concludes with a review of research methods that can be used to quantify waste and assess the sustainability of construction and demolition waste management alternatives.

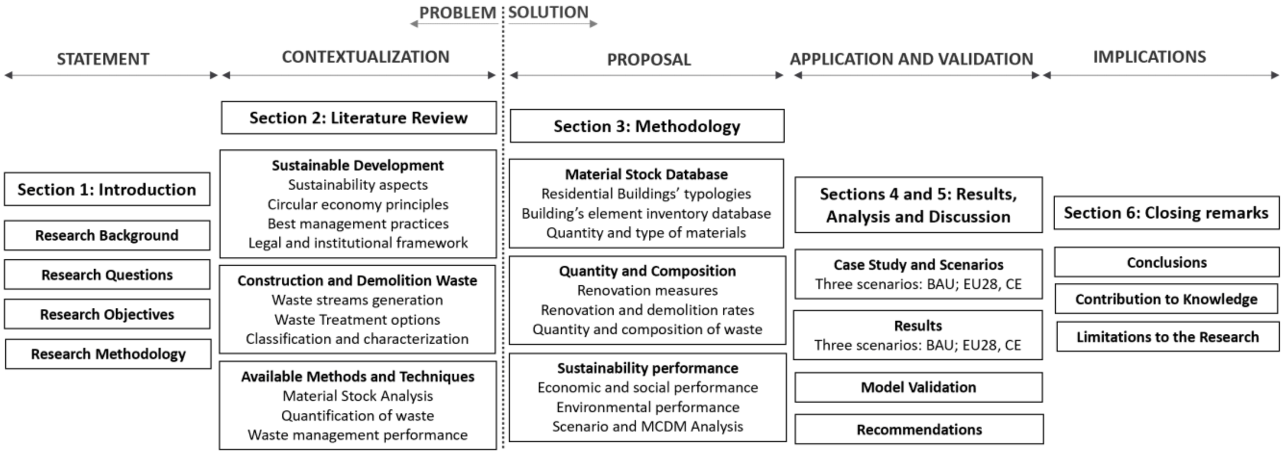


Figure 1 Research framework of the thesis

Chapter 3 is directly developed to meet the core research objective. The chapter elaborates on the steps required to develop the decision-support model that will enable the assessment of different construction and demolition waste management alternatives. The chapter analyses and evaluates the need for this model, the existing methods, tools, and techniques most suitable for it and provides a rationale behind choosing them. Additionally, a detailed description of the model and its main features were presented in this chapter. And finally, issues regarding the implementation and benefits of its application are also provided.

Chapter 4 presents the implementation phase of the research. To do this, multiple CDW management alternatives were developed. Two possible alternatives reflected that decision-makers strategy to boost sustainability and circularity and one that reflected the construction and demolition waste management current practice. A decision support model designed in the previous chapter was applied to these alternatives. The results are then presented systematically.

Chapter 5 evaluates the research that was undertaken and analyses the main results from the previous chapter. These results induced a discussion related to the benefits and disadvantages of the model's implementation, identification of the decision-support model's limitations, as well as suggestions for its improvement, which are also presented in this chapter.

Chapter 6 concludes the research. Building up on previous chapters, it includes the key research findings and the overall conclusion. The chapter also discusses the contribution to the knowledge gap identified. The chapter concludes with recommendations for future researchers, policy makers and practitioners.

1.6 Summary

This chapter presented the overall significance and the approach to the research, as well as the motivation for the research. In the beginning, the research background behind the thesis was described, and the research questions were highlighted. Additionally, the research objectives to be achieved were identified, and the methodology chosen to address them was briefly discussed. This chapter also described and depicted the chronological process of the research and the general structure of the thesis.

2 Literature Review – Construction and Demolition Waste Generation and Management

2.1 Introduction

This chapter serves as the starting point for the research. The chapter starts with a review of a half-century of the sustainable development initiative and a circular economy concept that gained the attention of researchers in recent years. The chapter then described the most important terms and definitions regarding the construction and demolition waste, composition and characteristics of particular waste streams and possible treatment options. The chapter continues with a review of factors that may affect the sustainability of waste treatment options. The factors from all three sustainability domains are considered. Additionally, available policy and institutional frameworks on construction and demolition waste management are considered, alongside the best management practice that is currently available and applicable. The chapter ends with a review of available methodologies for the quantification of construction and demolition waste and an assessment of waste management options.

2.2 (R)Evolution of Sustainability in the Construction Industry

To fully understand how sustainability evolved within the human environment, one must study the work of global organisations. To start, the most prominent among them, The United Nations (UN), has been devoting half of a century to promoting sustainable development. The Stockholm Declaration and Action Plan (United Nations 1973) was a pivotal point that turned the world towards care and improvement of the human environment. Three out of 26 principles that were agreed upon back then had the responsible management of natural resources (renewable and non-renewable) as their focus.

However, one of the first mentions of the phrase “sustainable development” was in Brundtland Report (United Nations World Commission on Environment and Development 1987). It was explained as “the development that meets the need of the present without compromising the ability of future generations to meet their own needs”. The report also highlighted the need to integrate economic growth, environmental protection and social equity in decision making to achieve sustainable development.

Following this report, another declaration and an action plan for the 21st century (Agenda 21) were devised (United Nations Division for Sustainable Development 1993). Although non-binding, the plan encouraged global partnership to achieve sustainable development goals by 2000. The plan included activities on changing the practice of production and consumption and promoting the more efficient use of resources. When it comes to waste, the plan included activities on minimising waste, reducing the amount of waste designated for final disposal, maximising reuse and recycling and promoting safe disposal and treatment. The Millennium Declaration and its eight Millennium goals adopted in 2000 only confirmed commitment to environmental protection (United Nations General Assembly 2000).

However, difficulties and challenges in the years that followed required a new, more ambitious and elaborative agenda (United Nations Division for Sustainable Development 2012). On that account, a UN Resolution (Agenda 2030) with 17 Sustainable Development Goals (SDG) and 169 specific targets to be achieved by 2030 was made (United Nations General Assembly 2015). The agenda called for a balance of all three pillars of sustainability and included goals such as: ending poverty and hunger, ensuring health and well-being, reducing inequality, combating climate changes, improving energy efficiency, promoting sustainable cities and consumption and production, etc.

Europe Unions' efforts to achieve sustainable development goals resulted in 358 both legislative and non-legislative initiatives (European Commission Joint Research Centre 2021). One of them was the Circular Economy Action Plan. The plan identified 54 actions to address ten out of seventeen SDGs. The major focus was on SDG 12, more particular "reduction of waste generation through prevention, reduction, recycling and reuse" (SGD 12.5) (European Commission 2015). The main idea behind the plan was to shift from a linear to a circular economy. The Circular Economy was described as the economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised".

By March 2019, all 54 actions had been or were being implemented (European Commission 2019a); therefore, a new plan was necessary. A new Circular Economy Action Plan with a set of other policies was presented as a part of the EU's "Green deal" initiative. A Green deal initiative represents one of the six priorities of the EU for the period 2019—2024. The overarching goals of this initiative are to make Europe the first climate natural continent and to separate economic growth from resource use by 2050 (European Commission 2019b). To achieve these, an investment plan of at least one trillion euros in the coming decade was made (European Commission 2020d). A minimum of one hundred billion euros will be mobilized for those regions that will be most affected by the initiative.

As mentioned, one of the 47 key actions from the Green Deal is the New Circular Economy Action Plan. The focus of this plan remained on sustainable consumption, resource efficiency and production and the reduction of waste (European Commission 2020a). So, what has been set for the construction industry in this action plan? To start, changing of construction products regulations to include recycled materials, revision of material recovery targets for waste, using the framework for sustainable building (Level(s)), etc. In addition, two more strategies were launched: the Sustainable Built Environment and the Renovation Wave strategy. The first is yet to be launched, and the second was published in 2020. The main objective of this strategy is to at least double the annual energy renovation rate of buildings by 2030 and to maintain the rate and depth of renovation by 2050 (European Commission 2020b).

The scientific community followed the efforts of the UN and the EU. Most researchers agree that the construction industry has a detrimental effect on the human environment, whether through large consumption of natural resources (raw consumption) or CO_2 emission from the production of cement or generation of construction and demolition waste, or energy and water consumption (World Economic Forum 2016; Goubran 2019; Lima et al. 2021). The construction industry's and built environment's traditional practices pose a significant obstacle to sustainable development. One researcher argued that even aesthetic degradation, opportunities for corruption, disruption of communities and health risks on work sites and in buildings might impact sustainability (Sev 2009).

Researchers and practitioners around the world compete in the estimation of how big is the influence of construction and the built environment. For instance, consumption of raw materials and waste generation ranges from 30% (World Economic Forum 2016) to 50% (European Commission 2011), respectively. When it comes to energy demand and greenhouse gasses, the latest data for 2020 show energy consumption of 36% and GHG emissions of 37% (Hamilton et al. 2021). Even fresh and potable water is endangered by construction activity with a share of 12% of the water use (World Economic Forum 2016).

At the same time, governments around the world spend large amounts of money to diminish these effects. Approximately only 3% (184 billion dollars) of the total investment in buildings construction and renovation globally is spent on energy efficiency (Hamilton et al. 2021).

Irrespective of the exact percentages and the amounts of money invested, it is apparent from the above that the construction industry needs to embrace the sustainability principles from all three dimensions to make it more environmentally and socially friendly. Sev (2009) argued that this might be done through three principal challenges: efficient resource management (energy, water, materials and land use), implementation of sustainability in life-cycle design (use of sustainable products, waste management and reusing and recycling of materials, etc.) and human-oriented design (preserving water, flora and fauna, thermal and acoustic comfort, natural ventilation, etc.) (Sev 2009).

A transition from a linear to a circular economy may be one of the answers to these challenges. Among other effects, embracing circularity in construction may have a huge impact, particularly on waste reduction, extraction of natural resources and greenhouse gas emissions (de Wit et al. 2018).

Keeping in mind that the CE approach as a means to achieve sustainable development was created by politicians and practitioners (Korhonen, Honkasalo, and Seppälä 2018), it is no surprise that an abundance of academic studies has been yielded in recent years. These studies clustered around energy efficiency, waste management, sustainability, smart cities and green buildings (Norouzi et al. 2021). In more detail, published papers mainly proposed research frameworks and tried to push the research in the direction of a comprehensive, holistic, interdisciplinary approach and adoption of all three dimensions of sustainability (Pomponi and Moncaster 2017; Korhonen, Honkasalo, and Seppälä 2018). Pomponi and Moncaster (2017) even considered governmental, behavioural and technological dimensions in addition to the economic, environmental and social dimensions. Even though almost half of the papers used a case study as a research method, merely a fifth of them considered this three-dimensional perspective (Homrich et al. 2018).

Other studies focused on initiatives and strategies (Esa, Halog, and Rigamonti 2016; Kalmykova, Sadagopan, and Rosado 2018; Petit-Boix and Leipold 2018) or drivers and barriers to adopting the CE approach (Mahpour 2018; Domenech et al. 2019), action plans (Whicher et al. 2018), implementation frameworks (Jacobi et al. 2018; López Ruiz, Roca Ramón, and Gassó Domingo 2020) and assessments (Ghisellini et al. 2018) of the CE approach, both within the global economy and in the construction sector in particular. For instance, Kalmykova et al. (2018) comprised two databases. The first (CE Strategies Database) includes 45 CE strategies available for the implementation, and the second database (CE Implementation Database) identifies 100 cases where these strategies were implemented (Kalmykova, Sadagopan, and Rosado 2018). On the other hand, Petit-Boix and Leipold (2018) investigated available initiatives and strategies at the municipal level to see how they align with current research. They identified urban strategies as the most important ones to be considered in the municipal circularity quest (Petit-Boix and Leipold 2018). They also recommended an integral assessment of strategies within the geographical context and with both barriers and opportunities for their realising analysed. Esaey et al. (2016) were focused on strategies for the implementation of circularity in the construction and waste management domain. They set up a three-level framework: micro, mezzo and macro to differentiate the potential levels of successful CE implementation (Esa, Halog, and Rigamonti 2016).

Hossain and Ng (2018) made a review of available research on environmental impact assessment studies to identify the gaps for comprehensive assessment and to provide a framework for CE adoption. This suggests that future sustainability assessments integrated with CE principles should provide a benchmark, enhance the accuracy of the assessment and industry collaboration, contribute to decision processes and integrate more resource recovery, etc. (Hossain and Ng 2018).

When it comes to the national level, it should be noted that China, the United States and Europe lead the academic effort (Türkeli et al. 2018; Norouzi et al. 2021). A review of Chines and European literature on cleaner production and circular economy conducted by Ghisellini et al. (2018) and Domenech et al. (2019) found that the full application of circular economy is hindered by legislative and economic barriers and a lack of environmental awareness. According to them, the increase in sustainability may be found in the better integration of economic and environmental dimensions and the development of harmonised assessments in the transition toward a circular economy (Ghisellini, Ripa, and Ulgiati 2018; Domenech et al. 2019).

A contribution to the body of CE knowledge from a few European countries (mainly the United Kingdom, Italy and Spain) calls for more research on this domain. One of the steps to ensure the implementation of CE principles may be found in research conducted by the Iacovidou et al. (2017) study. They proposed a three-phased framework to optimise value for resource recovery: system synthesis, analysis and refinement. These phases are further divided into material flow analysis, metric selections, scenario development, evaluation and reflection and detail analysis and refinement and final evaluation. In the final evaluation, changes in value are assessed from the economic, environmental, social and technical dimensions via a Multi-Criteria Decision-Making Analysis (Iacovidou, Millward-Hopkins, et al. 2017).

Recent review papers showed that academia has just scratched the surface when it comes to a circular economy. The studies predicted that future studies would revolve around smart cities and circular economy, the development and use of alternative construction materials and new circular business models (Domenech et al. 2019; López Ruiz, Roca Ramón, and Gassó Domingo 2020; Norouzi et al. 2021).

2.3 Understanding the Construction and Demolition Waste

2.3.1 Construction and Demolition Waste Stream

In broad terms, construction and demolition waste (also referred to as construction and demolition debris) may be defined as waste that is generated throughout the whole structures' life-cycle activities, from construction to demolition (The European Parliament and the Council of the European Union 2018a). Demolition may be total or partial. Total demolition is the removal of the entire structure, while partial demolition is carried out in the case of renovation, retrofitting or refurbishment of the structure. Although there is a considerable difference between these three terms, when it comes to CDW, the term may be used as interchangeable to include partial demolition and new construction, both of which produce waste.

This waste may be grouped into several waste streams containing construction materials that share similar characteristics. The most common is the mineral fraction (concrete, bricks, rock, gravel, sand, etc.), followed by the metallic fraction (ferrous and non-ferrous), glass, wood, plastic, textile etc. (Eurostat 2013). Additionally, depending on the presence of toxic components (asbestos, gypsum, heavy metals, coal tar, etc.), these fractions may be differentiated as hazardous and non-hazardous wastes.

It should be noted that construction and demolition waste may also be generated after natural disasters (earthquakes, floods, storms, etc.). However, waste generated this way is often contaminated (André Coelho and de Brito 2011) and comes with transportation and storage problems (Akhtar and Sarmah 2018).

Apart from the type of the activity, typical CDW composition or the CDW stream may vary depending on the type of structure that is being constructed or demolished. For instance, during the construction of new buildings, design errors, improper storage, packaging, or breakages may result in significant amounts of metal (from window frames), wood (from formwork), paper or plastic-based (from packaging) and gypsum (from plasterboards) waste streams (André Coelho and de Brito 2011; Paola Villoria Sáez, Porras-Amores, and Del Río Merino 2015). On the other hand, the demolition of buildings will most certainly result in large amounts of concrete and masonry (André Coelho and de Brito 2011; Paola Villoria Sáez, Porras-Amores, and Del Río Merino 2015). Similarly, the construction of roads, railways, airports, tunnels, etc., may produce enormous amounts of soil (Andre Coelho and De Brito 2011) or minor amounts of asphalt in case of road rehabilitation works. Demolition of infrastructure rarely occurs in the built environment. One may say that contrary to civil works, buildings have an abundance of different waste streams and consequently a greater potential for waste treatment.

CDW is mainly inert waste, meaning that there are no significant detrimental consequences on the human environment as other types of waste. However, taking into account its massive volume, the policymakers, practitioners and scientists often mark it as the priority waste stream (European Commission (Directorate-General for the Environment) et al. 2011) probably because a large amount of this waste may be recovered (around 88% in 2018 in the European Union (Eurostat 2021b) and returned into the economy as a resource in some manner.

2.3.2 Construction and Demolition Waste Treatment Options

There are several options available to convert CDW into a resource. The one that maintained the longest between environmental scholars and practitioners revolved around the so-called "3Rs" initiative, where the three Rs represent the acronym of words reduce (prevention), reuse, and recycle. However, back in 2008, these options became mandatory for some European countries when they became a part of the European Commission Waste Framework Directive (The European Parliament and the Council of the European Union 2008). The Directive included two more options: recovery (e.g., energy recovery) and disposal (landfilling). Additionally, the Directive encouraged the Member States to choose an option or options that are the most suitable for the environment. From the environmental point of view, the most desirable option is prevention and should be pursued as much as possible, while the least desirable is disposal.

Even though denominated as the most desirable option, prevention is hardly an option for the treatment of waste. It is described as a "measure taken before the product has become waste" (The European Parliament and the Council of the European Union 2008). The European Commission encourages the prevention of waste through "the use of resource-efficient, durable, reparable and recyclable" products. In the literature, prevention is often called reduction because it can reduce the overall quantity of waste and consequently its adverse impact on the environment.

Strategies for waste prevention of waste may be applied in all phases of a project's life cycle, from planning and design through procurement to the construction and demolition phase. However, the most efficient prevention of waste may happen in the design stage. Here, waste can be significantly reduced through the overall standardisation of materials and building elements, early collaboration of team members during the process, modular design and high quality and accuracy of the design documents (Esa, Halog, and Rigamonti 2017; Ajayi and Oyedele 2018). Apart from being the predominant factors that affect efficient deconstruction, the use of prefabricated components and assemblies may reduce a significant amount of construction waste (even up to 85%) (Huuhka et al. 2015; Akinade et al. 2015; Llatas and Osmani 2016).

Effective strategies for the prevention of waste may also include regulation enhancement (recovery targets, landfill bans and taxes, etc.), raising awareness through training and awards for proper waste management during the procurement stage, as well as efficient site management during the construction and demolition stage (Esa, Halog, and Rigamonti 2017; Kabirifar et al. 2020).

In contrast to prevention, remaining treatment options may be applied when the construction product or material becomes waste. According to the waste hierarchy, they may be prepared for reuse, recycled, recovered or disposed of at landfills (The European Parliament and the Council of the European Union 2008). The following text will explain these treatment options in more detail.

Preparing for reuse (RU) means that the construction products are processed and prepared so they may be used again for the same purpose (The European Parliament and the Council of the European Union 2008). In most cases, this is labour intensive process, which means a low use of energy, and as such, is preferred over other treatment options from the environmental point of view (Addis 2006). After the initial cleaning, the construction element may be subjected to several processes to extend its circularity within the economy. It may be repaired, refurbished or remanufactured to restore its original function, or its function may be repurposed (Kirchherr, Reike, and Hekkert 2017) before its placement on the secondary material market.

Reuse may be adaptive, i.e., the reuse of the entire building or structures or their components (Lauritzen 2019). However, both of these are extremely rare in the built environment because these structures are simply not designed for adaptive reuse. That is why scholars promote this type of reuse as the most superior option and advocate for designing for disassembly (Sanchez and Haas 2018) to enable adaptive reuse.

The most suitable construction and demolition waste for reuse are prefabricated concrete panels, concrete building blocks, clay bricks, clay roof tiles, structural wood and steel, stone paving and walling (Huuhka et al. 2015; Iacovidou and Purnell 2016; Gálvez-Martos et al. 2018; Nußholz et al. 2020). Aside from careful disassembling, cleaning and storage of these elements, the reuse of concrete blocks and clay bricks is faced with an additional challenge – cement-based mortar (Ergun and Gorgolewski 2015). A chemical bond made between bricks and blocks that is produced by cement-based mortar limits their eventual reuse as it requires complex separation techniques. The REBRICK Project, which includes automated sorting and cleaning of bricks by vibration developed by Gamle Mursten company, may be the answer to this challenge (Gamle Mursten Aps Denmark 2022).

Recycling (RC) is a recovery option by which waste is "reprocessed into products and materials or substances whether for the original or other purposes" (The European Parliament and the Council of the European Union 2008). CDW can be recycled directly on a demolition site with mobile recycling plants or off-site at a stationary recycling plant. In contrast to mobile plants, stationary plants may process large amounts of CDW. However, mobile plants prove to be a more viable option, especially when there is an intention to use the recovered material on the same site again (Osmani, Villoria Sáez, and Vitale 2018). Additionally, using mobile facilities for the treatment of concrete significantly decreases transportation costs (C. Zhang et al. 2019).

In contrast to reuse, recycling is a mechanically intensive process. It involves the separation, processing and treatment of waste. Separation techniques may include trommel separators and vibrating screens for particle separation and magnetic separation for metal and more advanced separation methods such as gravity and density separators, microwave and optic sensors and x-rays (Osmani, Villoria Sáez, and Vitale 2018). Other components of the recycling facilities may differ in their equipment depending on the type of waste stream and the desired quality and quantity of recovered material. Before being subjected to one of the waste hierarchy treatments, once separated, CDW is further processed in order to reduce its size or volume. Shredders, grinders, chippers, granulators and hammer mills may be used to reduce the particle size, while compactors and ballers may be used to reduce volume (Osmani, Villoria Sáez, and Vitale 2018).

Some authors propose three types of recycling plants: current advanced process plants, advanced process plants and advanced sorting process plants (Oliveira Neto et al. 2017). The current advanced process plants include an air separator next to the most basic equipment of crushers, screens and magnetic separators. The advanced process plants add two density separation systems to the previous one, while the advanced sorting process plants include near-infrared sorting (Oliveira Neto et al. 2017).

Almost all fractions of CDW may be recycled, but the most common fraction that is recycled is the mineral fraction (concrete and bricks) or mixed non-hazardous CDW. In most cases, these materials are crushed during a process called wet recycling into two fractions: the coarse (4—22 mm) and the fine recycled aggregate (<4 mm) that may be further used and the sludge that is a by-product and is usually disposed at landfills (C. Zhang et al. 2020). The coarse recycled concrete aggregate (CRCA) may be further used as a replacement of natural aggregate in the production of new concrete called recycled aggregate concrete (RAC). The fine recycled concrete aggregate (FRCA) or sieve sand (SS), a combination of cementitious particles and sand, which does not meet quality standards for the use in new concrete is currently used for reclamation of excavation, landscaping, road base filling covering of landfills (Deloitte et al. 2017; C. Zhang et al. 2019; 2020). In the literature, this treatment option is often referred to as downcycling (DC) (C. Zhang et al. 2020) since it degrades the previous application of the construction material.

The more complicated the sorting process is, the higher the quality of recovered material obtained. However, the real challenge for the plant owners is to find an economically viable combination that will result in a cheap separation process and high quality of the recovered material (B. Galán et al. 2019). Recently, more innovative solutions that enable higher valorisation of coarse aggregate and no sludge have been developed under EU funding: C2CA, VEEP (C. Zhang et al. 2020) and RE^4 (Whittaker et al. 2021) projects. C2CA involves an Advanced Dry Recovery (ADR) system that, when applied, may yield higher rates of coarse aggregate without sludge (C2CA Consortium n.d.). On the other hand, the VEEP Project combines an ADR system with a Heating-Air Classification System (HAS) technology as well as ultra-fine wet grinding (VEEP Consortium 2016) to separate clean sand and cementitious particles that can replace cement in new concrete production (C. Zhang et al. 2019). The RE^4

sorting technology is under testing and includes an automated mechanism based on electronic and optical systems (infrared) to detect unwanted particles and a robotic arm used for their removal (Whittaker et al. 2021).

The best reusability and recyclability of CDW are conditioned on the proper preparation of the demolition process on the site (European Commission 2018; B. Galán et al. 2019). This includes deconstruction techniques (share of selective or total demolition) and source separation. In contrast to conventional demolition, selective demolition (deconstruction) includes the disassembly of each construction element that results in sorted demolition waste streams, preserved functions of building components and high quality of recovered material. This type of demolition directly supports reuse and recycling treatment option (Ecorys 2016). On the other hand, conventional demolition derives mixed demolition waste streams that require complex separation procedures and result in limited opportunities for reuse. These mixed streams most often consist of either mineral or metal components (B. Galán et al. 2019). Although the environmental advantages of deconstruction over demolition may be explained by the fact that reuse is a more desirable treatment option, deconstruction may cost more (17%–25% higher) and may take longer (3—5% higher for 90 to 180 m^2 building) (Dantata, Touran, and Wang 2005).

Depending on the available space at the construction or demolition site and the number of resulting waste streams, separation may happen on or off-site. Even though on-site sorting may contribute to the quality and recyclability (Ecorys 2016) and decrease the contamination risk of sorted waste, it may, however, increase collection and transportation costs due to a large number of different streams (Osmani, Villoria Sáez, and Vitale 2018). Whether it happens on or off the site, separation may be manual or mechanical. Their single or combined use depends on the type of waste that needs to be separated.

Recovery (RE) involves using waste as a replacement of other materials for a particular function, such as using waste as a fuel to generate energy or for the treatment of agricultural land, etc. (The European Parliament and the Council of the European Union 2008). The former is often called energy recovery (ER) or incineration, while the latter is called backfilling. Energy recovery as treatment is possible for construction materials with high carbon content and high calorific values, such as contaminated wood, plastic, cardboards, reed and organic materials, or bitumen-based waterproofing membranes (Ecorys 2016). The usual procedure is that the combustible waste is collected and separated from mixed CDW and transported to municipal solid waste incinerators (Hwang, Kobayashi, and Kawamoto 2014). There, energy may be recovered through combustion (produces heat and/or electrical energy), gasification (produces combustible syngas) and pyrolysis (produces syngas, oil and char) (Hwang, Kobayashi, and Kawamoto 2014).

Disposal (D) involves the depositing of non-recovered waste onto land, in seas or oceans or permanent storage of waste containers in mines, etc. (The European Parliament and the Council of the European Union 2008). Even though highlighted as the cheapest option for the inert fractions of construction and demolition waste, it is also denominated as the least preferable, especially due to high volumes and high potential for recovery of this waste stream. Also, it is connected with severe environmental burdens: excessive land consumption, agricultural (arable) land, in particular, leachate emissions to soil and underground water, etc. (Butera, Christensen, and Astrup 2015; Zheng et al. 2017).

When it comes to construction and demolition waste disposal, one problem, in particular, needs to be mentioned. Illegal dumping (ID) is still one of the ways to dispose of CDW, particularly in developing countries without strict supervision and penalties. CDW is usually disposed of near river beds, on agricultural land, in borrow pits, on abandoned construction plots, etc. (Zheng et al. 2017). Even though waste treated this way is mismanaged, illegal dumping should be included in the sustainability assessments due to its impact on environmental degradation and social disturbance.

Finally, choosing an appropriate option for the treatment of CDW highly depends on the composition and the characteristic of a particular waste stream. The usual composition of CDW gives information on the type and the share of particular waste streams, while the characteristics help to determine their treatment option. Considering that information on both are a necessity for a sound and sustainable decision about CDW management, the following subchapters (Subchapters 2.3.3—2.3.4) will discuss these. The first subchapter will enumerate the classes of streams and their shares in the total quantity of CDW, while the following chapter will deal with their features such as the quality of waste streams, presence of hazardous substances, the most suitable treatment option, potential for the secondary material market, etc.

2.3.3 Classification of the Construction and Demolition Waste Stream

In broad terms and depending on its prevailing compound, construction and demolition waste may be grouped as petrous waste (concrete, masonry, stone and their mixtures), non-petrous waste (metal, glass, wood, plastic, gypsum, paper, etc.), organic (reed, etc.) and hazardous waste (products with asbestos, lead, chromium, arsenic-based, brominates, etc.) (Paceho-Torgal et al. 2013; Zheng et al. 2017).

Most of the European waste studies used the European Waste Catalogue (EWC) or the European List of Waste (ELW) for easier referencing when it comes to the composition and classification of waste. This is an effort made by the European Commission to establish and classify the list of all waste for administrative purposes. The 839 waste types are classified and grouped by the source and divided into 20 chapters (European Commission 2014b). Each chapter contains appropriate coding. For instance, the majority of waste that originated in the built environment may be found in Chapter 17 (Construction and demolition waste, including excavated soil from contaminated sites). This chapter is further divided into eight groups, as shown in Table 1. Waste contaminated with hazardous substances is marked with an asterisk (i.e., 17 06 05* - construction materials containing asbestos).

Table 1 List of construction and demolition waste (according to the EWC)

Code	Type of waste
17 01	Concrete, bricks, tiles and ceramics
17 02	Wood, glass and plastic
17 03	Bituminous mixtures, coal tar and tarred-based products
17 04	Metals (including alloys)
17 05	Soil (including excavated soil from contaminated sites), stones and dredging spoil
17 06	Insulation material and asbestos-containing construction material
17 08	Gypsum-based construction material
17 09	Other construction and demolition wastes

However, the European Statistical Office (Eurostat) uses a different classification for waste statistics. The EWC-Stat is used solely for statistical purposes and has 51 categories of waste with appropriate coding. For example, most of the construction and demolition waste streams belong to category 41, which is coded 12.1 (Mineral waste from construction and demolition wastes), and categories 13, 14 and 15, coded 6 (Metallic wastes – ferrous, non-ferrous, mixed), categories 16 and 17 coded 07.1 (Glass waste), etc. (Eurostat 2010). A detailed guide that provides the connection between these two classifications is available. The guideline also includes information on the chemical and physical characteristics, the main sources and inclusions and exclusions from the respective category (Eurostat 2010).

The typical composition of construction and demolition waste depends on several factors. First and foremost, it depends on the type of structure and the method of construction. Keeping in mind that buildings are constructed with different methods, components and volumes, they have entirely different compositions and amounts of CDW from roads and railways. For instance, the amount of minerals in roads is approximately 1.8 times higher than in residential buildings (Wiedenhofer et al. 2015). However, the mineral composition in buildings significantly differs from the one in roads or railways, as buildings are made mostly from concrete, bricks, ceramics and wood, while soil and aggregates dominate road construction and even steel in the case of railway construction. Even various building structures may yield different quantities of waste when demolished. For instance, the amount of concrete waste stream in predominantly concrete structures may be 2.5 to 7 times higher than in blocks and wooden structures, respectively (Cha et al. 2020).

On the other hand, the traditional construction method tends to produce more waste than the "modern" construction method. The differences in the generation of waste between these two methods even encouraged some researchers to compare how significant this difference might be. Mah, et al. (2016) found that the mixed-construction method may produce three times less waste than the traditional construction method (Mah, Fujiwara, and Ho 2016). This may be explained by the fact that instead of the labour-intensive casting of concrete on the site, structure components are fabricated in factories in a controlled environment and with a minimised amount of waste in production. With huge potential for reuse, prefabrication could also decrease potential demolition waste in the future (Kabirifar et al. 2020).

Another important factor that affects the composition and the characteristic of CDW waste is the type of activity. Typical construction and renovation waste differ from renovation and demolition waste. Recent studies show that, in addition to concrete, metal and wood have a significant contribution to the total amount of waste, up to 7.7 and 9.2% (Paola Villoria Sáez et al. 2018), respectively. On the other hand, if the soil is excluded, the major demolition waste streams in buildings are mixed CDW (36.3%) (Iodice et al. 2021), concrete (up to 64%) (Hoang et al. 2020) and bricks (up to 60%).

Even demolition waste may differ depending on the demolition technique, i.e., whether source separation exists or not. As one may assume, source separation largely contributes to better CDW management. In contrast to mixed CDW fraction that requires advanced sorting techniques at the recycling treatment facilities (Oliveira Neto et al. 2017), source separation includes separation of hazardous wastes and fixation materials, deconstruction and mechanical demolition (Ecorys 2016). This technique could purify the main waste stream and may yield a wide range of waste streams that could be reused, such as glass, woods (walnuts, oaks, etc.), window frames, steel structures, cladding materials, or concrete, mineral and glass wool, gypsum or insulation foam that could be recycled (Ecorys 2016).

The composition is also closely related to the geographical location of construction objects, meaning that the composition of CDW greatly varies worldwide. The most notable differences between Europe and Asia are in the brick waste stream, i.e., Asian countries, South Korea (Cha et al. 2020) and Vietnam (Hoang et al. 2020) generated less brick waste than European countries. Comparatively, there are differences even across Europe, particularly in the wooden and metal waste streams. The amount of wood waste is greater in Northern Europe (Sweden) (Gontia et al. 2018), where wooden building structure prevails, in contrast to Southern (Italy) (Miatto et al. 2019; Iodice et al. 2021) and Central (Austria) Europe (Kleemann et al. 2017) with high amounts of stone and brick-based waste. Sweden may generate more wood and metal waste than Italy and Austria.

Finally, it has to be noted that the period of the construction may also affect the composition of CDW. Apart from the obvious connection with the service life of construction materials and renovation and demolition rates, the period of construction is associated with the availability and usability of certain materials and products for buildings and the presence of hazardous substances. For instance, one of the important time-dependent characteristics of construction material is the use of lime in the mortar, which moderately declined with the introduction of cement. However, the environmental aspect and the possible reuse of bricks favour lime over cement as a binder, as cement has stronger chemical bonds with bricks, which makes it harder to separate (Ergun and Gorgolewski 2015).

A more detailed description of construction material physical and chemical characteristics, especially contaminates, possible treatments when these materials become waste, and possible application of recovered components and products will be provided in the following subchapter.

2.3.4 Characterisation of Construction and Demolition Waste

The following chapter contains a detailed overview of major CDW streams with the possible and most used options for treatment, the products that may be recovered during this process and their possible application. A more concise overview is given in Table 2. Waste streams are grouped according to the EWC classification. Since hazardous substances require special treatment, they were excluded from the table but included in the text that follows. When it comes to disposal, although it is still one of the options for CDW treatment, it was excluded from the table as it should be avoided for the majority of waste streams.

As mentioned before the largest share of CDW is the concrete waste stream owing it to the fact that it is one of the most frequently used materials in the construction of buildings and infrastructure (Villagrán-Zaccardi et al. 2022). With its worldwide usage, there is no evidence that the world demand for concrete will decrease. Concrete may be found in buildings, where it is used for the structure of the entire building, i.e. foundations, slabs, columns, walls, beams, etc. Its widespread use also hides the great potential to reduce the environmental impact either through minimisation of primary raw materials (aggregates) extraction or through avoidance of new cement production.

After an on-site separation of impurities (wood, plastic, etc.), recoverable materials concrete waste can be reused, recycled, recovered (i.e. through backfilling), or disposed of at landfills. The most common treatment of this type of waste is recycling and using it in new concrete production or downcycling and using it for low-grade applications such as backfilling. Commonly, recycling facilities use crushers for size reduction, magnetic separators and rotating screens for recovering metals and fine particles. Recycled aggregate is then classified by spirals, air sifters and wet jigs (B. Galán et al. 2019) into coarse recycled aggregate and fine recycled aggregate.

Recycled aggregates have wide applications: high-grade in new (structural) concrete and low-grade in concrete products such as blocks, tiles, composites with other materials or as backfilling and land reclamation material. According to some standards and codes of practice, CRCA may replace natural aggregate in structural concrete production for up to 30%, while FRCA may be used in cementitious mixtures in the range of 20—30% (Villagrán-Zaccardi et al. 2022). Some argued that when properly pretreated and carbonated with CO_2 to increase compressive strength and fire resistance and reduce drying shrinkage, RAC can fully substitute natural aggregates in concrete blocks (Meng, Ling, and Mo 2018). However, this high-grade application is still limited even in countries with mature CDW management practices, such as the Netherlands, where only 3% of concrete is used for new concrete (C. Zhang et al. 2020).

Table 2 Overview of CDW streams, treatment options and possible application of recovered materials

EWC Code	Waste type	TO	Recovered products	Possible application
17-01	Concrete Bricks Tiles and ceramics	RU, RC, RE (DC)	Recovered prefabrication elements Recovered bricks Coarse RCA (4—22 mm) Fine RCA (<4 mm) Mixed recycled aggregate	Prefabrication elements; Concrete and concrete products (incl. RAC, asphalt, blocks, tiles, composites with glass, etc.); Backfilling (road base, etc.), reclamation of excavation, landscaping, landfill covering;
17-02	Wood Glass Plastic (PP, PS, EPS, XPS, LPDE, HDPE, and PVC)	RU, RC, ER, RE (glass, wood)	Wooden beams, boards, chipped wood, RDF and SDF Glass pellets, fibres, wool, foamed glass Recovered plastic pipes and claddings Recycled plastic aggregate Plastic fibres RDF and SDF	Beams, particle boards, laminated wood, wood composites (for flooring, sound barriers, ceilings, internal walls), shredded wood for landscaping, energy recovery of contaminated wood; Glass-based composites with plastic (for wall panels, cladding, pipes and ducts, etc.), glass-based composites with concrete and polymer, fibreglass insulation, aggregates in concrete; Recovered plastic elements, plastic composites, insulation (PS), highway barriers (PVC), energy recovery
17-03	Bituminous mixtures, coal tar and tarred-based products	RC, RE, ER	Recycled asphalt concrete RDF (bituminous roof sheets)	Asphalt and asphalt products; Road bases, parking and pathways Energy recovery
17-04	Metal (Copper, bronze, brass, aluminium, iron and steel)	RU, RC	Recovered elements Scrap metal	Recovered elements; Melted and processed in new metal sheets
17-05	Soil, stones and dredging spoils	RU, RE	Recovered stone elements	Recovered elements; Backfilling (road base), reclamation of excavation, landscaping, landfill covering;
17-06	Insulation material and construction material containing asbestos	RU, RC, ER, RE	Recovered insulation. layers Recycled RDF	Cement and fibre-based composites Energy recovery Asbestos should be disposed of at landfills under special conditions (proper sealing)
17-08	Gypsum-based construct. material	RC	Crushed aggregate (Coarse and fine)	Plasters, composites with plastic, wood, rubber and ceramics (boards, bricks and tiles), gypsum boards, soil amendment;

Data source: (Savić 2015), (Gu and Ozbakkaloglu 2016), (Iacovidou and Purnell 2016), (V. W. Y. Y. Tam, Soomro, and Evangelista 2018), (Osmani, Villoria Sáez, and Vitale 2018), (Sormunen and Kärki 2019), (Whittaker et al. 2021) (C. Zhang et al. 2022). TO – treatment options; PP – polypropylene; PS – polystyrene; EPS and XPS – expanded polystyrene; LPDE, HDPE – low-density and high-density polyethylene; PVC – polyvinyl chloride; RU – reuse; RC – recycling; RE – recovery; ER – Energy recovery; DC – Downcycling; RDF – Refuse derived fuel; SRF – Solid recovered fuel;

Concrete, i.e. components made of prefabricated concrete (beams, columns, hollow core slabs, etc.), may also be reused in new structures, but this rarely happens as buildings need to be designed for easy disassembling without damaging the elements (dry joints between the precast elements) (Iacovidou and Purnell 2016). On the other hand, concrete blocks connected with lime mortar, pavings slabs and roof tiles may be easily disassembled and reused.

The second most used materials with an increasing demand after concrete are bricks, meaning that construction and demolition activities generate large amounts of brick waste streams. Bricks (and blocks) are building elements produced mostly from clay. They are often referred to as masonry as they need to be laid and bound with mortar. In buildings, they are used for walls and slabs to some extent. Other clay products used for the roof, floor and wall coverings and bathroom fixtures in buildings are tiles and ceramics.

Before any treatment of the brick waste stream, it is desirable to recover any whole bricks and prepare them for reuse. Similarly to concrete blocks, this is only possible for bricks that are connected with traditional mortars, such as lime (Iacovidou and Purnell 2016). Other bricks need to be cleaned from mortar and plaster as much as possible before recycling. In recycling facilities, bricks are further crushed, screened and sorted in different sizes into coarse and fine particles. The coarse brick recycled aggregates may replace natural aggregates in concrete, while fine particles (brick powder) may replace cement in the mortar (T. Wang et al. 2018). Recycling of mortar still poses a challenge to researchers. There are two main reasons for this: it is hard to separate mortar from concrete in the recycling process, and even if recovered, mortar would reduce the compressive strength of concrete made from it (T. Wang et al. 2018).

Similar to crushed concrete, crushed bricks are characterised by high absorption of water and low density and compressive strength (Meng, Ling, and Mo 2018). However, a combination of fine particles of RCA and crushed bricks provide a better strength of the recovered product as fine particles of crushed brick fill the gaps. This is the reason why some researchers suggest the application of fine recycled brick aggregate in a range of 50-75%, while coarse aggregate is limited to 25% (Meng, Ling, and Mo 2018).

Most of the metal waste in the construction industry, especially in residential building construction, comes from its use in concrete as reinforcement or for mechanical or electrical installation and finishing works. Other uses include structural elements such as beams, columns, claddings, pipes in non-residential buildings and infrastructures. These metals can be ferrous and non-ferrous, i.e., steel, aluminium and copper. In terms of metal waste, any other recovery or disposal other than reuse and recycling should not be considered. It can be either remelted to produce new elements, or steel elements may be disassembled and prepared for reuse (C. Zhang et al. 2022). According to Villoria Sáez and Osmani (2018), the collection process involves disassembling of large components and collecting metal scraps. These scraps are then subjected to a system of conveyers, mills, radiation detectors and air flows and liquid floating systems to separate ferrous, non-ferrous and non-metallic materials (Osmani, Villoria Sáez, and Vitale 2018).

When it comes to wood in the built environment, it is used for building and roof structure, flooring, window and door frames, doors, etc. As a waste stream, if properly maintained and disassembled et the end of the service life, the wooden elements that have the highest potential for reuse are structural wood (beams and columns) and wooden floorboards (Iacovidou and Purnell 2016). Wood also has high recycling potential, and if not reused, it can be recycled and further used for chip-based (laminated wood, wood-based panels) or fibre-based products (pellets, animal bedding, etc.) (Whittaker et al. 2021). A wood cleaned from preservatives, fungal infestation, and metal fittings and paints is a precondition for high reuse and recycling rates (Whittaker et al. 2021). Recycling of wood is sometimes limited by the presence of chemicals that require additional physical, chemical or biological treatment before further use. For that reason, the only option for the treatment of contaminated waste wood may be a recovery of energy in incineration facilities (Osmani, Villoria Sáez, and Vitale 2018).

When it comes to glass and plastic, the most prefered treatment options are reuse and recycling. For instance, glass panes and panels may be reused, while other types of glass may be recycled and further used in new glass production, for backfilling or even as an additive for new concrete (C. Zhang et al. 2022). The recycling process for glass involves washing, drying, sorting, milling and melting into glass culet (Sormunen and Kärki 2019). On the other hand, plastic pipes and claddings may be recovered for reuse or plastic waste may be recycled or used as fuel for energy recovery (C. Zhang et al. 2022). Recycled plastic may be used as aggregate in the production of lightweight concrete, or it may substitute steel fibres in concrete (Gu and Ozbakkaloglu 2016).

Gypsum waste is currently mostly landfilled, although it can be effectively recycled (Jiménez Rivero, Sathre, and García Navarro 2016). Some authors argue that up to 25% of recycled gypsum can be successfully used for the production of new plasterboards (Osmani, Villoria Sáez, and Vitale 2018). This is limited by the amount of paper and fibre, and other impurities. Gypsum waste may also be used to absorb moisture and reduce soil erosion. On the other hand, depositing gypsum in mixed waste landfills may have a hazardous impact on the environment, as the occurrence of rain in these landfills may cause the release of hydrogen sulphide that may be lethal in high concentrations (European Commission (Directorate-General for the Environment) et al. 2011).

A significant number of other hazardous substances are present in different elements of buildings, and they may be released into the environment during renovation and demolition activities. These substances have to be separated at the source (V. W. Y. Y. Tam, Soomro, and Evangelista 2018) before other treatments or disposed of in a proper way to diminish risks to the environment and human well-being. Aside from phenols and polychlorinated biphenyls (PCBs), which may be found in coatings, adhesives, sealing and flame-retardant paints, buildings contain a lot of lead-based paints and asbestos (V. W. Y. Y. Tam, Soomro, and Evangelista 2018). Long exposures to lead and lead poising have significant toxic effects on neurological, cardiovascular, haematological, immunological and reproductive health, especially in children or older adults that have had higher exposures in the past (Abadin et al. 2020). Even though most countries have recognized the toxic effects and banned or limited the application of lead-based paints (Tagliarino, Moses, and Excell 2016), they may be found in doors, window and door frames, stairs, railings, etc. in structures built before when these regulations came into force.

Another harmful substance that may be found in the built environment is asbestos, which is classified as carcinogenic (U.S. Department of Health and Human Services (HSS); Agency for Toxic Substances and Disease Registry 2001). If breathed in during demolition activities, it can cause lung scarring and inflammation (U.S. Department of Health and Human Services (HSS); Agency for Toxic Substances and Disease Registry 2001). The stoppage of asbestos use in the built environment started in the 1970s and 1980s when most European countries introduced bans on some sort of asbestos products. The EU officially banned all types of asbestos in 1999 (European Commission 1999). However, some countries still use it for residential buildings either for cement-asbestos pipes (United States of America) or corrugated asbestos cement sheets for roofing (India, Russia, Brazil) (Jinhui Li et al. 2014; Paglietti et al. 2016).

2.4 Managing the Construction and Demolition Waste Stream

2.4.1 Sustainability Aspects of the Construction and Demolition Waste

When it comes to the sustainability aspect of construction and demolition waste management sectors, two important things must be noted. The first is that the performance of different CDW management alternatives must include all three aspects of sustainability (environmental, economic and social), and the latter is that the sustainability impacts must be assessed for the entire management process, through all stages, from demolition, sorting and transport to different recovery options and disposal. Only this holistic approach to sustainability and CDW management may facilitate better judgments and more informed decision-making. For this reason, the following subchapters (Subchapters 2.4.1.1—2.4.1.3) are devoted to a better understanding of the sustainability and CDW management domains.

2.4.1.1 Environmental Impacts of Construction and Demolition Waste

The environmental performance of the various system and products has been in the scientific and practitioners' focus for decades, with Life Cycle Assessment (LCA) as the most used technique for the evaluation of environmental impacts. The framework and principles under this technique were also recognised by the International Organization for Standardisation (ISO), which published a standard ISO 14040:2006 related to LCA. It is no surprise then that LCA was also the most used for the analysis of environmental performance in the CDW management sector (Ghisellini, Ripa, and Ulgiati 2018; H. Wu, Zuo, Yuan, et al. 2019).

For years different LCA methodologies have been developed with their own set of indicators. According to Ghisellini, Ripa, and Ulgiati (2018), the most used methodologies in environmental impact assessments in the CDW management sector were Eco-Indicator 99 (Goedkoop and Spriensma 2001), CML2001 (Guinée et al. 2001), IMPACT 2002+ (Jolliet et al. 2003), and IPCC 2007 (Pachauri and Reisinger 2007). Furthermore, two more methodologies stood out: ReCiPe (National Institute for Public Health and the Environment and Ministry of Health Welfare and Sport Government of Netherlands (RIVM) 2011) and ILCD 2011 (European Commission (Joint Research Centre - Institute for Environment and Sustainability) 2010).

Built upon existing methodologies, particularly ILCD, the European Commission has recommended another methodology for the evaluation of life cycle environmental performance – the Product Environmental Footprint (PEF) in recent years (European Commission 2013). However, the use of this method in the existing studies is still very limited.

Although different in the evaluation approaches, the methodologies usually have common environmental indicators. These indicators are grouped under the environmental areas that need to be protected, such as human well-being (human health), environment (both natural and man-made) or ecosystem quality and resources. Some methodologies evaluate the climate change indicator as a separate category (Jolliet et al. 2003). Table 3 offers a review of the methodologies, the environmental indicators used in them and their categories. Although the areas of protection overlap for certain indicators in most methodologies, as some indicators belong to two or more categories, due to simplicity, the indicators in Table 3 are assigned to the most prevailing category (area of protection).

Table 3 shows that when it comes to human well-being, most methodologies cover several impacts that contribute to human health damage: human toxicity, ionising radiation and stratospheric ozone depletion that can cause cancer and particulate matter and photochemical ozone formation that can cause respiratory problems (Goedkoop and Spriensma 2001; Jolliet et al. 2003).

In terms of ecosystem quality, pollution to air, water and soil, as well as global warming potential and land used, are the environmental impacts covered with the majority of methodologies. In particular, the presence of ecotoxic substances (heavy metals) in the environment such as arsenic (As), chromium (Cr) and antimony (Sb) (European Commission (Joint Research Centre - Institute for Environment and Sustainability) 2012) and acidification and eutrophication that is caused by the depositions of sulphates, nitrates and phosphates in soil and water (Goedkoop and Spriensma 2001). Two other indicators that may influence ecosystem quality are land use and global warming potential. The land use indicator differs between two states: land that is already occupied and cannot be returned to its previous (natural) state and the land that will be converted (Goedkoop and Spriensma 2001). And finally, the most used indicator in the LCA methodologies is the global warming potential (sometimes also referred to as climate change or carbon footprint). Global warming is caused by greenhouse gasses (GHG) and aerosol emissions such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), etc. (Pachauri and Reisinger 2007). To measure and compare the global warming effects of different GHGs, a common scale expressed in carbon dioxide equivalents (CO_2eq) was developed. This means that the global warming potential of CO_2 is set at 1, while the global warming potential for CH_4 is 28, which implies that its potential is 28 times higher than the same amount of CO_2 (Shukla et al. 2022).

Table 3 Review of environmental impact assessment methodologies and their indicators

Impact assessment category Indicators	**Eco-indicat.99**	**CML2001**	**IMPACT2002+**	**IPCC2007**	**ReCiPe**	**ILCD/PEF**
Human well-being						
Human toxicity	●	●	●		●	●
Particulate Matter	●		●		●	●
Ionizing radiation	●	●	●		●	●
Stratospheric ozone depletion	●	●	●		●	●
Photochemical ozone formation		●	●			●
Odour (air and water)		●				
Noise		●				
Casualties		●				
Ecosystem quality						
Ecotoxicity (Freshwater, marine, terrestrial)	●	●	●		●	●
Acidification	●	●	●		●	●
Eutrophication	●	●	●		●	●
Waste heat		●				
Desiccation		●				
Global warming (climate change)	●	●	●	●	●	●
Land use	●	●	●		●	●
Resources						
Resource depletion (Abiotic and biotic)	●	●	●		●	●

When it comes to resources, the most investigated indicators are the depletion of resources caused by mineral (iron ore) and bulk materials (sand, gravel, lime) extraction, non-renewable energy consumption (fossils fuels), environmental resources consumption (water, air, soil) and biotic resources consumption such as fish, wood, etc. (Goedkoop and Spriensma 2001).

The indicators from all three areas of protection may be evaluated for each stage in CDW management: demolition, collection and sorting, transport, treatment and disposal. However, some researchers argued that the environmental performance of CDW management might be focused just on key indicators (Blengini and Garbarino 2010; H. Yuan 2013). Evaluation of indicators may result in either environmental burdens (depletion of mineral resources, non-renewable energy consumption, arable land consumption, air, water and soil pollution) or environmental benefits (avoided mineral extraction, savings in landfill space or reduced demand for non-renewable energy).

When looking at the individual stages of CDW management, the demolition and the transport stage have no environmental benefits. During the demolition process, a significant emission of GHG and dust is produced in addition to large amounts of diesel that are consumed by the machinery, especially during traditional demolition (Martínez, Nuñez, and Sobaberas 2013). However, the majority of research papers highlight the transportation stage as the one with the highest negative impact on the environment (Penteado and Rosado 2016; Borghi, Pantini, and Rigamonti 2018; Ferronato et al. 2021). This is because, with the increase in transportation distances, both the GHG emissions and the consumption of fossil fuels increase. For that reason, researchers argue that on-site recycling is better than off-site recycling (Ortiz, Pasqualino, and Castells 2010; Hossain, Wu, and Poon 2017).

When it comes to treatments, both the environmental burdens and benefits may be evaluated. Burdens mainly come from processes such as recycling and energy recovery, which consume energy and produce greenhouse and other toxic gasses (e.g. dioxins) (Duan et al. 2019). Additionally, disposal has no benefits (Butera, Christensen, and Astrup 2015) as it consumes arable land, reduces soil productivity and may cause landslides (Zheng et al. 2017). CDW on landfills may contain heavy metals (Zheng et al. 2017), and uncontrolled landfill fires produce fly ash while heavy rains cause leachate (Duan et al. 2019) that may contaminate soil and cause underground water pollution. On the other hand, better treatment of CDW may bring considerable benefits to the environment. These benefits in most cases comes from the avoidance of raw material extraction and landfill avoidance (Di Maria, Eyckmans, and Van Acker 2018; Wijayasundara, Mendis, and Crawford 2018; Jain, Singhal, and Pandey 2020; Ram, Kishore, and Kalidindi 2020) and the reduced demand for energy (K. Chen et al. 2021).

The aforementioned implies that the total environmental benefits of better CDW management depend on the particular waste stream and may occur only as a trade-off between the burdens from demolition, transport and disposal and benefits from treatments such as the avoidance of material extraction land use and energy consumption. These trade-offs for the metal and wood waste stream are also noted by numerous researchers, who reported that the benefits of metal recycling (avoidance of raw material extraction) and energy recovery from wood (generation of thermal and electrical energy) go beyond the burdens that these treatments impose (Blengini and Garbarino 2010; Kucukvar, Egilmez, and Tatari 2014; Vitale et al. 2017; T. Wang et al. 2018).

2.4.1.2 Economic Impacts of Construction and Demolition Waste

In the broadest term, the economic viability of CDW management practice may be assessed through the evaluation of the cost incurred and the revenue earned during the entire (including demolition, collection, treatment and transport) process. To evaluate these indicators, different methodologies were employed by the scientific community and practitioners. Life Cycle Costing (LCC) and Cost-Benefit Analysis (CBA) were one of the most used.

Often coupled with the LCA (Martinez-Sanchez, Kromann, and Astrup 2015; Miah, Koh, and Stone 2017) to evaluate the performance of different waste management alternatives, LCC is a widely used method for the evaluation of economic performance. It is a technique for the economic analysis of cost and benefits across the life-cycle of the investment. Typically, it covers all stages of the financial investment, such as "*investment, operation, maintenance, demolition and disposal*", and includes a risk and sensitivity analysis (Miah, Koh, and Stone 2017).

Another widely accepted method but rarely used for the evaluation of CDW management is the

CBA. This is a decision support technique for the financial and economic analysis of long-term investment projects in different sectors. While the financial analysis provides information about whether the project is financially viable, i.e., does it need to be co-financed, the economic analysis gives justification for this co-financing by proving that the project will be beneficial to society. The technique considers future costs and benefits expressed in real market prices (financial analysis) and shadow prices (economic analysis) that reflect social opportunity costs (European Commission 2014a). A Discounted Cash Flow (DCF) method is then applied to the cash flow balance (difference between revenues and costs), and a net present value is calculated. To allow for comparison between different alternatives, the project performance is expressed with two sets of indicators, the financial and the economic. Financial indicators are the Financial Net Present Value (FNPV) and the Financial Rate of Return (FRR), while the economic indicators are the Economic Net Present Value (ENPV), the Economic Rate of Return (ERR) and the Benefit-Cost (B/C) ratio (European Commission 2014a).

Irrespective of the methodology used for the evaluation of CDW management performance, cost (out-flows) and benefits (in-flows, revenues) in this sector may be grouped in several categories. Costs may be capital costs incurred for the initial phase such as land acquisition, design and construction of facilities, equipment procurement; operational costs that are the costs for material, labour, equipment, utilities (energy, water, etc.), insurance costs, etc. used for the operation phase of the project; replacement incurred for replacement of short-life equipment and finally clearance and demolition costs incurred at the end of service-life of projects (European Commission 2014a).

On the other hand, benefits in CDW management performance studies are gained from the sale revenues of goods provided in the operational phase of the project (CDW treatment), such as the recovered materials or energy, the government subsidies and other fees that are complied with the polluter-pays principle such as the gate fee (tipping fee), the landfill tax, illegal dumping penalties, environmental costs of pollution (carbon tax) or resource depletion (raw materials taxes), etc. (European Commission 2014a).

Both the costs and revenues are needed to be measured in all CDW management stages to calculate the overall economic performance of the different alternatives (H. Yuan 2013). However, economic performance greatly depends on the recovery potential of a CDW stream. Namely, while metal recycling proved to be economically viable in almost all cases due to the high price of the recovered material (Dahlbo et al. 2015), the price of the recovered materials from concrete recycling was strongly influenced by transport distances, the amount of CDW that is processed, the gate and disposal fees (Duran, Lenihan, and Regan 2006; André Coelho and de Brito 2013c; Oliveira Neto et al. 2017; Hoang et al. 2021). For instance, Duran et al. (2006) concluded that recycling of the mineral CDW stream would be economically viable when the cost of disposal and the cost of primary raw material extraction become higher than the costs of other treatment options and the cost of recovered materials.

2.4.1.3 Social Impacts of Construction and Demolition Waste

The social performance of CDW management practices was rarely evaluated as stand-alone by the scientific community. It was often coupled with the economic analyses or with both the economic and environmental analyses when the entire sustainability domain was assessed. On those rare occasions, the authors were challenged with what types of indicators to choose to describe the impact that CDW management practice has on society. The indicators ranged from total employment and occupational health to public awareness and discomfort and human health and well-being.

One of the most investigated was the total employment, i.e. new job creation (Kourmpanis et al. 2008; Roussat, Dujet, and Méhu 2009; Coronado et al. 2011; Khoshand et al. 2020; Iodice et al. 2021). It is followed by public awareness, public acceptance or participation rate (Kourmpanis et al. 2008; Coronado et al. 2011; Khoshand et al. 2020), which is described as the capability of the CDW management alternative to inspire public acceptance. The rest of the indicators overlap with the environmental indicators (socio-environmental) in some studies, as they are related to human health and human well-being. These indicators include occupational health and the physical working conditions (Klang, Vikman, and Brattebø 2003; H. Yuan 2013; Iodice et al. 2021), public discomfort caused by odour, visual impacts, noise and vibration and dust from CDW management activities (Roussat, Dujet, and Méhu 2009; Coronado et al. 2011; Iodice et al. 2021), human health indicators such as human toxicity, air pollution, particulate matter, etc. (Iodice et al. 2021) and land consumption (Roussat, Dujet, and Méhu 2009; Iodice et al. 2021). Some authors even argued that a set of regulatory indicators such as harmonization, legislation priorities and national and EU targets might be used for the evaluation of social performance as well (Kourmpanis et al. 2008; Coronado et al. 2011).

The methodologies for calculating the values of indicators are numerous. While the socio-environmental indicators use the existing methodologies described in Subchapter 2.4.1.2, the indicator that evaluates public discomfort uses the Hedonic Price Method (HPM) (Rosen 1974), which assesses how CDW management activities affect the market price of properties nearby. The indicator related to employment is often expressed as the number of employees per one tonne of waste, while the occupational health indicator is calculated as the ratio of the total labour and the number of accidents (Iodice et al. 2021). The indicator that describes the physical working conditions is often based on the opinion of the workers involved in CDW management (Klang, Vikman, and Brattebø 2003).

It has to be noted that the CBA methodology described in Subchapter 2.4.1.2 may serve for the social performance evaluation of CDW management practices, particularly the converted prices used for the economic analysis and assessing the investment's impact on society. The conversion factor used for these prices reflects the social adjustment of economic cost and revenues and includes customs, taxation, labour wages and unemployment rates, etc. (European Commission 2014a).

Most of the social performance studies show that the higher the treatment is in the waste hierarchy, the better it will be for society. In other words, better CDW management practices benefit the most to the society in the categories such as total employment, human toxicity and land use savings (Iodice et al. 2021). This is mostly due to selective demolition, avoided transport and raw material extraction. On the other hand, public discomfort and occupational health, especially for brick reusing were recognized as burdens in most CDW management scenarios (Klang, Vikman, and Brattebø 2003; Iodice et al. 2021).

2.4.2 Key Stakeholders in Construction and Demolition Waste Management

Construction and demolition waste management is a complex and multidisciplinary sector as it gathers a wide range of stakeholders that may be potentially affected by these processes. Understanding their goals and motivations, roles and mutual relationships may help in formulating better and more realistic CDW management strategies. In addition, experiences from developed countries suggest that the interaction between stakeholders is one of the primary actions for better CDW management (Aslam, Huang, and Cui 2020). For all these reasons, the following subchapter will be dedicated to the stakeholders.

In a broad sense, the CDW management stakeholders may be grouped around policymakers, researchers and practitioners. Policymakers are the ones responsible for creating new strategies, regulations and policies on the national, regional and local levels. Researchers have multiple roles in the CDW management sector. They investigate emerging technologies to facilitate easier implementation into CDW management practices, develop models for the estimation of CDW quantities, examine properties of recovered materials and their possible usage to facilitate the creation of quality standards that will increase confidence and formulate and evaluate new business models, etc.

While the first two groups are mainly guided by the environmental and social benefits, the practitioners are guided by profit. This means that they will opt for a better CDW treatment only when they see an economic benefit. Additionally, developed countries see practitioners as the main promoters of better CDW management practices, in contrast to developing countries where governments play the dominant role (Kabirifar et al. 2020).

Hence the main role of governments is to promote better CDW management practices and supervise their implementation (Aslam, Huang, and Cui 2020; Su et al. 2020). In an attempt to do this, national governments publish strategies, action plans and regulations related to CDW management, while local governments make them specific to the exact location. This is likely because due to its heavyweight and low economic value CDW is mainly managed locally (H. Wu et al. 2020). In most cases, local governments are responsible both for subsidies to waste treatment facilities or recovered material markets (for CDW operators) and taxation for disposal and extraction of raw materials (for contractors and/or demolition companies) (Aslam, Huang, and Cui 2020; Su et al. 2020). The local government may subsidize CDW operators in numerous ways, such as technological innovation subsidies, industry awards, eco-labelling schemes, tax deductions, etc. (Su et al. 2020). In addition to taxes and subsidies, they also have the power to supervise illegal dumping and to establish or raise penalties for it (H. Liu, Long, and Li 2020).

When governments act as developers, they are driven by benefits to society rather than profit, so it is possible to use their power to promote circular economy practices and create both the demand and market acceptance for recovered materials. The experience from the developed economies suggests that the use of recovered materials may be requested by public works contracts by incorporation of recycled and reuse thresholds (Ghaffar, Burman, and Braimah 2020; Su et al. 2020). An additional option would be to impose site waste management plans before the construction phase for projects above a certain monetary amount (Kabirifar et al. 2020).

The stakeholders that play a major role in promoting sustainable CDW management practices are the developers (investors, clients). However, driven by a profit, they consider the management of waste at the building and demolition sites as an additional cost and financial burden on their projects (Manowong 2012). Therefore, to opt-out of the use of recovered material and/or elements in their project and better CDW management practices, they must see significant direct or indirect economic benefits.

These benefits are mainly connected with creating values for their companies and customers (end-users), such as innovating procedures and knowledge, gaining a positive corporate image and creating price-competitive products in comparison to linear economy practices. Therefore they may either request the use of recovered materials and/or elements or request the recovery of elements from buildings prepared for demolition (Nußholz et al. 2020). Another approach would be to adopt and impose green building certification systems (Su et al. 2020) such as BREEAM (Building Research Establishment Environmental Assessment Methodology) and LEED (Leadership in Energy and Environmental Design) to make their project more competitive.

Without clear instruction and intention from developers, designers have no interest to incorporate better CDW management practices into their design. They either have no understanding of factors that lead to the generation of waste or believe that waste generation is solely the contractor's responsibility (Kabirifar et al. 2020). However, aside from incorporating recovered materials or elements into designs, they can significantly contribute to waste minimization by designing reversible and modular elements that can be easily assembled and dissembled at the end of their service life (van den Berg, Voordijk, and Adriaanse 2020).

The main role of contractors is twofold: as consumers of recovered products (purchasers) or indirect producers of waste on the construction and demolition sites. As consumers, they prefer raw materials and are reluctant to purchase recovered materials mostly due to a lack of confidence in their quality and non-competitive prices in comparison with raw materials (Su et al. 2020). However, a developer may decide to create a demand for these materials, request their use in the project and thus cover the costs of their purchase. Apart from fulfilling the developer’s requirements related to the use of recovered materials, the contractor is also responsible for complying with waste management requirements. In an attempt to achieve this with minimal costs and time, contractors still tend to illegally dump CDW as this is free of charge as long as it is not detected (Du et al. 2020). Similar to contractors, the demolition company’s main focus is rapid and cost-efficient demolition and disposal of waste; this means that they will transport this waste to the cheapest CDW operator. According to some researchers, they will choose to recover an element for further reuse only for three reasons: when there is an economic demand for the element, when there are proper protocols established for the disassembling and when the contractor can control its performance until using it in the new building (van den Berg, Voordijk, and Adriaanse 2020).

From the economic point of view, when there is a demand for recovered material, created by either the developer or the contractor, and when this material is competitive in terms of cost, quality and quantity, the CDW operators will decide on recycling (Ghaffar, Burman, and Braimah 2020). While cost competitiveness may be achieved through taxation of raw material extraction (Söderholm 2011), a better quality of the recovered product may be achieved with high-quality recycling. However, many recycling companies still produce low-quality materials that may be used in non-structural elements as high-quality recycling requests technological innovations and incurs additional costs (Oliveira Neto et al. 2017; Su et al. 2020). One of the options to cover these costs may be subsidies from the government to treatment facilities.

2.4.3 Key Factors Affecting Generation and Management of CDW

Many researchers have investigated what are the most contributing factors that affect CDW management practices. In most of the studies, the factors that were found to have a positive influence were referred to as drivers, while the ones with a negative influence were referred to as barriers. Both the drivers and barriers are highly dependent on the economic development and cultural differences of a country or a region. In an attempt to group these factors on a global scale, several review papers have been produced recently (Rakhshan et al. 2020; Kabirifar et al. 2020). While Kabirifar et al. (2020) grouped the factors based on different CDW management aspects that they affect, i.e. the regulatory, stakeholders’ attitudes, project life cycle and management tools, Rakhshan et al. (2020) classified the factors based on their nature, i.e. regulatory, economic, environmental, social, organizational and technical.

The latter classification of factors sounds more intuitive to the author of the thesis, and this classification was adopted in the explanation of factors that follows. A significant number of scientists highlighted the regulatory factors as one of the factors that affect CDW management the most (J. Chen, Hua, and Liu 2019; Bao and Lu 2020; Ghaffar, Burman, and Braimah 2020; Kabirifar et al. 2020). This could be anticipated as both the national and local governments have the power to promote and influence more circular and sustainable waste management practices. To do so, they have a wide range of instruments to overcome the current barriers to effective CDW management, such as the lack of regulations (H. Yuan 2017), the lack of standards for CDW treatments and the lack of quality standards for the recovered materials (Ghaffar, Burman, and Braimah 2020), high rates of illegal dumping etc. These include adopting environmentally oriented policies and financial incentives for better treatment practices and recovered market development (Huang et al. 2018; Bao and Lu 2020; Kabirifar et al. 2020), establishing green building rating systems and awards (Kabirifar et al. 2020) and recovery thresholds in public projects (Ghaffar, Burman, and Braimah 2020) (*Green public procurement*). The less popular instruments may be introducing landfill taxes and bans (H. Yuan 2017; Ghaffar, Burman, and Braimah 2020; Z. Wu, Yu, and Poon 2020) and strengthening illegal dumping supervision and penalties (J. Chen, Hua, and Liu 2019; Z. Wu, Yu, and Poon 2020; C. Zhang et al. 2022).

Other contributing factors belong to the sustainability domain. The first group of factors are related to costs that may be incurred or saved if better CDW management practices are implemented. Many scientists argue that sales from recovered materials and energy and cost savings from avoidance of landfills and raw material extraction (Kabirifar et al. 2020) are the economic reasons why stakeholders opt for reusing, recycling and energy recovery. On the other hand, higher costs of these treatments, an immature recovered material market and unbalanced demand and supply are the reasons why they remain reluctant to improve their management practices (Kabirifar et al. 2020).

Environmental and social factors that may act as either drivers or barriers to effective CDW management practices are mainly related to resource depletion, environmental pollution and stakeholders' perception of the CDW treatment process. Several environmental and social benefits that push stakeholders in the reuse and recycling direction include savings in raw materials and fossil fuels extraction, decreases in air, water and soil pollution and land consumption, creation of job opportunities and positive perception and increased participation in better CDW management practices (Manowong 2012; H. Yuan 2017; Kabirifar et al. 2020; Rakhshan et al. 2020). In terms of negative perception, the recovered materials are often perceived by stakeholders as materials with a lower quality due to their visual appearance. Additionally, the stakeholders are reluctant to opt for selective demolition and advanced treatment options due to health and safety risk concerns such as hazardous substances, dust, etc. (Rakhshan et al. 2020).

The last two groups of factors are factors related to organizational and technical issues that may affect CDW management practices. Many authors reported that the stakeholders choose to recover CDW when there are organisational and technical capacities to do so. These include contractual provisions for either recovery thresholds and/or waste management (Kartam et al. 2004; Kabirifar et al. 2020; Z. Wu, Yu, and Poon 2020), a collaboration between stakeholders (H. Yuan 2017; Aslam, Huang, and Cui 2020), appropriate knowledge base, experience and procedures in selective demolition and treatment process (Manowong 2012; H. Yuan 2017; Z. Wu, Yu, and Poon 2020), advanced sorting and treatment technologies and quality standards (H. Yuan 2017; Bao and Lu 2020; Z. Wu, Yu, and Poon 2020; C. Zhang et al. 2022). On the other hand, impediments to effective CDW management practices mostly comes from the fact that existing constructions are not designed for deconstruction, lack of skills, knowledge and expertise on how to perform deconstruction (Iacovidou and Purnell 2016) and factors related to logistic such as inappropriate sorting and treatment technologies and an insufficient number of treatment facilities (Huang et al. 2018; Ghaffar, Burman, and Braimah 2020).

Table 4 summarizes and classifies the most important drivers and barriers to effective CDW management practices reported in the scientific literature.

Table 4 Review of factors that contribute to the effective CDW management practices

Drivers	Barriers
Regulatory	
Environmental policies Financial incentives (especially for reuse and recycling) Reuse and recycling thresholds in public projects (Green public procurement) Recovered material market support Illegal dumping supervision and penalties (High) landfill taxes and bans	Immature regulatory environment Lack of financial incentives for reuse and recycling Lack of quality standards for reuse and recycling Lack of confidence in the quality of recovered material Minimal supervision of illegal dumping (Low) landfill taxes
Economic	
Sale revenues from recovered materials and energy The great market potential for recovered materials Costs savings from avoidance of landfills Cost savings from raw material extraction	The immature market for recovered material Unbalanced demand and supply of recovered materials Additional costs related to selective demolition Additional costs of CDW treatment process
Environmental	
Savings in raw material extraction, energy and water (Abiotic and biotic resource depletion avoidance) Decrease of air (GHG emissions), water and soil pollution Avoidance of (urban and arable) land consumption Green image of stakeholders	Increased GHG emissions related to selective demolition, additional transport and CDW treatment activities Presence of hazardous substances during demolition and CDW treatment activities, such as lead, asbestos, etc.
Social	
Creating job opportunities Positive perception and willingness of stakeholders to participate in better CDW management practices	A negative perception of recovered materials' quality Occupational health concerns during the treatment activities Lack of trust in suppliers of recovered materials
Organisational	
Contractual provisions (recovery thresholds and waste management plan requirements) Proper collaboration between projects stakeholders Training for smart demolition, reuse and recycling Application of demolition audits Green image of companies	Lack of equipment for selective demolition Lack of storage and sorting space, treatment facilities Lack of skills, experience and knowledge in selective demolition, reuse and recycling Lack of reused and recycled elements integration in new designs
Technical	
Standard design, materials and technology Advanced recycling and energy recovery technology Certification of recovered materials and/or products Existing deconstruction and treatment procedures and standards	Existing buildings are not designed for deconstruction Lack of effective sorting technologies Inappropriate recycling technology Lack of standards for demolition, reuse and recycling Lack of data on CDW quantities

Data source: Kartam et al. (2004), Manowong (2012), Iacovidou and Purnell (2016), H. Yuan (2017), Huang et al. (2018), J. Chen, Hua, and Liu (2019), Bao and Lu (2020), Ghaffar, Burman, and Braimah (2020), Kabirifar et al. (2020), Rakhshan et al. (2020), Z. Wu, Yu, and Poon (2020), Whittaker et al. (2021)

To summarize, several drivers that can contribute the most to overcome the mentioned barriers stood out from the literature. Their thing in common is that they need to be initiated by the governments. They include strong interventions by the government through specific regulation and economic incentives, including the one oriented to recovered material market development on one side and strong supervision and disposal charges and taxes on the other side. Additional measures that may also have a significant impact on CDW management practices are the introduction of advanced technologies for the recovery and technical standards and quality certificates for recovered products.

2.4.4 Legal and Institutional Framework in the European Union

There are several construction and waste industry related strategies that dictate the development of new and the amendment to the existing policies in the construction and demolition waste management sector. The most important is the Green Deal strategy, which is the EU's answer to the existing and future environmental challenges to achieve climate neutrality by 2050. As mentioned in Subchapter 2.2, the main goals of this strategy are to decrease the net emission of GHG to zero by 2050 and to separate the economic growth from resource use (European Commission 2019b).

One of the main pillars of the Green Deal strategy is the New Circular Economy Action plan. This action plan identified construction and buildings as one of the key-value chains that require immediate action to achieve the Green Deal objectives. These actions will be formulated in a Strategy for a Sustainable Built Environment, which is expected to be published in 2022. The Strategy will promote the introduction of recycled content in construction products, development of digital logbooks for buildings, application of Level(s) in public procurements and revision of material recovery targets set in the EU directives (European Commission 2020a). Aside from contribution to the Green Deal objectives, the Digital Building Logbook, when developed and implemented, should enable multiple benefits in the building sector. It should be a framework for the built environment stakeholders aimed to facilitate better decision-making by increasing the sectors' transparency, innovation and circularity and value chain integration. Current suggestions on types of data include eight categories: administrative, general, building description, operation and maintenance, building performance, smart readiness and finance (Volt et al. 2020). On the other hand, the Level(s) is a common framework developed by the Joint Research Centre (JRC) that provides a set of indicators and a metric to evaluate the sustainability performance of office and residential buildings, especially their environmental performance, health and comfort, life cycle costs and value and potential risks to future performance (Dodd et al. 2017).

A search for relevant and existing policies that regulate the construction and demolition waste domain started with waste-related directives, decisions and regulations. The EU does not have a specific legal document that governs individual CDW streams. Instead, Directive 1999/31/EC on the Landfill of Waste and the Waste Framework Directive 2008/98/EC (WFD) are applied. The Directive on the Landfill of Waste provides basic definitions of the waste types and landfill elements and sets operational and technical requirements for landfills (The European Parliament and the Council of the European Union 2018b). CDW that is mostly inert is excluded from the scope of this Directive. However, the latest amendment of this Directive was made in 2018 and included landfilling restrictions on waste suitable for recycling or energy recovery as of 2030 (The European Parliament and the Council of the European Union 2018b).

The WFD sets a management framework regarding all waste types in the whole EU. It does so by providing the basic definitions and clarifications on waste, the waste treatment (hierarchy), the end-of-waste status, the polluter pays principle, extended producer responsibility, etc. Additionally, it sets several requirements the EU needs to follow and objectives to accomplish to become a recycling society. For instance, all Member States should establish waste management plans that will encompass information on the generation and waste treatment facilities, additional infrastructure if needed, waste management policies and measures to fight and prevent littering, etc. (The European Parliament and the Council of the European Union 2018c).

When it comes to CDW, the Waste framework directive includes one of the quantitative targets to be achieved by the Member States is to prepare for reuse, recycle or recover a minimum of

70% (by weight) of CDW by 2020. However, only a few Member States have introduced CDW specifics when transposing the Waste Framework Directive into their legislations (Osmani, Villoria Sáez, and Vitale 2018).

In an attempt to improve waste management in the EU, the WFD was amended in 2018. The Amended WFD encourages the Member States to reduce and repair and reuse construction materials and products to "promote selective demolition to facilitate reuse and high-quality recycling and to establish soring systems for a least wood, mineral fractions (concrete, bricks, tiles and ceramics and stones), metal, glass, plastic and plaster". Additionally, the European Commission (EC) covenants set targets for preparing for the reuse and recycling of construction and demolition waste and its specific waste streams by the end of 2024 (The European Parliament and the Council of the European Union 2018c).

When it comes to the construction and demolition waste management sector, in addition to waste statistic regulation, only three quality standard regulations for several waste streams have been enforced to date. The waste statistic regulation sets a framework for monitoring the data on the generation and treatment of waste at the EU level (The European Parliament and the Council of the European Union 2010). The quality-related regulations are aimed to increase confidence in the recovered material, i.e., iron and steel (Muchová and Eder 2010), aluminium scrap (Muchova, Eder, and Villanueva 2011) and glass cullet (Rodrigez Vieitez et al. 2011). In terms of concrete and aggregate to concrete, there are two standards, EN206:2021 and EN 12620:2013, that regulate the amount of coarse RCA in the new concrete production of concrete (Whittaker et al. 2021).

Aside from the above-mentioned regulatory acts, the EU have published decisions, protocols, manuals and guidelines to facilitate a better understanding of its policies and to support achieving of its goals. A decision that established a list of 20 different categories of waste is one of the most important (European Commission 2014b). The other two were created as support documents to the Waste Statistic Regulation: the Manual on Waste Statistics (Eurostat 2013) and a Guidance on the classification of waste according to EWC-Stat categories (Eurostat 2010).

And finally, two other documents were published in support of CDW management practices. One of them is Construction and Demolition Waste Management Protocol, which aimed to increase confidence in CDW treatment processes, mainly recycling and confidence in recycled materials. The protocol includes guidelines to enhance CDW management plans and the treatment practices of CDW. It also suggests a proper policy condition and adequate enforcement to facilitate the use of the protocol (Ecorys 2016). Another important guideline is related to pre-demolition and pre-renovation audits of buildings and infrastructures, which provides best practices for the assessment of CDW streams and maximization of materials and components recovery (European Commission 2018).

2.4.5 The Best CDW Management Practices across the World

The search for the best CDW management practices and strategies started with the investigation of CDW recovery rates (reuse and recycling rates in particular) in developed countries. When high recovery rates were identified, additional investigation and comparison of CDW management practices adopted in particular countries were performed. The comparison of specific CDW management practices was carried out on the basis of the categories that were identified in Subchapter 2.4.3 as the most contributing ones.

The CDW management practices from eleven developed countries were compared. These countries included the United States of America, the United Kingdom, Singapore, Japan, South

Korea, Australia and several north-western EU countries (Netherlands, Denmark, Sweden, Germany and Belgium) that, according to some authors, have better overall performance (Deloitte et al. 2017). The review of CDW management specifics per country is shown in Table 5, followed by their brief description.

Table 5 Comparison of different CDW management practices in developed countries

CDW management specifics	**US**	**UK**	**SG**	**JP**	**KR**	**AU**	**NL**	**DK**	**SE**	**DE**	**BE**
Recycling rate (in %)	74	98	99	57—99	99—100	76	100	97	91	100	97
Energy recovery rate (in %)	1			1—16		1		2	3		
Disposal rate (in %)	25	2	1	1—42		23		1	6		3
Strong legal framework	•			•	•	•	•	•	•	•	
Green procurement or green building rating incentives	•		•		•	•	•		•	•	•
Landfill taxes (in euro per tonne of CDW)	49.4	3.6—116.3		8.65		0—88.5	33.2	79	51		40—267.5
Landfill bans (on recycling and/or combustible waste)			•		•		•	•	•	•	•
Advanced CDW recycling technologies			•	•	•				•		
Quality standards for recovered materials				•	•		•				
Mature recovered materials market	•		•	•		•	•				

Data sources: United States of America (US) – Environmental Protection Agency available at https://www.epa.gov/ date accessed 01.02.2022., Aslam, Huang, and Cui (2020), Z. Wu, Yu, and Poon (2020); United Kingdom of Great Britain and Northern Ireland (UK) – Waste and Resources Action Program (WRAP) available at https://wrap.org.uk/ date accessed 01.02.2022.; Deloitte et al. (2017); Singapore (SG) – National Environmental Agency available at https://www.nea.gov.sg/ date accessed 01.02.2022.; Japan (JP) – Ministry of the Environment available at http://www.env.go.jp/ date accessed 01.02.2022., Vivian W Y Tam (2009) Z. Wu, Yu, and Poon (2020); South Korea (KR) - Z. Wu, Yu, and Poon (2020) J. Kim (2021); Australia (AU) – Australian Government, Department of Agriculture, Water and the Environment available at https://www.awe.gov.au/ date accessed 01.02.2022., H. Wu et al. (2020) Z. Wu, Yu, and Poon (2020); Netherlands (NL), Denmark (DK), Sweeden (SE), Germany (DE), Belgium (BE) – Treatment of waste by waste category (Eurostat 2021b), Landfill taxes and bans available at https://www.cewep.eu/ date accessed 01.02.2022., Deloitte et al. (2017). Exchange rates for US and AUS dollars and pound sterling on 01.02.2022. were taken from the European Central Bank available at https://www.ecb.europa.eu/ (1 euro=0.83 Pound sterling, 1.58 Australian dollars, 1.12 US dollars).

As shown in Table 5, almost all countries with high recycling rates have a strong regulatory framework with effective implementation. This means that aside from the waste management act that is regularly adopted in developed and developing countries, these countries have adopted or incorporated specific regulations on construction and demolition waste. These specific regulations may include specific targets for different CDW waste streams or provisions such as recommendations or obligations on pre-demolition audits, deconstruction and waste sorting and collection. In terms of CDW specific targets, EU countries are still waiting for a transformation of its general 70% recovery target into material and treatment processes targets (Arm et al. 2017). On the other hand, Japan had recycling targets for specific streams ranging from 60% for mixed CDW to 99% or more for asphalt and concrete (Promotion Council for Recycling Construction Materials and Wastes 2019). In terms of regulation, both countries went a step forward with their Construction Material Recycling Acts enforced in 2002 in Japan (Z. Wu, Yu, and Poon 2020) and in 2003 in South Korea (J. Kim 2021). These acts included mandatory deconstruction, sorting and recycling of specific streams or even the use of recycled aggregates in public projects, which in the case of South Korea may go up to 50—55% (J. Kim 2021).

The use of recycled material and products presents one of the integral criteria for the *Green public procurement* initiative. Both the *Green public procurement* initiative and the *Green building rating system* (*eco-labelling scheme*) incentives are instruments adopted and implemented by the national or local governments to promote sustainable CDW management practices. Almost all countries with efficient CDW management practices have some form of these instruments implemented. While Japan and Korea request to use or even set a threshold for recycled aggregate, other countries are mainly limited to a recommendation of this practice. In contrast, *eco-labelling schemes* such as BREEAM and LEED are widely applied. For instance, similar to these rating systems that are mainly applied in the United Kingdom and the United States, Singapore and Australia award points to residential and non-residential buildings under the *Green Mark Scheme* (Building and Construction Authority (BCA) 2008) and the *Green Star Environmental Assessment System* (Green Building Council of Australia 2013). In an additional effort to promote recycling, some countries (the United Kingdom) even authorize tax credits to landfill operators if waste is sent to recycling or energy recovery facilities rather than landfills (Government of United Kingdom of Great Britain and North Ireland 2022).

The countries with high levels of CDW management maturity also impose particular economic burdens that are manifested through a landfill tax (disposal charge or landfill levy) aimed to increase the costs of disposal and divert waste from landfills. These taxes are usually charged per tonne of waste, and the values depend on the type of waste stream (they are higher for hazardous waste). Table 5 shows that landfill tax values range from 3.6 to 267.5 euros per tonne of all waste types in the EU (The Confederation of European Waste-to-Energy (CEWEP) 2021). Aside from this, several countries with limited space for landfills or insufficient quantities of raw materials have introduced landfill bans on combustible or recyclable waste (Singapore, South Korea, EU countries) (J. Kim 2021) (The Confederation of European Waste-to-Energy (CEWEP) 2021) or even imposed taxes on raw material extraction (Netherlands, United Kingdom, Sweden, Denmark) (Söderholm 2011).

When it comes to the recycling infrastructure, countries exhibit different characteristics. Although most countries have a sufficient number of recycling facilities (Deloitte et al. 2017), only a few countries have managed to fully implement advanced recycling technologies (Singapore, Japan, South Korea and Sweden) that use air blowing and magnetic force for sorting (J. Kim 2021). This means that the recycled aggregate produced in these countries may be used for the production of high-quality concrete, i.e., upcycling, as opposed to commonly performed downcycling in road sub-base and as backfilling material in most countries.

Aside from high-quality recycling, two other things that could push upcycling may be quality standards and certificates and a developed market for the recovered materials and products. However, the only quality standards for recycled products, aggregates, in particular, were found Japan, South Korea and the Netherlands. The Dutch standard NEN 5950:1995, published in 1995, was one of the first standards that included provisions related to the replacement of natural aggregate with recycled (up to 20% without additional tests) (Royal Netherlands Standardization Institute (NEN) 2022). Japanese and Korean standards were published more recently in 2006 and 2017, respectively, and included requirements of recycled aggregate for different concrete classes and different uses of concrete (for general purpose concrete, foundations and piles and low strength concrete) (Promotion Council for Recycling Construction Materials and Wastes 2019) (J. Kim 2021). Additionally, the United Kingdom's Waste Resource Action Program (WRAP), published in 2013, is a quality protocol that contains the end-of-waste criteria for the production of aggregates from inert waste (Waste Resource Action Programme (WRAP) 2013), while the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) issued "Guide to the use of recycled concrete and masonry materials" (Commonwealth Scientific and Industrial Research Organisation (CSIRO) 2002).

And finally, countries that recover large quantities of CDW do not necessarily have mature markets for the recovered material. The United States, Singapore, Japan, Australia and Netherlands were the only countries with mature markets for the recovered material out of all the countries whose CDW practices were investigated (Z. Wu, Yu, and Poon 2020). The markets of recovered materials in these countries are supported either through the information exchange on potential recyclers (United States, Japan, Singapore) or through quality certification systems such as quality labels in Netherlands or support by construction associations (Australia) (Z. Wu, Yu, and Poon 2020). In addition, Singapore and the Netherlands have additional motivation due to limited quantities of natural resources (aggregates).

2.5 Estimating the Construction and Demolition Waste

2.5.1 Review of Available Models for Estimating CDW Quantities

Researchers worldwide have been trying to quantify the amount of construction and demolition waste for almost 30 years. Over the years, the number of these studies has accumulated to more than one hundred, with different methodologies suggested and employed.

A significant number of researchers tried to group a myriad of different methods (Z. Wu et al. 2014; Zheng et al. 2017; N. Zhang et al. 2019; Villoria-Sáez, Porras-Amores, and del Río Merino 2020). A waste generation rate-based method was singled out as the most used in the estimation studies (Z. Wu et al. 2014; Zheng et al. 2017). This method is followed by site visits and direct measurements (record based), Material Flow Analysis (MFA) and GIS aided methods (Zheng et al. 2017). The use of computer-aided methods is also on the rise in recent years (Villoria-Sáez, Porras-Amores, and del Río Merino 2020).

The author now suggests a slightly different categorisation to include the quantification methodologies suggested in the meantime and to reflect the improvements and modifications made on the previous ones. Additionally, researchers often combine different methodologies to calculate the amount of CDW. However, only the prevailing methodology or methodologies were included in this categorisation. The most important details of relevant CDW estimation studies are provided in Table 6. The table is given in chronological and alphabetical order. The overall approach of each methodological category with its advantages and disadvantages is explained in the following subchapters. The most important studies and their findings are also indicated.

Table 6 Review of selected CDW quantification studies

Author(s)	Scope					Forecast •=YES	Composition •=YES	Methods
	Location	Level	Activity	Const.	Period			
Bogoviku and Waldmann (2021)	Luxembourg	NAT	R, D	RB	2020—2100	•		MS(BU)

Lederer et al. (2021)	Vienna Austria	CIT	R, D	B	2016—2050	•	•	MS(BU)
Villoria-Sáez et al. (2020)	EU10	NAT	ALL	ALL	2016			WPC, WPGDP, WPCT
Cha et al. (2020)	Daegu, Busan Korea	CITY	R, D	RB	n/a			FO
Hoang et al. (2020)	Hanoi Vietnam	PRO	C, D	B	2018—2019		•	FO
Jain et al. (2019)	India	NAT	ALL	B	2012—2050	•		CA
Miatto et al. (2019)	Padua Italia	CIT	D	B	2030	•	•	MS(BU)
Gontia et al. (2018)	Sweden	NAT	n/a	B	1880—2010		•	MS(BU)
Jain et al. (2018)	India	NAT	ALL	ALL	2016		•	MS(TD)
Villoria Sáez et al. (2018)	Jerez, Madrid Spain	CIT	R	RB	2014—2015		•	WPA
Kim et al. (2017)	Daegu City Korea	PRO	D	RB	n/a		•	CA
Kleemann, Lederer et al. (2017)	Vienna Austria	CIT	R, D	B	<1918 — >1997		•	MS(BU)
Kleemann, Lehner et al. (2017)	Vienna Austria	CIT	D	B	2013		•	MS(BU)
Ram and Kalidindi (2017)	Chennai India	CIT	C, D	B	2013		•	WPA, WPC
Song et al. (2017)	China	NAT	C, D	B	2015—2018	•	•	CA
Zheng et al. (2017)	China	NAT	C, D	ALL	2003-2013			WPA
Bernardo et al. (2016)	Lisbon Portugal	REG	R, D	B	2012			FO+WPA
Paz and Lafayette (2016)	Recife Brazil	PRO	C	B	n/a			WB
H. Wu et al. (2016)	Shenzhen China	CIT	D	B	2010—2015	•	•	WPA
Lu, Peng, et al. (2016)	Hong Kong China	PRO	C	B	2016—2030	•		CA
Lu, Webster, et al. (2016)	China	NAT	ALL	B	2011—2015			WPA
Mah et al. (2016)	Malaysia	PRO	C, D	B	2007—2014		•	FO
Sartori, Sandberg, and Brattebø (2016)	Norway	NAT	ALL	B	2015	•		MS(BU)
Ergun and Gorgolewski (2015)	Toronto Canada	CIT	D	B	2100		•	MS(BU)
Wiedenhofer et al. (2015)	EU25	PRO	R, D	RB, CW	2008—2012	•	•	MS(BU)

Ding and Xiao (2014)	Shanghai China	CIT	ALL	B	2004—2009		•	WPA, WPC
Kleemann et al. (2014)	Vienna Austria	PRO	D	B	2020	•	•	FO
Sáez et al. (2014)	Madrid Spain	PRO	C	RB	2000—2012			FO
J. C. P. Cheng and Ma (2013)	Hong Kong China	PRO	R, D	RB	n/a	•		CA
J. Li et al. (2013)	Shenzhen China	PRO	C	RB	n/a		•	FO
Y. Li and Zhang (2013)	n/a	PRO	C	B	n/a			WB
Z. Wu, Fan, and Liu (2013)	Hong Kong China	CIT	n/a	n/a	2009	•		CA
Coelho and De Brito (2011)	Portugal	NAT	ALL	ALL	n/a	•		WPA WPC
Coelho and de Brito (2011)	Lisbon Portugal	CIT	ALL	ALL	n/a		•	FO
Braz et al. (2011)	Lisbon Portugal	CIT	C	B	2006—2020			WPA
Katz and Baum (2011)	Israel	PRO	C	RB	1919—2000	•	•	FO
Lu et al. (2011)	Shenzhen China	PRO	C	RB	2006—2007		•	FO
Hu, Van der Voet, and Huppes (2010)	Beijing China	CIT	R, D	RB	n/a	•		MS(BU)
K. M. Cochran and Townsend (2010)	United States	NAT	ALL	ALL	2009		•	MS(TD)
Kofoworola and Gheewala (2010)	Thailand	NAT	C	B	1949—2050		•	WPA, WPC
Martínez Lage et al. (2010)	Galicia Spain	REG	ALL	ALL	2002	•	•	WPA
Hashimoto et al. (2009)	Japan	NAT	D	ALL	2002—2005	•		MS(TD)
Bergsdal, Bohne, and Brattebø (2007)	Oslo Norway	CIT	ALL	B	2011	•	•	WPA
Hashimoto et al. 2007)	Japan	NAT	D	B	1954—2000	•	•	MS(TD)

NAT – national; REG – regional; CIT – city; PRO – project; C-construction; R-renovation, retrofitting or refurbishment; D – demolition; RB – residential buildings; NRB – non-residential buildings; CW – civil works (infrastructure); WPC - waste per capita; WPGDP – waste per GDP; WPCT – waste per construction turnover; WPA – waste per area; FO – field observation; MS - material stock; (TD) – top-down; (BU) – bottom-up; CA – computer-aided; WB – web-based; n/a - not applicable or not available information.

When it comes to CDW estimation scope, the studies can be classified as the ones that estimate the quantities on a project level and the ones that estimate the quantities on a wider scale (city, region, or country). In terms of time, studies either assess the current quantities of waste or project the future amounts. One of the most important features is whether they include waste composition or not (i.e., are the amounts expressed as particular waste streams (mineral CDW, wood, stone, etc.) or as an aggregation of CDW. Intuitively one may conclude that the studies with CDW composition may lead to better and more informative judgments in CDW management.

Finally, the data used for the estimation in all these studies were collected mainly from national statistics (construction or demolition activity, material consumed, population, gross domestic product) and field observations (sorting and weighing on-site, truckload records, and site surveys, etc.).

2.5.2 Waste Generation Rate Models

Waste generation rate (WGR) models are parametric models used for quick and short-term estimations of CDW, mostly on a national and a regional level. However, they employ a large amount of data from previous studies or projects and are sensitive to multiple external factors (Villoria-Sáez, Porras-Amores, and del Río Merino 2020). Even though the largest number of CDW quantification studies use some type of a waste generation rate indicator, there is still a gap in the knowledge that needs to be filled. This is mostly related to the need to compare WGR between the developed and developing countries (Jin, Yuan, and Chen 2019), which may lack quality and reliable data.

These indicators are expressed as a ratio of CDW generated annually and some macroeconomic, demographic or construction parameters. Depending on the aimed indicator, models most commonly employ national, regional or municipal statistics on population, GDP and construction, renovation or demolition activity, etc.

One of the easiest WGR indicators to calculate is waste per capita (WPC), denominated in kilograms or tonnes of waste per capita (person) per year. Evidently, the indicator is the ratio of the amount of CDW within a particular geographic area (city, county, region or state) and the population of that area. For example, one of the latest reported values of this indicator for Europe for 2016 ranges from 0.09 (Poland) to 1.60 (Belgium) tonnes per capita of CDW, with an average of 0.72 tonnes per capita (Villoria-Sáez, Porras-Amores, and del Río Merino 2020).

Some studies used the WPC indicator in combination with waste per area (WPA) indicators that are usually assumed or taken from earlier studies (Kofoworola and Gheewala 2009; Andre Coelho and De Brito 2011). Here the WPA indicator is used to calculate the amount of CDW waste from a construction, renovation or demolition activity. The WPC indicator is then calculated to facilitate the comparison with results from other studies. In this way, Kofoworola and Gheewala (2010) used national statistic records on construction areas derived from construction permits issued between 2002 to 2005 to calculate the amount of construction waste in Thailand. Their results showed an average rate of 18 kg per capita per year of construction waste in Thailand.

In Portugal, Coelho and De Brito (2011) combined several data sources to estimate the CDW from buildings and civil works in Portugal for 2008. They used a WGR from previous literature for the amount of waste from the construction of new buildings, while real figures were used for the quantities of waste from demolition and retrofitting of buildings and the rehabilitation and demolition of roads and highways. The results put the waste from residential buildings in the spotlight, with 72% of the CDW generated from this type of construction. Commercial buildings and civil works contributed to the total amount of CDW with 13 and 15%, respectively. The total amount of CDW in 2008 was estimated to be 186 kg per person. Additionally, Andre Coelho and De Brito 2011 used statistical data series on construction permits from 1994 to 2006 to predict the CDW by 2020. They used a polynomial function to consider two possible scenarios. The resulting amount predicted a significant growth of CDW by 2020. Scenario 1 estimated 605.6 kg of CDW per person, while Scenario 2 estimated 225.8 kg of CDW per person (Andre Coelho and De Brito 2011).

More recent uses of the WPA and WPC indicators were documented in Asia (Ding and Xiao 2014; Ram and Kalidindi 2017). Ding and Xiao (2014) studied the quantity and the composition of CDW for the period from 2000 to 2012 in Shanghai, China. They used WPA indicators taken from Chinese construction handbooks and further adjusted them to include different decades and different structure types. They, too, reported an increase in the amount of CDW from 724 kg per capita per year to 842 kg per capita per year. The composition analysis showed that concrete, bricks and blocks constitute 80% of the CDW amount.

Ram and Kalidindi (2017) also used the WPA indicator to determine the amount of concrete and masonry waste in Chennai city in India, in 2013. They used the WPC indicator to compare the results with other studies. However, before adopting the WPA indicator from a handbook, they exercised a regression analysis on 45 demolition project case studies to estimate the WPA indicator. Additionally, they cross-checked the values of the WPA with randomly selected truckload records from four demolition sites. Finally, the WPA indicator of 60 kg per m^2 was adopted and multiplied by the construction and demolition floor area resulting in 175 kg of concrete and masonry waste per capita (Ram and Kalidindi 2017).

Another way to compare the WGR within the literature is with the use of the waste per gross domestic product indicator (WPGDP). This indicator is the ratio of the amount of CDW within a geographic area and the GDP of that area. The GDP should be expressed as the purchasing power standard to enable result comparison between different economies. The latest calculations of this indicator for the EU showed an average value of 24.57 tonnes of CDW, with the smallest value in Portugal (4.47 tonnes) and the highest in Belgium (46.74 tonnes) (Villoria-Sáez, Porras-Amores, and del Río Merino 2020).

Similarly, the amount of CDW may also be divided by the construction turnover within a geographic area expressed in local currency. This indicator, named the waste per construction turnover (WPCT) indicator, may provide important information on the relations between construction, renovation and demolition activity and the amount of CDW. The average value for the EU for 2016 was 222.57 tonnes per million euros, ranging between 59.24 (Portugal) and 393.24 (Germany) tonnes per million euros (Villoria-Sáez, Porras-Amores, and del Río Merino 2020).

Finally, the most used waste generation indicator in the literature is the waste per area (WPA) indicator. This indicator describes the ratio between the amount of CDW and the area or volume of building or civil works constructed within a particular geographic area. It is usually denominated in kilograms or tonnes per square meter or cubic meter.

To the best of the author's knowledge, the only efforts to review the available literature on the WPA indicator were made by Mália et al. (2013). They surveyed previous studies in a search for this indicator for construction, renovation and demolition activity in both the residential and non-residential building sectors. When it comes to the average composition of waste, they confirmed findings from previous studies that almost 80% of the CDW is concrete and masonry. They compared the numbers through activities and found that demolition works generated the greatest quantity of waste, while renovation generated a higher quantity of waste than new construction, i.e., the waste from demolition and renovation of concrete structures were in the range of 401—840 and 18.9—191.2 kg per m^2, respectively, while waste from new construction ranged between 17.8 and 40.1 kg per m^2. However, the obtained WPA rates were not location or building structure-specific since the previously published studies could not be generalised in this manner.

Clearly, the WPA indicator depends on the structure and the type of project. The general approach in WPA studies was either to calculate or establish the WPA indicator. Most studies were comprised of three steps: 1) quantification of the total floor area or volume, 2) determination of the waste per area indicator, and 3) validation of the waste per area indicator.

The most utilised way to calculate the total floor area or volume in the WPA studies is by using the national or regional statistical data on construction, renovation or demolition activity or floor plans from building permits or building case studies. Another way is to estimate the floor area on the basis of the available statistical data and renovation and demolition rates.

The waste per area indicator is either assumed (Chi S Poon 1997) or taken from existing studies (Lu, Webster, et al. 2016; K. Cochran et al. 2007), industry guides and handbooks, codes of practice or databases (K. Cochran et al. 2007; Solís-Guzmán et al. 2009; Coronado et al. 2011; Zheng et al. 2017; N. Zhang et al. 2019) or determined from interviews with CDW practitioners (H. Wu, Duan, et al. 2016), or calculated from experimental data (field surveys) (Bergsdal, Bohne, and Brattebø 2007; Mercader-Moyano and Ramírez-De-Arellano-Agudo 2013; Paola Villoria Sáez et al. 2018). A very few studies offered validation of their results. When offered, the validation was performed either by on-site measurements or benchmarking with other studies (Llatas 2011; Lu, Webster, et al. 2016).

Lu, Webster, et al. (2016) estimated the amount of CDW in China from 2007 to 2014. They used national statistical data on construction activity to estimate the construction floor area and the renovation floor area. The demolition floor area was also estimated from the only available statistical records for the city of Shanghai. The waste generation rates were obtained from the literature and used to calibrate and make the results more accurate. The adopted generation rates for construction, renovation and demolition were set to 40.7 kg per m^2, 125 kg per m^2 and 1,196.57 kg per m^2, respectively (Lu, Webster, et al. 2016).

Zheng et al. (2017) employed a similar method to establish the WPA indicator to estimate the amount of CDW from 2003 to 2013 in China. They used technical codes and a survey among practitioners conducted in the H. Wu, Duan, et al. (2016) study for construction and demolition waste generation rates. The total waste generation rates for construction and demolition were set at 34.2 kg per m^2 and 1,360.2 kg per m^2. They found that demolition waste contributed to the total amount of CDW in 2013 with 97% of the demolition stream being concrete, masonry and ceramics waste. Additionally, they used a scenario analysis to examine the composition and the recycling potential of CDW as well as the landfill space demands. Interestingly, the optimistic recycling scenario revealed that the landfill volume could be decreased by 90% (Zheng et al. 2017).

Other sources of WPA indicators are industrial databases that contain economic and environmental data on construction elements, such as the Catalan BEDEC (Structured Database for Construction Elements) and the Andalusian BCCA (Construction Cost Database). Apart from the waste per area indicators for significant waste streams, the environmental information from these databases includes conversion factors for packaging waste, wreckages, increased volumes, etc. These factors were used extensively to determine the amount of construction waste (Solís-Guzmán et al. 2009; Llatas 2011; Paola Villoria Sáez, Del Río Merino, and Porras-Amores 2012; Mercader-Moyano and Ramírez-De-Arellano-Agudo 2013).

In an attempt to validate the WPA indicators from the available literature and databases, several studies conducted experiments and measured the amount of CDW coming from construction, renovation and demolition projects (Bergsdal, Bohne, and Brattebø 2007), construction and renovation (Braz et al. 2011), renovation activity only (Paola Villoria Sáez et al. 2018) or waste weight records at recycling plants (Martínez Lage et al. 2010).

Martínez Lage et al. (2010) forecasted the amount of CDW in 2011 in Galicia, Spain. They used the information on building permits for a decade to estimate the construction, renovation and demolition surface area for the horizon year. Construction waste generation rates were derived from new construction projects and records of waste measured upon the arrival at the recycling plant, while demolition waste generation rates were calculated as weights of materials from buildings constructed in the 1940s and 1950s whose useful life expired divided by demolition surface area. The renovation waste generation adopted the same rate as construction and demolition since these two activities generate renovation. The results ranged from 80 kg per m^2 for construction waste and 1,350 kg per m^2 for demolition waste in 2011 (Martínez Lage et al. 2010).

One of the very few studies that covered waste from renovation activity was a study by Villoria Sáez et al. (2018). In their study, CDW generation was quantified using the theoretical analysis for the seven most common works on the improvement of the building's vertical envelope. Additionally, experimental data from two construction sites were used to record waste generation ratios from the refurbishments. The results depended on the techniques of refurbishment that were conducted, and they were in the range of 2.46—65.24 kg per m^2 or 0.012—0.008 m^3 per m^2 (Paola Villoria Sáez et al. 2018).

The WPA indicator that came from the largest number of projects (311 projects in Oslo) was included in the Bergsdal, Bohne, and Brattebø (2007) study. They built up a model on the historical data of building stock in Trondheim, Norway. Their methodology comprised three steps: estimation of the construction, renovation and demolition activity; determination of waste generation rates and calculation of the waste generation. They used historical data for construction activity and assumptions about building life span and renovation cycles to determine renovation and demolition activity. Finally, A Monte Carlo simulation was applied for the estimation of future amounts of waste (Bergsdal, Bohne, and Brattebø 2007).

(Braz et al. 2011) estimated CDW in Lisbon, Portugal, for 2006 and 2007. The estimation was based on the methodology that encompassed three sets of data: data on construction activity and the waste generation rate for construction, waste load movements for renovation and waste disposal at illegal dumping sites. The results showed an annual waste amount of 0.6 tonnes per capita or 954 tonnes per day (Braz et al. 2011).

Only one more study that used the WPA indicator to forecast the amount of CDW was found in the literature. H. Wu, Duan, et al. (2016) estimated the amount of demolition waste for six years and projected the amount of demolition waste to 2030 in Shenzhen, China. They utilized the WPA method to calculate the amount of CDW. Additionally, they calculated the recycling potential of demolition waste based on the average recycled material prices that were determined through interviews within six major recycling companies. As opposed to other studies that used a similar methodology, they used a survey among 85 demolition practitioners to investigate the WPA for each material depending on the structure type. The results of the survey derived a total waste amount of 1.3 tonnes per m^2, with concrete, masonry and mortar as the biggest contributors. A grey model that was used to generate projections of demolition waste from 2016 to 2030 estimated that the annual amount of demolition waste expected in 2030 was 40 million tonnes (H. Wu, Duan, et al. 2016).

The main advantage of the waste generation methods is their applicability for quick and short-term estimations, especially on the national and regional levels. In addition, these methods are simple for calculation and use data that are easy to acquire. This is particularly important when estimations are made for countries with modest statistical data.

On the other hand, statistics on construction, renovation or demolition permits may cause an overestimation of results because sometimes projects remain unfinished, either abandoned or indefinitely delayed. Most of the studies use indicators collected from the literature or handbooks rather than data measured on-site and calculated for each study. Evidently, the latter may be a complex task that requires significant resources when estimations are done on the regional and national levels.

Also, the results of these studies are not easily transferable between countries due to economic inequality, various population rates, different construction practices, the local social and environmental context and even structure types. For instance, the WPGDP indicator is not comparable between different economies as it does not include conversion rates. Similarly, GDP per capita at market prices does not reflect the differences in price levels.

Finally, these indicators were rarely used in literature to calculate future amounts and composition of CDW.

2.5.3 Field Observation Models

Depending on the manner of collecting the waste data, field observation models may be further divided into on-site measurements of waste bins or truckloads, surveys or interviews with CDW practitioners and project record analysis.

As mentioned before, most field observation studies found in the literature use on-site measurements for the validation of suggested estimation models. However, there are few studies, mostly for high-rise buildings, that employ this method to calculate or predict the amount of waste (Lu et al. 2011; Mah, Fujiwara, and Ho 2016). The amount of CDW is obtained as a function of the waste's weight and/or volume obtained by direct measurements at construction and demolition sites or illegal dumps during a certain period. However, the studies may or may not include on-site sorting before waste measurement.

One of the first and the only ones to use direct measurement only to estimate the amount of construction waste in Europe was the study by Bossink and Brouwers (1996). Their research included 14 months of field observation and sorting and measuring of five residential projects in the Netherlands. They found that the largest component of the construction waste was stone tablets, with 29% of the waste, followed by piles and concrete with 17 and 13%, respectively (Bossink and Brouwers 1996).

A few other authors researched the amount of CDW in Asia. These studies measured waste mostly on high-rise building projects in Shenzhen (Lu et al. 2011) and Malaysia (Mah, Fujiwara, and Ho 2016). The first study observed the amount of waste from a single room in four different high-rise building projects for two months and applied the waste rates to the entire floor. The second study observed and measured waste bins from eleven high-rise projects for six months. The results showed to be very diverse and ranged from 3.27 to 8.79 kg per m^2 for China and from 32.9 to 98.8 kg per m^2 for Malaysia.

Two more recent studies from Asia surveyed low-rise buildings (Hoang et al. 2020; Cha et al. 2020). While Hoang et al. (2020) conducted interviews and surveyed 15 construction and demolition sites in Hanoi, Vietnam, to identify waste generation, its composition, rate and management practices, Cha et al. (2020) surveyed the demolition of 1,034 residential buildings to determine the generation rates and the recycling potentials of demolition waste in Korea. The Korean researchers measured and recorded the geometry of these buildings' elements. The buildings were divided into four categories depending on the prevailing structure: reinforced concrete, concrete bricks, masonry blocks and wooden structure. The demolition generation rates varied depending on these structures. Concrete, blocks and bricks were the dominant streams for reinforced concrete and masonry structures, with rates that ranged from 146 to 549 kg per m^2 for concrete, 69.3 to 654.4 kg per m^2 for blocks and 17.2 to 806.8 kg per m^2 for bricks. Blocks and bricks dominated even within the wooden structures with 227.7 and 193.9 kg per m^2 (Cha et al. 2020). The results of the Vietnamese study were similar, and depending on the building size, the waste generation rate ranged between 318 kg and 610 kg per m^2 (Hoang et al. 2020).

Katz and Baum (2011) went a step further when they used data from visual observations of waste bins from ten construction sites in Israel to make an empirical model for the prediction of the amount of construction waste depending on the duration of the project and construction method. The amount of waste generated in the course of these projects was estimated at 0.2 m^3 per m^2. Additionally, they found a good correlation between the amount of CDW and project duration. However, no correlation was found between the amount of CDW and the construction methods carried out on the sites.

Another way used by scientists to estimate the amount of CDW is through surveys and interviews with practitioners (C. S. Poon, Yu, and Jaillon 2004; Jingru Li et al. 2013). While C. S. Poon, Yu, and Jaillon (2004) interviewed practitioners to identify the causes of construction waste on sites in Hong Kong, J. Li et al. (2013) investigated the amount of purchased material and the material waste rate on a construction site in Shenzhen, China. They used information gathered from project and site managers to calculate the total WPA indicator for each waste stream. The total waste generated on this building site was 40.7 kg per $m^{2,}$ with concrete as the main contributor (43.5%) (Jingru Li et al. 2013).

Finally, the amount of construction and demolition waste on-site may be estimated by analysing construction and demolition projects’ documents such as bills of quantities, drawings, specifications, delivery and waste records, etc. (André Coelho and de Brito 2011; Kleemann et al. 2014; Sáez et al. 2014). For instance, in Portugal, Coelho and de Brito (2011) used drawings and specifications from new construction and retrofitting projects to quantify the CDW and actual quantities of waste obtained from demolition companies. Kleemann et al. (2014) also used construction plans and on-site inspections before demolition to evaluate the material composition of different buildings in Vienna. In Spain, Sáez et al. (2014) analysed several building sites, 802 dwellings in total, to estimate the amount of construction waste. Additionally, they used on-site delivery notes of waste bins to propose a model for the calculation of construction waste throughout the project. The total amount of construction waste based on their model was estimated to be 117.50 kg per m^2. They also concluded that most waste is generated during the middle stage of the project at around 60—80%, as opposed to the initial and final stages of projects where 10—20% and 5% of construction waste were generated, respectively (Sáez et al. 2014).

The above-mentioned studies suggest that field observation methods are best suited for project-level waste estimation studies. This method is one of the most accurate methods because it involves direct separation and measurements of different waste streams at the very source of the waste (construction or demolition site). The method also allows for recording the amount of CDW in real-time throughout different construction stages.

However, the accuracy of these methods depends on whether the demolition discharge comes in the mixed or individual stream form. The latter would request separation at source and may consume a lot of time and incur significant costs to estimators. Also, on-site observations are performed within a short period and very often, visual inspections of waste bins, and subjective evaluation (without sorting and measuring) of composition and quantity may lead to misestimations. In addition, a considerable amount of CDW remains undetected as it is either never dumped or illegally dumped on public property.

Even without all these difficulties, the total amount of waste and particular waste stream could not be easily transferred to other economies or even projects because the amount and especially the composition of the waste are project-specific. Also, to obtain a representative sample that will be more accurate, this model requires the examination of a large number of CDW samples, which may be time-consuming, especially when bulk waste such as CDW is in question.

2.5.4 Material Stock Models

A substantial number of studies that are devoted to the calculation of the accumulated material in buildings and infrastructure (Material Stock) in a particular region may be found in the literature in the past decade (2010—2021). The environmental impact of dwellings (Lavagna et al. 2018) was the main motive behind the research, particularly the energy efficiency (Dascalaki et al. 2011; Sandberg et al. 2016; Stephan and Athanassiadis 2017), GHG emissions (Stephan and Athanassiadis 2017;), the water and energy demand (Mata, Sasic Kalagasidis, and Johnsson 2014; Stephan and Athanassiadis 2017), the growth and renovation rate of the stock and the lifetime of buildings (Sartori, Sandberg, and Brattebø 2016; Mastrucci et al. 2017; Miatto et al. 2019) and finally identification of potential secondary materials (Condeixa, Haddad, and Boer 2017; Stephan and Athanassiadis 2017). Although there is a compelling number of studies that are focused on the material stock in buildings and infrastructure, very few of them used the knowledge of the quantity of materials in building stock and their age to estimate and predict the amount of demolition waste on a particular location.

There are two general approaches to calculating the CDW from Material Stock (MS) that may be found in the literature: top-down and bottom-up. The top-down models are highlighted as the least time consuming and thus appropriate for preliminary estimation as opposed to bottom-up, which are used when more accurate estimation is needed (Villoria-Sáez, Porras-Amores, and del Río Merino 2020). Depending on the approach to the time scale, these methods can also be static or dynamic. The static method assumes that the building stock is constant over time, while the dynamic method includes additions or reductions of materials from construction or demolition activities.

Irrespective of the approach, two more parameters are needed when MS is used to predict the amount of renovation and demolition waste. One of these parameters is the material service life of construction, in most cases, the building’s lifespan. This span covers the period from construction to the demolition of buildings or infrastructure. Another parameter is the frequency of renovation or the renovation rate. It is the interval at which renovation occurs within a building's lifespan.

The top-down method is often used to map the entire anthropogenic stock within an economy (Schiller, Müller, and Ortlepp 2017). However, several studies kept their focus only on the construction industry in Japan (Hashimoto, Tanikawa, and Moriguchi 2009), the United States (K. M. Cochran and Townsend 2010) and, more recently, India (Jain, Singhal, and Jain 2018). All of these studies used aggregated historical data on construction materials’ inputs and outputs (material production, consumption and material service lifetime) on a national level from building and infrastructure services. This information is often found in national statistics records. Material stock is then derived as a difference between material inputs and outputs calculated annually (Augiseau and Barles 2017).

One of the first studies that introduced this methodology was the one conducted by Hashimoto, Tanikawa, and Moriguchi (2007). They analysed the demand for construction minerals on the Japanese market and the construction mineral's stock to estimate their generation from 1970 to 2030. They used a material flow analysis to determine the MS and the probability function to determine these constructions' life span. The result showed a consistent increase in the amount of cement, sand, gravel and crushed stone. In addition, this study identifies the dead stock and dissipated waste, i.e., the crushed stone beneath the foundation or material landfilled at the demolition site (Hashimoto, Tanikawa, and Moriguchi 2007).

They further investigated the amount of these dissipated minerals in their second study (Hashimoto, Tanikawa, and Moriguchi 2009). Here they differentiated minerals that could become demolition waste or secondary resources from dissipated minerals that are either reused for levelling the ground or left on the demolition site, such as foundation piles. Materials used in structures with a low probability of demolition were also included in their material flow analysis. The results showed that about 60—70% of consumed construction minerals do not become waste or secondary resources (Hashimoto, Tanikawa, and Moriguchi 2009).

In the United States, the top-down analysis was used to estimate and forecast the amount of CDW from 2002 to 2052 (K. M. Cochran and Townsend 2010). All major construction materials such as concrete, wood, metal, gypsum and clay products and asphalt were included in the analysis. The construction waste was calculated by applying a percentage of discarded material during construction to historical data on their consumption. The amount of demolition waste depended on the construction waste and service life of materials, i.e., the material that was consumed in the past after its service life has expired minus the construction waste that became demolition waste. There were three assumptions set for the service life of the material: long, typical and short. Depending on the service life, the total amount of CDW ranged from 610 to 780 million Mg. Two major contributors were Portland cement concrete and asphalt concrete with 42—59% to 26—43%, respectively (K. M. Cochran and Townsend 2010).

A more recent study that used a top-down MFA was the one by Jain, Singhal, and Jain (2018). They estimated the amount of CDW from buildings and the civil works sector in urban and rural areas in India in 2016. The material consumption in these areas was observed through three different scenarios. Even though the focus of the paper was on several materials only (cement, concrete and mortar and bricks), the results ranged from 110 (the best scenario) and 375 kg of CDW per capita (the worst scenario) for urban areas and from 67 to 281 kg of CDW per capita for rural areas. They also found that civil works had a small contribution (4—10%) to the total amount of CDW (Jain, Singhal, and Jain 2018).

On the other hand, the idea behind the bottom-up material stock method is to create a database of materials (material inventory) of constructions (in most cases, buildings) from different periods. Buildings are grouped into cohorts built in the same period and with similar architectural characteristics and construction technologies. The material database uses two sets of data. The data about the physical size (width, length, height, area or volume) of the building stock's components and the density of construction materials from which the components are made of. The physical size of components may be collected through dynamic modelling of different parameters (Sartori et al. 2008; Hu, Van der Voet, and Huppes 2010), spatial analysis (Kleemann et al. 2016; Mastrucci et al. 2017; Miatto et al. 2019) or through investigation of national/regional or municipal statistical records or historical building plans (Gontia et al. 2018). The density of construction materials may be found in the literature. These data are then used to calculate the mass of each component and, finally, the mass of construction materials embedded in the building stock.

The later data also serve to derive a specific coefficient called the material intensity coefficient (MIC) or the material composition indicator (MCI). The MIC describes the material consumption (average mass of the material) of different components in building stock, such as elements, area or volume and is often measured in kg per m, m^2 or m^3, respectively. For this reason, the method is also known as the coefficient-based method (Gontia et al. 2018). The significance and the usability of this coefficient drew the attention of many researchers as they compiled MIC databases for their regions and different construction types. So far, the MIC databases are available for residential buildings in Rio de Janeiro (Condeixa, Haddad, and Boer 2017), Sweden (Gontia et al. 2018), Vienna (Kleemann et al. 2014), non-residential buildings in Germany (Ortlepp, Gruhler, and Schiller 2016a; Schebek et al. 2017) and buildings and infrastructure in UK and Japan (Tanikawa and Hashimoto 2009). The results of these studies only emphasised the high sensitivity of the MIC and, consequently, of MS, to the local natural environment, construction trends, level of economic development and the need for more research.

The first attempt to estimate building stock was through parametric modelling. However, these studies rarely estimate or predict the quantity of CDW. They mostly employ variables that drive the building demand, such as population, per capita floor area, dwelling per capita, floor area per dwelling and other demographic and socio-economic indicators (Sartori et al. 2008; Hu, Van der Voet, and Huppes 2010). In addition to these variables, Sartori et al. (2008) investigated how the lifetime of dwellings and renovation rates may affect the construction, renovation and demolition activity in Norway. In the most recent work, Sartori and his colleagues further improved this methodology by removing the parameters that caused uncertainty and by dividing the stock into several cohorts (Sartori, Sandberg, and Brattebø 2016). They also projected the construction, renovation and demolition activity in Norway up to 2100.

In China, Hu, Van der Voet, and Huppes (2010) applied dynamic MFA through parametric modelling to forecast the stream of concrete up to 2050 in Beijing, China. They used historical values of several parameters: population, per capita floor area, building lifetime and gross domestic product. Also, they investigated three scenarios. The first was the baseline, the second was the extremely high growth of the per capita floor area, and the third was the prolonged lifetime of buildings. The results showed that the first peak of concrete waste may be reached around 2030, with more than 40 million tonnes per year(Hu, Van der Voet, and Huppes 2010).

One of the most comprehensive bottom-up studies of material stock for 25 countries of the European Union (EU25) was made by Wiedenhofer et al. (2015). The material stock of non-metallic minerals for the period 2004—2009 was based on 72 residential building types, four roads and two railways types. Their methodology included multiplication of the extent of each stock type (number of buildings or km of roads or railways) in each country within the particular year and MICs for each stock type. The results for 2009 estimated non-metallic minerals at 72 tonnes per capita in residential buildings, 128 and 3 tonnes per capita for roads and railways, respectively. Additionally, they estimated that 75% of the materials needed for the maintenance of the material stock in EU25 might be covered by recycled materials, assuming that the recycling rates target of 70% set for 2020 is achieved (Wiedenhofer et al. 2015). Similarly, in Japan, GIS was coupled with statistical data to grasp the entire material stock, including both buildings and civil works (roads, railways, airports, etc.) (Tanikawa et al. 2015).

Other studies were mostly focused on city level Building Stock (BS). They were either devoted to a single material stream (bricks) (Ergun and Gorgolewski 2015) or multiple material streams (Kleemann et al. 2017; Miatto et al. 2019; Lederer et al. 2020; 2021).

One of the few efforts to estimate the annual amount of individual waste streams was the one by Ergun and Gorgolewski (2015). They used MFA to investigate the annual quantity of bricks available for recycling and reuse in Toronto, Canada, in 2012. The bricks' volume was determined from architectural plans of five building types from different construction periods. Additionally, 30% of the brick walls volume was assumed to be mortar. Also, the loss of material due to damage during deconstruction was assumed to be between 10 and 50 % of the volume of the brick. Therefore, the quantity of bricks available for reuse ranged from 2523—4542 m^3, in contrast to 6187 m^3 of bricks available for recycling (Ergun and Gorgolewski 2015).

A significant contribution to building stock knowledge was made by Kleemann and his colleagues (Kleemann et al. 2014; 2016; 2017). Firstly, they combined construction plans analysis with onsite investigations to determine the MIC of several buildings set for demolition in Vienna (Kleemann et al. 2014). Secondly, they employed GIS and performed a spatial analysis of the building stock and the MIC in Vienna in 2013 (Kleemann et al. 2016). Both studies set the MIC within a range of 270—470 kg per m^3 and 310—460 kg per m^3, respectively. Additionally, in the latter study, they expressed the amount of material per capita as approximately 210 tonnes.

Using a similar methodology, Kleemann et al. (2017) also validated demolition statistic data for the city of Vienna in 2013. Spatial analysis was used to confirm the addresses of demolished buildings obtained from the municipality and to identify and measure all demolished buildings, both reported by the municipality and identified through changes of aerial images. Buildings were then grouped into 15 categories depending on their use and construction period. The estimation and composition of the demolition waste were achieved when the MICs were multiplied by the volume of buildings. The results showed a significant difference in the volume of demolished buildings obtained through spatial analysis over the municipal data, i.e., 2.8 million m^3 in contrast to 1.7 million m^3 obtained from the municipality records. The overall amount of CDW gained through the detection of changes from aerial photos from 2012 and 2013 yielded 1.1 million tonnes of waste (610 kg per capita) (Kleemann et al. 2017).

And finally, the more recent Viennese studies investigated the MS and the future amounts of CDW by consideration of three possible demolition scenarios: demolition practice from 1991 to 2015, higher demolition rates, and, finally, extensive thermal renovation instead of demolition (Lederer et al. 2020; 2021). Results showed a slightly lower MS in comparison with previous Viennese studies, 180 tonnes per capita in contrast to 210 tonnes per capita. In terms of raw material extraction avoidance, even if a recycling rate of 100% is assumed in the most optimistic scenario, only 42% of primary raw material may be substituted by recovered material (Lederer et al. 2021).

In another city-level study, Miatto et al. (2019) used a spatial analysis for the period 1902–2007, to determine the changes in the building stock and to calculate the demolition waste potential in Padua, Italy for 2007. They also included a forecast for 2030 based on stock accumulation and building life trends. The buildings that were detected as demolished were grouped into several types based on the height and the location, and the volumes of their constructive elements were calculated. The volumes were then multiplied with MICs to obtain the weight of each element. The weights were then aggregated to the total amount of building material, which in combination with building lifespan trends, gave an estimation of the demolition waste. The result found that the amount of demolition waste material per capita in 2030 will reach approximately 1.9 tonnes, with a significant share of concrete (Miatto et al. 2019).

More recent data on a national scale may be found for Sweden (Gontia et al. 2018) and

Luxembourg (Bogoviku and Waldmann 2021). In Sweden, a MIC database was compiled from 46 typical residential buildings categorised according to their building and structure type and the period of construction. Architectural plans were used to derive an inventory of building elements and their volume. The mass of materials within the building elements was determined when the volume was multiplied by the material density. And finally, masses were aggregated by material type and divided by gross floor area to obtain the MICs. Depending on the age of construction, the results ranged from an average of 895 kg per m^2 (for the period 1890—1910) to 400 kg per m^2 (for the period 1970—2000) for single-family buildings and an average of 675 kg per m^2 to 1349 kg per m^2 for multi-family buildings (Gontia et al. 2018).

On the other hand, a combination of spatial and image analysis was used to estimate the mineral MS and to forecast the mineral CDW stream in Luxembourg (Bogoviku and Waldmann 2021). Their methodology consisted of MS estimation in five steps: spatial, age and material analysis, mineral CDW flows and future CDW volumes. The results highlighted 122 years as the average service life of a building in Luxembourg, with a total built-in material of 450.8 tonnes per capita. More interesting are the mineral CDW projections by 2100 that they calculated ranged from 226.9 (existing BS) to 885.3 million tonnes (future BS), with the highest generation rates in the period 2020—2050.

One of the main advantages of models described in this subchapter is their applicability for forecasting building and infrastructure stock and, consequently, the quantity of CDW. Additionally, models that use individual construction elements and their physical size provide a good and robust base for the modelling of different CDW estimation and management scenarios.

On the other hand, these models are data demanding and often require an expert's knowledge either to restore construction elements from plans and drawings or to further process geospatial data or restore historical cadastral maps. Also, construction objects (buildings or civil works) are difficult to generalize. The characteristic of one construction project rarely matches with another. Material intensity coefficients are derived from literature or different databases rather than from on-site measurements. Additionally, the top-down method may overestimate the amount of CDW as a significant amount of construction materials may never become waste. And finally, this model may be difficult to apply in countries without reliable statistical data on building and/or infrastructure construction or material production and consumption.

2.5.5 Computer-aided and Web-based Models

One of the first researchers that used a computer system to analyse spatial data related to building and infrastructure stock was Tanikawa and Hashimoto (2009). They used a 4D-GIS database to show the spatial distribution of construction materials and predict the demolition activity in Salford, United Kingdom, and Wakayama City, Japan (Tanikawa and Hashimoto 2009). Since then, an abundance of studies employed GIS to achieve different goals: to map illegal dumping and analyse the disposal of CDW (Diogo Henrique Fernandes da Paz, Lafayette, and Sobral 2018), to analyse changes in the building stock (Miatto et al. 2019) or demolition activity (Kleemann et al. 2017), to visualise the spatial distribution of materials within a particular location (K. L. Cheng et al. 2018; Bogoviku and Waldmann 2021) and even to verify municipal statistics on demolition (Kleemann et al. 2017). The usage of GIS in the most relevant CDW estimation or building stock studies was mentioned in detail in the above subchapter. Here only the advantages and disadvantages of GIS-based models will be highlighted.

The main limitation of using GIS in CDW estimation studies is the quality of GIS data. When GIS maps are available, there is good reliability and high confidence in these data. However, uncertainty exists when there is a lack of historical maps, or these maps are difficult to process and restore.

When it comes to the geographic scale, GIS is mainly used for estimations on a city level. Using GIS for national and regional estimation may require dealing with large data sets that are difficult to process. Similar problems may occur if we change the time frame. Additionally, buildings that were demolished and reconstructed within the same year may be left out of the analysis. On the other hand, GIS can help to identify non-reported demolition activities.

Another very useful tool that can help the estimation is BIM. This tool may be used in different stages of a project for different uses (project visualisation, quantity take-off, cost estimation, design reviews, etc.). However, in construction and demolition waste management, it is predominantly used for construction waste planning in the design stage and for construction waste reduction (J. C. P. Cheng and Ma 2013; Z. Liu et al. 2015; Won, Cheng, and Lee 2016). Other possible uses of BIM suggested in the literature are as a tool for the estimation of the secondary resources that could be recovered from a building (Akanbi et al. 2018) and as a framework for determining the potential for a building's deconstruction (Akinade et al. 2015) or integrated with Radio Frequency Identification (RFID) to track steel components in constructions (Ness et al. 2015).

Only a few studies have focused on demolition waste so far (J. C. P. Cheng and Ma 2013; Y. C. Kim et al. 2017). J. C. P. Cheng and Ma (2013) proposed a BIM-based waste estimation system as an add-in for the Revit software. Within the BIM model, users choose elements to be demolished or renovated, set the material density and reuse or recycle data. The add-in then calculates the amount of CDW, categorises it into inert and non-inert waste, and estimates the disposal charging fee and the number of hauling trucks (J. C. P. Cheng and Ma 2013).

Another use for the estimation of demolition waste was suggested by Kim et al. (2017). They proposed a framework for the estimation of demolition waste by type in the early design stages based on BIM. The amount of demolition waste was based on waste generation rates reported in the literature (Y. C. Kim et al. 2017).

Irrespective of the use, the application of BIM in the estimation and management of CDW has many advantages. One of the main advantages is the possibility to review and validate designs and identify design errors that may cause on-site rework and, consequently, demolition waste. A Digital building model may also allow for easier and quicker calculation and categorisation of MICs and, consequently, the amount of waste. More importantly, in addition to data on the physical size of construction elements, the BIM model may carry information on material intensity and service life, disposal fees and other costs, etc. Finally, other computer and web-based models are not interoperable with other software.

However, the application of the model in existing constructions is very limited (Volk, Stengel, and Schultmann 2014). The BIM model is highly sensitive to the quality of BIM data. Therefore, one of the major challenges that face wider application is the automation of data capture and the creation of a BIM model of existing buildings at low costs. That is the reason why the application of BIM to estimate and manage demolition waste remains to be researched yet, although demolition waste presents the largest share of CDW.

Finally, several other studies that used complex computer software in the estimation of CDW need to be mentioned. These studies were mainly focused on the prediction of CDW amounts or indicators that lead to a prediction of waste using different variables (Z. Wu, Fan, and Liu

2015; Kern et al. 2015; Lu et al. 2015).

For instance, Z. Wu, Fan, and Liu (2013) employed gene expression programming to forecast the amount of construction and demolition waste in Hong Kong, China. They used four variables: gross floor area, GDP, the gross value of construction works and the charging scheme to predict the amount of waste (Z. Wu, Fan, and Liu 2015). In another Chinese study, the Gray model and support vector regression models were used for the prediction of floor areas, while CDW generation rates were obtained from the existing literature (Song et al. 2017). The Gray model was also used in combination with waste per area (Jain, Singhal, and Jain 2019). They used population projections to forecast the demand for buildings and the average dwelling sizes to determine construction activity, while the renovation and demolition activities were assumed.

Another study used Artificial Neural Networks (ANN) (Lu, Peng, et al. 2016). They collected historical disposal records and project characteristics for 138 high-rise building projects in Hong Kong to fit the S-curve, which they used to forecast the future construction waste generation on projects. The disposal statistic was used to find the best-fit S-curves, which are then linked by artificial neural networks with project characteristics such as contract sum, location, public or private nature and duration (Lu, Peng, et al. 2016). Although they promoted this model as a simple tool for construction waste forecasting, it is however based on previous building cases of high-rise buildings with steel and concrete composite structures. This significantly limits the use of the model in low-rise buildings.

When it comes to web-based platforms for the estimation of CDW, two of them that stood out for a while for the estimation of waste from construction (Net Waste Tool by Waste & Resources Action Programme - WRAP) (Birch, Burton, and Friedrich 2010) and renovation and demolition activity (DeconRCM) (Banias et al. 2011), but are not available now.

Two other uses of web platforms for the estimation of CDW are WCWES in China (Y. Li and Zhang 2013) and SIGERCON in Brazil (Diogo H F Paz and Lafayette 2016). Y. Li and Zhang (2013) developed a web-based platform suitable for project-level estimations based on the mass balance principle. The platform incorporates the work breakdown structure, material classification, quantity take-off conversion ratios and percentage of waste for each (Y. Li and Zhang 2013).

On the other hand, Diogo H F Paz and Lafayette (2016) developed a management system for the estimation of construction waste based on WGR indicators. In addition to waste generation per area, the system introduced two other measurements: waste generation per duration of the works and waste generation per number of floors. All indicators came from the monitoring of 19 construction sites and assumed values of 97 kg per m^2, 42.3 tonnes per month and 52.9 tonnes per floor, respectively. They also suggested a waste generation per stage of work indicator. The system was then validated on 12 other construction sites. The validation showed that the estimation method based on a waste generation per construction area was the most accurate and the closest to the field observations (Diogo H F Paz and Lafayette 2016).

Although the obvious advantages of web-based models are the facts that they are easily operated, accessible and based on actual on-site waste data, very limited research hinders their wider application.

2.5.6 Hybrid Models

A few authors believed that a combination of methods would overcome the disadvantages of individual methods and be more appropriate for the estimation of CDW. A recent study even recommended a combination of methods depending on the quality of input data and the final purpose of the estimation (N. Zhang et al. 2019).

As mentioned before, waste per activity area and field observation was the most used combination. Field observation mainly served for validation of the prevailing WPA methodology, except in the Bernardo et al. (2016) study where they calculated the amount of demolition waste from residential and non-residential buildings in the Lisbon Metropolitan Area from 2008 to 2012. They used data from the demolition of 54 buildings of different types and ages to estimate the WGR and the age of construction. National statistics were used to calculate the proportion of residential and non-residential buildings and to estimate the proportion of buildings that needed repair or demolition. The gross building area for residential buildings was taken from previous studies, while the gross building area for non-residential buildings was taken from field observation records. Two scenarios for the number of demolished buildings were run, and two assumptions regarding the geographical starting point were made. The average result estimated the amount of CDW to be 465 tonnes from demolition works in 2012. Additionally, this research provided the analysis of the correlation between CDW generation and population and building density, building ageing index and percentage of urban land (Bernardo, Gomes, and de Brito 2016).

2.6 Auditing the CDW Management Alternatives

2.6.1 Review of Available Models for CDW Management Sustainability Assessments

Before making any sound decision in the transition to sustainable practice, several aspects of CDW management must be considered. In the recent decades (1990—2021), various managerial aspects of CDW were considered by the scientific community. The most investigated were CDW management practices. Scientists worldwide wrote on CDW management practices in developed and developing countries (Duan and Li 2016; Mihai 2019; Duan et al. 2019; Blaisi 2019). They either compared different practices (Vivian Wing Yan Tam and Lu 2016; K. R. A. A. Nunes and Mahler 2020; Z. Wu, Yu, and Poon 2020; Aslam, Huang, and Cui 2020) and their components (Kabirifar et al. 2020), examined barriers and opportunities (H. Yuan 2017) or highlighted the best practices (Gálvez-Martos et al. 2018).

Other studies considered the technical and the logistic aspect of CDW, such as the optimal location of landfills (Gorsevski et al. 2012), recycling facilities (Berta Galán et al. 2013) and sorting areas (Diogo Henrique Fernandes da Paz, Lafayette, and Sobral 2018; Biluca, de Aguiar, and Trojan 2020), potential illegal dumping areas (Seror and Portnov 2018; Diogo Henrique Fernandes da Paz et al. 2020), etc. One of the most observed aspects was the stakeholder point of view on CDW management practices, their behaviour and motivation in particular (Z. Wu, Yu, and Shen 2017; J. Chen, Hua, and Liu 2019; Su et al. 2020).

And finally, the digital revolution resulted in the development of new CDW management studies where the application of different information technologies was considered, such as GIS (Blengini and Garbarino 2010; Seror and Portnov 2018), BIM (J. C. P. Cheng and Ma 2013; Akinade et al. 2018), Big Data (Lu et al. 2015; Bilal et al. 2016; Lu, Chen, et al. 2016), RFID (Lu, Huang, and Li 2011), etc.

However, studies that are of importance for this thesis had sustainability performance and the different aspects of CDW management in focus. Over the years, a significant number of these studies were developed by researchers worldwide, from Australia to Latin America, with all levels in focus, from the national to project levels. In temporal scope, these studies cover both the estimation of current and projections of future CDW practices. A brief overview of the most notable studies in chronological and alphabetical order is provided in Table 7, while more a detailed description of studies and their findings will be given in the next few subchapters (Subchapters 2.6.2—2.6.6).

Table 7 Review of selected CDW management sustainability assessment studies

Author(s)	**Scope**			**Treatment options**	**Sustainability aspect**			**Methods**
	Location	**Level**	**Period**		**ECO**	**ENVI**	**SOC**	
Ferronato et al. (2021)	La Paz Bolivia	CIT	n/a	RC, LF		•		LCA
Hoang et al. (2021)	Hanoi Vietnam	CIT	2020	RC	•	•		DCF
Iodice et al. (2021)	Campania, Italy	REG	2015	RC, LF	•	•	•	Taelman et al. (2019), MCDM
F. Zhang et al. (2021)	Xi'an China	PRO	n/a	RC	•	•	•	MCDM (TFNs, TrFNs, ANN)
Cha et al. (2020)	Daegu, Busan South Korea	CIT	n/a	RC	•	•		Novel method
Jain et al. (2020)	New Delhi India	CIT	n/a	RC, LF		•		LCA
Li et al. (2020)	Shenzhen China	PRO	n/a	RC		•		WtP
Liu et. (2020)	Guangzhou China	CIT	2007—2017	RC, LF, ID	•	•	•	SD
Khoshand et al. (2020)	Teheran Iran	NAT	n/a		•	•	•	MCDM (FAHP)
Ram et al. (2020)	Chennai India	CIT	2014	RC, LF		•		LCA
J. Liu et al. (2019)	Guangzhou China	PRO	1 year	ID, LF, RC	•			FCA
J. Wang et al. (2019)	Shenzhen China	CIT	n/a	RC, LF		•		WtP
C. Zhang et al. (2019)	Netherlands	NAT	2015-2019	RC	•	•		LCA, LCC
Borghi et al. (2018)	Lombardy Italy	REG	2014	RC, LF		•		LCA
Di Maria et al.(2018)	Flanders, Belgium	REG	1 year	RC, LF	•	•		LCA, LCC
Jia et al. (2018)	Shenzhen China	CIT	2005—2022	RC, LF, ID	•			SD
Mah et al. (2018)	Iskandar Malaysia	PRO	2015	RC, LF	•	•		LCA, LCC
Wang et al. (2018)	Shenzhen China	CIT	n/a	RC, LF		•		LCA
(Wijayasundara et al. (2018)	Australia	NAT	2008—2009	RC, LF	•	•		BT
Yazdanbakhsh (2018)	New York United States	CIT	2011—2015	RC, LF		•		LCA

Chau et al. (2017)	Hong Kong China	PRO	70 years	RU, RC, LF		•		LCEA
Hossain et al. (2017)	Hong Kong China	PRO	n/a	RU, RC, LF		•		LCA
Jia et al. (2017)	Shenzhen China	CIT	n/a	RU, RC, LF, ID	•			SD
Oliveira Neto et al. (2017)	Europe	n/a	20 years	RC	•			DCF
Vitale et al. (2017)	Italy	PRO	n/a	RC, ER, LF		•		LCA
Penteado and Rosado (2016)	Limeira Brazil	CIT	2013	RC, LF		•		LCA
H. Wu, Wang, et al. (2016)	Shenzhen China	CIT	2015—2060	RC, LF	•			GIS
Butera et al. (2015)	Denmark	NAT	100 years	RC, LF		•		LCA
Dahlbo et al. (2015)	Finland	NAT	n/a	RU, RC, ER, LF	•	•		MFA, LCA, ELCC,
Diyamandoglu and Fortuna (2015)	Burlington Vermont, US	PRO		RC, ER, LF	•	•		LCA, R
Marzouk and Azab (2014)	Egypt	NAT	2004—2024	RC, LF, ID	•	•		SD
Kucukvar et al. (2014)	United States	NAT	n/a	RC, ER, LF		•		LCA (hybrid)
Carpenter et al. (2013)	New Hampshire United States	CIT	2006	RC, ER, LF		•		LCA
Martínez et al. (2013)	Spain	PRO	n/a	RU, RC, LF		•		LCA
H. Yuan (2012)	Shenzhen China	PRO	n/a	ID			•	SD
Coronado et al. (2011)	Cantabria Spain	REG	2003—2008	RC, LF	•	•	•	MCDM (EV, WS, ELECTRE II and REG)
Blengini and Garbarino (2010)	Turin Italy	CIT	n/a	RC		•		LCA, GIS
Ortiz et al. 2010).	Barcelona Spain	REG	n/a	RC, ER, LF		•		LCA
Roussat et al. 2009)	Lyon France	PRO	n/a	RU, RC, ER, LF	•	•	•	MCDM (ELECTRE III)
Kourmpanis et al. (2008)	Cyprus	NAT	1990—2002	RC, LF	•	•	•	MCDM (PROMETHE E II)
Klang et al. (2003)	Östersund Sweden	PRO	n/a	RU, RC	•	•	•	Novel method

NAT – national; REG – regional; CIT – city; PRO – project; RU – reusing; RC – recycling; ER – energy recovery; LF – disposal; ID – illegal dumping; ECO – economic; ENVI – environmental; SOC – social; LCA – Life Cycle Assessment, MCDM – Multi-Criteria Decision-Making Analysis; TFNs – Triangular Fuzzy Numbers; TrFNs – Trapezoidal Fuzzy Numbers; ANN – Analytic Network Process; WtP – Willingness to pay; SD – System Dynamics; FAHP – Fuzzy AHP method; FCA – Full Cost Accounting method; LCC – Life Cycle Costing; BT – Benefit Transfer; LCEA – Life Cycle Energy Assessment; DCF – Discounted Cash Flow; GIS – Global Information System; MFA – Material Flow Analysis; R – Revenues; EV – Evamix; WS – Weighted Summation; REG – Regime.

Whether considered from the environmental, economic or social aspects, the approach to the CDW management assessment studies was the same. Most of the studies focused on the selection and estimation of chosen indicators. The selection of indicators depended on the sustainability aspect that was evaluated. For instance, environmental indicators were used from several databases (Eco-indicator 99, CML, IPCC, IMPACT 2002+, etc.).

The economic indicators involved costs and revenues from the entire treatment process, from selective demolition, sorting and collection, transportation, treatment and final disposal. They included costs of capital investments and waste treatment operations (labour, transportation, energy, etc.), taxes subsidies and revenues from recovered materials, etc. And finally, the social indicators that were considered in the studies included job opportunities, physical working conditions, public satisfaction, etc.

The methodology used for the evaluation of indicators also depended on the sustainability aspects. LCA was mostly used for environmental assessment, while LCC and CBA were used in economic assessments. Where the environmental and the economic impact needed to be assessed, a combination of these methods was applied. On the other hand, the social aspect of the CDW management was, on most occasions, assessed through a System Dynamics method. Except for social performance, a System Dynamics method was often used for the economic and environmental performance as well.

When it comes to waste streams and waste treatment options, the majority of studies had mixed CDW stream and recycling and disposal options as the CDW management scenarios. It has to be noted that, when it comes to CDW quantities, the majority of these studies relied on static CDW stream flows, which originate from either statistical records or the existing literature. However, the CDW stream flows have a dynamic nature and are also location-specific. Therefore, in order to build more confidence in these studies and integration with material stock-based methods for CDW quantification similar to the one made by (Dahlbo et al. 2015; Butera, Christensen, and Astrup 2015), are necessary.

2.6.2 Environmental Impact Assessments of CDW Management

The environmental impact was one of the most investigated aspects of sustainability in the last decade (2010—2021). The indicator that was used for environmental performance in most of the studies was GHG emissions, i.e., the carbon footprint or global warming potential, followed by energy consumption (savings). Other indicators included impacts on human health (toxicity, respiratory effects, ionizing radiation and respiratory effects), impacts on air, water and soil pollution (ozone depletion, aquatic and terrestrial ecotoxicity, terrestrial acidification and nitrification, etc.) and impact on land occupation and mineral extraction.

Additionally, the choice of the CDW stream, CDW treatment and the treatment stages investigated in the studies directly affected the environmental performance. Most of the studies had mixed CDW in focus that was transported to a recycling facility where it was sorted and further processed. Non-recyclable waste streams were eventually then transported to landfills. The scenario analyses that were considered rarely included all CDW treatment options and were limited in recycling and disposal. In the majority of studies, transportation of CDW and steel recycling showed to be the most significant contributors to environmental performance. Other important findings and more details of selected studies are presented further in the text.

Chinese environmental performance studies were the most numerous ones. They differ in the environmental indicators, CDW treatment scenarios and waste streams that were in focus. The studies also investigated management practices at different spatial levels, from the project to the national level. For example, Chau et al. (2017) investigated energy consumption for all treatment options of waste generated during the deconstruction of one building in Hong Kong. Treatment options were grouped in two scenarios; the first scenario implied maximum recovery rates for reusing, recycling and energy recovery, while the second scenario involved options with the highest energy savings potential. The energy savings considered both the energy consumption from recovered materials and embodied energy during the construction of the building. In terms of waste streams, the highest contributors were the recycling of aluminium and external walls, with a share of 30.7 to 30.6%, respectively. As expected, maximum reuse yielded more savings than maximum recycling, while energy recovery had no energy savings (Chau et al. 2017).

Hossain et al. (2017) widened the spatial scope of two construction sites in Hong Kong, China. Their study included all stages of construction waste management: sorting, transportation, reuse, recycling and disposal. One of their main contributions was a comparison of the environmental impacts of on-site and off-site sorting. Their results illustrated a significant difference in the amount of CO_2-eq in favour of on-site sorting, with saving that ranged from 144 to 212 kg CO_2-eq for one tonne of construction waste (Hossain, Wu, and Poon 2017).

The environmental impact of the most common CDW streams' recycling on the city level was evaluated in a study by T. Wang et al. (2018) for Shenzhen, China. The waste streams that were in focus were concrete, brick, steel and mortar. The environmental consequences of their recycling, observed and calculated in the study, included global warming, ozone depletion, solid waste, land consumption, acidification and eutrophication. The results showed that the most environmentally beneficial secondary recovery material is recycled steel, with 1,811 kg CO_2-eq reduced per tonne of steel, while recycling of brick, mortar and concrete has a negative effect on the environment, 32.2, 7.54 and 4.83 kg CO_2-eq respectively (T. Wang et al. 2018).

While most of the mentioned studies used the LCA methodology, J. Wang et al. (2019) used willingness to pay to monetise nine environmental impact assessment indicators: water and energy consumption, raw material consumption, GHG emissions, acidification, eutrophication, dust, photochemical pollution and land occupation. Additionally, they evaluated the CDW management fee on a national level. The results showed that the highest management fee is for metal waste (approximately 9.30 dollars), followed by wood and masonry waste with approx. 5.92 and 4.25 dollars, respectively (J. Wang et al. 2019).

Using the same methodology (i.e., willingness to pay), Li et al. (2020) assessed the environmental impact of 15 mobile recycling projects in Shenzhen. However, only five indicators were considered: global warming potential, acidification and eutrophication potential, photochemical ozone creation and land occupation. The total environmental costs and benefits of mobile recycling were estimated at 0.06 and 0.38 dollars per tonne of CDW on average, with global warming potential and land occupation as the highest contributors (Jingru Li et al. 2020).

In recent years, India also contributed to environmental performance studies. For instance, Jain et al. (2020) compared disposal with wet process recycling at two recycling facilities in New Delhi, India. Their study was focused on global warming potential, i.e., the total amount of GHG emitted in the process. As expected, recycling performed better than disposal, mostly due to avoiding transportation and land use for landfills (Jain, Singhal, and Pandey 2020).

Another Indian study analysed current and future disposal scenarios in addition to two recycling scenarios CDW (Ram, Kishore, and Kalidindi 2020). They compared 15 environmental categories for all scenarios. The recycling scenarios (with or without transfer stations) resulted in environmental benefits in all categories, with the avoided CO2 emissions of 6.41 kg per tonne of CDW in the recycling scenario without transfer stations and 4.92 kg per tonne of CDW in the recycling scenario with transfer stations. Additionally, primary energy savings ranged from 66.7—89.9 MJ, while arable land consumption savings ranged from 0.29—0.32 m^2 per one tonne of CDW (Ram, Kishore, and Kalidindi 2020).

In the United States, Carpenter et al. (2013) analysed several environmental indicators (GHG emissions, air and water pollution) for seven CDW management scenarios in New Hampshire. The scenarios ranged from different options of disposal (ash, gas faring or energy recovery from gas) to recycling. The incineration of the wood waste stream to generate electricity was also considered. As expected, the results illustrated that recycling is more favourable to the environment than disposal. In comparison to disposal, the annual savings in GHG emissions from recycling CDW ranged from 77.2—143.3 kt CO_2-eq, with significant savings in air pollutants (Carpenter et al. 2013). Other US researchers investigated similar scenarios for waste treatment of nine building materials in the United States. They assessed GHG emissions, energy consumption and water pollution in three different CDW management strategies: recycling, energy recovery and disposal. The results indicated that only recycling might benefit the environment in terms of energy, carbon and water footprints, followed by energy recovery. When it comes to different waste streams, the most beneficial stream is the non-ferrous metal that, if recycled, has the lowest impact on the environment (Kucukvar, Egilmez, and Tatari 2014).

Using a similar methodology but with more indicators, Yazdanbakhsh (2018) compared the environmental impact of four potential CDW management scenarios for New York City. The scenarios included options such as a disposal, backfilling and recycling of all mineral CDW with different recovery rates of coarse aggregate. The results showed that the highest environmental burden was attributed to the most circular strategy, i.e., the one that planned the highest usage of recovered aggregate in new concrete production. The increased need for cement in the production of this type of concrete significantly exceeded the environmental benefits gained with high recovery rates (Yazdanbakhsh 2018).

In Latin America, a group of researchers analysed the environmental impacts of six CDW management scenarios that combined different percentages of CDW landfilled, backfilled or recycled in Limeira, Brazil. The environmental impacts that were assessed included acidification, global warming, eutrophication, photochemical oxidation and depletion of abiotic resources. The results confirmed a significant share of CDW transport in the environmental performance: 41% for disposal and 67% for recycling. Additionally, recycling remained more beneficial to the environment than disposal as long as the transportation distances from a demolition site to a recycling facility were below 30 km (Penteado and Rosado 2016). Using the same indicators, Ferronato et al. (2021) evaluated the environmental impacts of possible CDW management in La Paz, Bolivia. Selective CDW collection and transport distances related to recycling were the focus of the study. The environmental impacts of transport were estimated in the range of 1.05—20.7 t CO_2-eq per km, suggesting the transportation limit should be set at 40 km to make CDW recycling environmentally feasible (Ferronato et al. 2021).

In Europe, CDW management practices from Italy and Spain were the focus of the majority of environmental performance studies. One of the first was by Blengini and Garbarino (2010), who compared mobile, semi-mobile and stationary recycling in Turin, Italy. In their analysis, they combined a GIS and an LCA approach to analyse land use, transportation and avoided landfills. A total of 14 environmental indicators were used: global warming, mineral extraction, non-renewable energy, land occupation, human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, aquatic and terrestrial ecotoxicity, photochemical oxidation, aquatic acidification and eutrophication, terrestrial acidification and nitrification. Interestingly, the results showed that the recycling process alone has more negative than positive impacts on the environment. However, when the entire recycling chain, including collection, transportation, and avoided landfills, is considered, the positive impacts become higher than the negative impacts for 13 indicators (Blengini and Garbarino 2010).

The same indicators were used in the Vitale et al. (2017) paper. They studied the environmental impacts of demolition and subsequent waste treatment for one residential building located in South Italy. The environmental performance was evaluated for three end-of-life stages: demolition, transportation and treatment. The results emphasize the great contribution of steel recycling on a decrease of the environmental burdens, as steel recycling *"accounts for the most of the avoided impacts in the crucial categories*" (Vitale et al. 2017).

Another Italian environmental impact research study had a regional character. The researchers analysed environmental categories that belong to the ILCD methodology (European Commission (Joint Research Centre - Institute for Environment and Sustainability) 2010) with the exclusion of land use and ionizing radiation. An indicator that reflects the consumption of non-renewable primary raw materials was added. CDW management of the Lombardy region was in focus. The results showed that the current CDW management scenario with 85.1% of the CDW recycled had a negative impact on the environment. This impact becomes positive with all CDW sent to recycling plants, minimized transport distances and high shares of high-quality recycling (90%) (Borghi, Pantini, and Rigamonti 2018).

The environmental performance of different CDW management scenarios was also compared in Spain, where Ortiz et al. (2010) evaluated six environmental indicators for three different scenarios in the Catalonia region. Additionally, they calculated maximum waste transport distances for all scenarios. Depending on the waste stream treatment potential, the scenarios included recycling, energy recovery and disposal. As anticipated, when it comes to GHG emissions, recycling and energy recovery scenarios performed better than disposal, irrespective of transport distances, except for the stone waste stream. In the case of stone and with respect to the GHG emission, the option that benefits the environment the most is on-site recycling (Ortiz, Pasqualino, and Castells 2010).

On the other hand, Martínez et al. (2013) examined the alternatives that included reusing and recycling with and without sorting and disposal. The alternatives formed two positive scenarios, based on selective demolition and a negative scenario, based on traditional demolition. The indicators that were considered were GHG emissions, human toxicity and non-renewable energy consumption of 20 CDW streams that may occur at the end-of-life stage of one building in Spain. The results disclosed that the contribution to the environmental impacts of the positive scenario is significantly lower than in the negative scenario, with a reduction of 89% for GHG emissions, 67% for non-renewable energy consumption and 49% for human toxicity potential (Martínez, Nuñez, and Sobaberas 2013).

And finally, one of the most comprehensive European environmental analysis in terms of environmental impact categories was the one performed by Butera et al. (2015) with Denmark as a case study. It included both hazardous and non-hazardous mineral CDW, but it was limited to just two scenarios: backfilling and disposal. The indicators that were evaluated were the ones recommended by ILCD (European Commission (Joint Research Centre - Institute for Environment and Sustainability) 2010), except ozone depletion and ionizing radiation, which were excluded from the analysis. The results showed that disposal burdens the environment more than backfilling in most categories. While backfilling may result in small environmental benefits from avoided extraction of primary raw material, disposal has no benefit to the environment. Negative effects of backfilling are mostly due to transportation and crushing, the two most important impact categories for non-hazardous waste, with a share of 70—80% of all negative impacts, while leaching contributed with 35 and 75% and to carcinogenic and non-carcinogenic human toxicity. On the other hand, leaching at landfills had small effects on the environment (Butera, Christensen, and Astrup 2015).

2.6.3 Economic Impact Assessments of CDW Management

The second most investigated aspect of sustainability was the economic aspect. The first studies investigated the economic viability of recycling facilities worldwide, from China (Zhao, Leeftink, and Rotter 2010; H. P. Yuan et al. 2011) and Australia (Vivian W Y Tam 2008) to Lebanon (Srour et al. 2013), Portugal (André Coelho and de Brito 2013b; 2013c), Greece (Banias et al. 2011) and Ireland (Duran, Lenihan, and Regan 2006) to Brazil (K. R. A. Nunes et al. 2007).

In recent years, China also led the effort on CDW management economic impact assessment studies. A few researchers used the GIS model to forecast and visually present the distribution of CDW in Shenzhen, China. They also evaluated the recycling potential and the demand for disposal land area under different CDW management scenarios. The scenarios ranged from the worst case, where all the waste except metal was sent to landfills, to the optimistic scenario with higher recycling rates (65%) (H. Wu, Wang, et al. 2016).

In addition to disposal and recycling, Liu et al. (2019) calculated the costs of illegal dumping. While the previous study calculated the economic effects on a municipality level, they were focused on one project. Their four treatment alternatives included illegal dumping, disposal, stationary and on-site recycling of construction waste generated on one construction project in Guangzhou, China. The results showed on-site recycling as an option with the lowest costs, followed by disposal and stationary recycling (J. Liu et al. 2019).

Other notable Chinese studies were focused on the effects that subsidy and penalty systems had on CDW management, especially on illegal dumping (Jia et al. 2017; Jia, Liu, and Yan 2018). Both studies suggested the penalty range for one tonne of illegally disposed waste should be between 300—400 yuan (approximately 41—55.5 euros) to significantly reduce (by 63%) the amount of waste. Additionally, a disposal fee for one tonne of waste was recommended at 70—90 yuan (approximately 9.7—12.5 euros) (Jia, Liu, and Yan 2018). When it comes to subsidies that are used to encourage reusing and recycling, Jia et al. (2017) suggested that an increase of 310% in the amount of waste reused or recycled is possible with a subsidy of just 40 yuan per tonne (approximately 5.55 euro).

In Europe, Oliveira Neto et al. (2017) evaluated the economic feasibility of different recycling technologies: current, advanced recycling with air jigs and spirals and advanced sorting process with optical and near-infrared sorting. Different capacities of recycling platforms were adopted to evaluate the economic impact of these scenarios. The capacities ranged from 100 thousand tonnes per year, which is the most commonly used in the EU, to over 300 thousand tonnes for metropolitan areas and 600 thousand tonnes per year, which was considered an extreme situation. The costs that were considered were an investment (site and permits, construction, plant and equipment) and operating costs (labour, administration, insurance, maintenance, water, fuel energy, etc.). They came to two important conclusions when it comes to achieving the economic viability of recycling plants. The first is that the recovery target for high-quality recycled aggregate should be a minimum of 40% and that the price range of recovered material should be in the range of 15—18 euros per tonne. The second conclusion highlighted that the annual technical capacities of recycling facilities should exceed 300 thousand tonnes in contrast to 100 thousand tonnes facilities spread over the EU. Finally, they suggested policy interventions that will aim to increase the awareness of the use of secondary raw materials as well as raising the price of primary raw materials, implementation of legal requirements that will divert CD waste from landfills, better planning of CDW management and better infrastructure oriented to a reduction of transport costs such as the increase of transfer stations (Oliveira Neto et al. 2017).

2.6.4 Environmental and Economic Impact Assessments of CDW Management

A combination of environmental and economic indicators enabled a wider view of sustainability appraisals and better decision-making in the CDW management sector. Therefore, it is no surprise that the scientific community devoted its effort to evaluate this combined performance. These studies are often referred to as eco-efficient studies in the literature.

The first environmental and economic assessment studies that appeared used the System Dynamics approach and the recovered material sales value to evaluate these combined effects. The System Dynamics approach was used in Egypt to evaluate the economic and environmental effects of CDW recycling and disposal. The economic impacts that were considered included the disposal fee, the economic costs of waste disposal (including illegal dumping) and the economic benefits of recycling. GHG emissions (both induced and avoided) and energy savings from disposal avoidance were considered environmental impacts. The results showed that CDW disposal is not a viable option even if economic and environmental impacts are taken into consideration. They concluded that apart from higher GHG emissions and energy consumption, disposals may incur high costs for mitigation of its negative effects on the environment and human health (Marzouk and Azab 2014).

On the other side of the planet, Diyamandoglu and Fortuna (2015) analysed energy consumption, GHG emissions and sales values from recovered materials in the process of wooden-frame single-family house deconstruction in Burlington in Vermont (United States). Both GHG emissions and energy consumption of all waste treatment processes were compared through four scenarios. The baseline scenario was designed to reflect current management practices in the United States and the European Union. The US scenario assumed a metal recycling rate of 65% with all other waste transported to the landfills. The EU scenario assumed different recovery rates per each waste stream: wood (recycling 31%, 44% incineration and 25% disposal), steel and metal (84% of recycling), inert CD waste (60% recycled and 40% landfilled). The other three scenarios included a maximum and a partial reuse rate (only soft-stripped materials are reused) and maximum recycling rates. The results highlighted that recycled lumber, steel, and medium-density fibreboards were responsible for the largest savings in GHG emissions and energy consumption. When it comes to comparison between scenarios, the highest reduction in GHG emissions was reported in reuse after soft-stripping and maximum recycling scenarios (Diyamandoglu and Fortuna 2015).

Dahlbo et al. (2015) were one of the first that combined LCA and LCC to achieve a broader approach to sustainability assessment. They also integrated MFA to analyse particular waste streams and make the results more robust. While the first two methods were used for the evaluation of economic and environmental performance, the last was used to assess the quantity of material and recovery rates. Their focus was on the appraisal of the current CDW management in Finland, which included treatment (recycling and disposal) of metal, mineral, wood, miscellaneous and mixed CDW streams. The life cycle assessment evaluated climate change, energy savings and avoidance of primary raw material extraction, while life cycle costing included direct internal costs and profit. The transportation process was included in the LCC but excluded from the LCA. The results showed that disposal, energy recovery from solid recovered fuels and recovery of metals impose a significant environmental burden. The overall climate change (including avoided impacts) ranged from 350 and 360 kg CO_2-eq per one tonne of CDW. In terms of costs, the highest revenues were generated from the recovery of metal, wood and miscellaneous wastes. When all streams were considered and combined, CDW management in Finland was economically viable, with a net profit of 80 euros per tonne of CDW. As per the individual streams, the recovery of metal and wood showed to be the best in terms of both the economic and environmental feasibility, while the mineral fraction of CDW performed badly in both aspects (Dahlbo et al. 2015).

Similar to the previous study, Di Maria et al. (2018) combined LCA and LCC and analysed four alternatives for CDW management in the Flanders region in Belgium. The alternatives included both selective and traditional (conventional) demolition. The first included the transfer of wood and metal to reused markets and advanced recycling with high recovery rates of CRCA (80%). The latter had three routes: 1) advanced recycling, with a 73% recovery rate of CRCA, 2) downcycling with low-quality RCA used for road construction, and 3) disposal. The environmental impacts were calculated and expressed as equivalent to the impact caused by one person in one year (person equivalent). The economic impacts included several categories of costs (labour costs, landfill tax, gate fee and transportation cost), while the only revenue that was included was the one generated from the recovered secondary raw materials. The environmental analysis showed that disposal induced the highest impacts on the environment while recycling after selective demolition induced the lowest impacts (56% less than disposal). Transportation was the highest contributor in all cases. In terms of the economic impacts, disposal has the highest impact, followed by recycling after selective demolition, advanced recycling and downcycling (Di Maria, Eyckmans, and Van Acker 2018).

Another notable study analysed demolition waste treatment (recycling) for more than one thousand buildings with different structure types demolished in Korea. Two scenarios of recycling treatment were considered: current and maximum recycling. The economic and environmental impacts were explored in each stage of the demolition and treatment process. Operational costs and GHG emissions were the only indicators that were considered for eleven material waste streams. Additionally, the building structures' recycling potential for each waste stream was estimated. In terms of particular waste streams, the highest recycling potential was for the plastic waste stream, meaning that the operational costs of recycling and cost of CO_2 were less than the revenues from recovered plastic. In contrast to plastic waste, the mineral CDW stream had the lowest recycling potential (Cha et al. 2020).

Another study that predominantly compared recycling scenarios was developed for Hanoi, Vietnam (Hoang et al. 2020). This study compared three CDW management scenarios: disposal, one stationary recycling plant (capacity 1000 tonnes per day) and three mobile recycling plants (capacity 360 tonnes per day). Residues from all recycling plants were disposed to landfills. The scenarios' comparison included the evaluation of economic (capital and operational costs and revenues from recycled concrete aggregate, savings in CDW transport, etc.) and environmental impacts (GHG emissions, land use). The results proved stationary recycling plants as economically and environmentally feasible options in contrast to mobile recycling plants. Additionally, the price of recycled concrete aggregate is highlighted as the most contributing factor to CDW recycling feasibility (Hoang et al. 2020).

Apart from CDW management strategies that included different options for various waste streams, most of the studies had only concrete recycling in focus (Mah, Fujiwara, and Ho 2018; Wijayasundara, Mendis, and Crawford 2018; C. Zhang et al. 2019). Mah, Fujiwara, and Ho (2018) evaluated the eco-efficiency of four treatment options for concrete waste streams in Iskandar, Malaysia. The options included the disposal of concrete and recycling with different recovery rates for various materials. These three scenarios involved alternatives where the entire concrete waste was recovered as road base material or recovered as material for new concrete production or a combination of these two. The environmental aspects were observed through the evaluation of GHG emissions, while the economic aspects included disposal and recycling operational costs and the cost of natural aggregate. However, capital costs and the costs of environmental pollution were excluded. Results showed that the lowest economic and environmental impact was attributed to the scenario where recovered recycled aggregate was used in concrete production as opposed to disposal, which had the highest impact on both aspects (Mah, Fujiwara, and Ho 2018).

On the other hand, Wijayasundara, Mendis, and Crawford (2018) analysed eco-efficient costs and benefits connected with the use of RCA in structural concrete production in Australia. Additionally, they evaluated only the externalities that they considered the most important: avoidance of landfills, extraction of natural aggregate and transportation of CDW to the landfills. They conclude that the replacement of natural aggregate with recycled in the range of 30 to 100% may achieve a net benefit in the range of 9 to 28%. This result is based on the recycling process of one test case in Japan that yielded approximately 55—73% of coarse and 27—45% of fine RCA. No sludge from the wet processing was taken into consideration (Wijayasundara, Mendis, and Crawford 2018).

However, this technical aspect of recycling was considered by Zhang et al. (2019), which compared the eco-efficiency of four recycling scenarios. The economic impact was assessed based on the evaluation of transport, personnel, equipment, utility, treatment costs and the costs of primary raw materials, while the ILCD indicators were used for the environmental impact assessment. The scenarios involved a conventional wet stationary process and three innovative recycling processes: advanced drying (ADR) (stationary and mobile) and a combination of mobile ADR and heating air classification system (AHS). These innovative processes may yield different quantities of high-grade RCA (68—93.6%) and RFA (6.4—32%) from recycled concrete. The LCA and LCC analyses were integrated for the evaluation of the economic and environmental impact. The comparison process disclosed a combination of ADR and AHS recycling as the most eco-efficient, which may decrease the economic and the environmental impact by 55% in comparison to a conventional recycling process (C. Zhang et al. 2019).

2.6.5 Social Impact Assessments of CDW Management

In terms of sustainability, the social performance of CDW management was rarely assessed as stand-alone. In most cases, it was evaluated jointly with the economic and environmental aspects of sustainability. To the best of the author's knowledge, the only known attempt to evaluate the social performance of CDW management was proposed by (H. Yuan 2012). Their study used the system a dynamics approach to evaluate the social performance of CDW management. The entire CDW management system was represented with six causal loops between eleven variables and their mutual dynamic interactions. These loops involved variables such as illegal disposal of waste and consequential public appeal for better waste management, public satisfaction and new job opportunities with better waste management, physical working conditions and impact on the long-term health of workers, etc. The application of the model in one construction project in China resulted in very low social performance, largely due to the physical working environment and the long-term health and safety of workers (H. Yuan 2012).

2.6.6 Holistic Assessments of CDW Management

And finally, several studies facilitated a more comprehensive sustainability assessment and offered a holistic view of the entire domain. To date, there have been five studies that had different focuses. The studies covered local (Klang, Vikman, and Brattebø 2003; Roussat, Dujet, and Méhu 2009), regional (Coronado et al. 2011; Iodice et al. 2021) and national (Kourmpanis et al. 2008) levels of CDW management and investigated all CDW treatment options.

One of the first studies was by Klang et al. (2003). They developed a model for evaluation of the economic, environmental and social impact of CDW reusing and recycling. However, their study was limited to only three CDW: streams, bricks, steel and sanitary fittings. Their findings revealed that even though the model can be very useful in comparison to different CDW management alternatives, it is highly dependent on the data collection process, which may be costly and time-consuming. To speed this process up, they suggested a meticulous selection of indicators that cover each aspect of sustainability and provide a good overview of the CDW system (Klang, Vikman, and Brattebø 2003).

For instance, Kourmpanis et al. (2008) proposed a model that used seventeen criteria to evaluate nine demolition waste management alternatives for CDW generated in Cyprus. This was one of the first models that included the estimation of CDW quantities. A waste generation rate (80 m^3 per $100m^2$ of surface area) was used as the basis for the calculation of CDW quantities. The criteria that were used to assess the CDW management sustainability were focused on four aspects: environmental, economic, technical and social-legislative criteria. The environmental criteria included the environmental impact, air emissions, the generation of wastewater and solid waste, noise pollution and visual nuisance. The economic criteria that were evaluated comprised the investment, operational costs and land demands, while the technical criteria included performance, flexibility, existing experience and adaptability to local conditions. Finally, the social-legislative criteria included public acceptance and the creation of new jobs, as well as the respect for legislative priorities and harmonization. The CDW treatment alternatives included both conventional and selective demolition, stationary and mobile recycling centres and transferring of non-recyclable materials to landfills. Their results favoured three CDW management alternatives, all of which included complete selective demolition, recovery of recyclables on-site or in stationary recycling centres and transfer of non-recyclables into landfills (Kourmpanis et al. 2008).

On the other hand, Roussat et al. (2009) used only eight criteria to evaluate nine demolition waste management alternatives, which included all treatment options. However, their study was limited to one demolition project in Lyon, France. The environmental impact of demolition waste treatment alternatives for this project that was assessed included abiotic depletion, energy consumption, the greenhouse effect and the dispersion of dangerous substances. The economic impact took into consideration the costs of demolition and waste disposal and the use of secondary raw materials. And finally, the creation of new jobs and the quality of life were the social aspects that were considered. Multi-Criteria Decision-Making (MCDM) analysis was used to rank these options. As one might expect, their results emphasize the need for selective demolition in sustainable CDW management. Interestingly, the results suggested backfilling rather than the production of new concrete as more sustainable use of recycled aggregate (Roussat, Dujet, and Méhu 2009).

Similar to the Kourmpanis et al. (2008) study, Coronado et al. (2011) proposed and integrated a model for the estimation of CDW and evaluation of CDW management alternatives in the Cantabria region in Spain. The quantity of CDW was based on the waste generation rates, i.e., waste per surface area of activity and municipal licenses for these activities. Five different management options that included different percentages of disposal and recycling were evaluated by four MCDM methods. A total of eight sustainability criteria and seventeen sub-criteria were employed for this evaluation. They included transport costs, tipping fees, atmospheric and acoustic pollution, local disturbance, CO_2 emission, landfill space saved, local employment, compliance with national and EU regulations, etc. The results of the MCDM analysis showed that 100% of recycling is the best solution for this region, which may be achieved with four recycling plants and one transfer station (Coronado et al. 2011). However, these results should be observed and interpreted in the context of the criteria that were used for the evaluation. Namely, only two purely economic criteria were used in the analysis, the transportation costs and the tipping fees, while the capital investment and operation costs for recycling facilities were left out, and these may significantly alter the results.

A completely different approach was adopted by Liu, Liu, and Wang (2020), who used system dynamics to predict the economic, environmental and social impact of current CDW management practices in Guangzhou, China. The CDW was recycled, landfilled or illegally dumped. The results showed that GHG emissions from recycling will decrease to 0.57 million tonnes by 2030, in contrast to GHG from CDW disposal, which will significantly increase (up to 78.5 million tonnes by 2030). On the other hand, disposal is reported as a treatment option with the lowest costs, followed by the costs of illegal dumping and recycling (J. Liu, Liu, and Wang 2020).

In recent years, two sustainability assessment studies have been singled out. The one was focused on sustainability criteria and sub-criteria ranking in Teheran, Iran (Khoshand et al. 2020), while the other compared several CDW management scenarios (linear, current and best case scenario) that included disposal and recycling in the Campania region in Italy (Iodice et al. 2021).

Sixteen sub-criteria classified in four criteria were ranked in the first study. The economic criteria consisted of investment, operating and maintenance costs. The environmental criteria included water, air and soil pollution and the consumption of energy, while the social criteria were based on job creation, public acceptance and participation rate. Finally, health and safety, final quality, training personnel, adaptability to local conditions and existing capability and technical feasibility were considered as the technical criteria. The criteria and sub-criteria were ranked with respect to all alternatives for waste treatment (from disposal to reusing). The experts from Teheran assigned the greatest weight in the CDW management decision-making process to economic (51%) and environmental criteria (31%). These were followed by technical (12%) and social criteria (6%). When it comes to the ranking of sub-criteria of their particular groups, the highest weight was assigned to investment costs (economic), water pollution (environmental), final quality (technical) and public acceptance (social) (Khoshand et al. 2020). However, the main goal of this study was to propose a framework for the sustainability criteria and sub-criteria ranking. To validate this framework and make it more beneficial for benchmarking with other studies, the study lacked a detailed case study and scenario analysis like the one made for the Campania region in Italy.

In Italy, the linear economy scenario predicted the disposal of the total CDW quantity in a landfill. On the other hand, the current practice scenario included (stationary and mobile) recycling of inert mineral fractions as well as recycling of CDW streams such as glass, plastics, and wood, in addition to disposing of non-recyclable fractions in landfills. The best practice scenario was based on selective demolition that included the separation and sorting of waste at the demolition site and facilitated greater reusability and recyclability of this waste. The scenarios were compared and ranked against 20 indicators from three dimensions of sustainability (and five areas of protection) as suggested by Taelman et al. (2019): economic (prosperity), environmental (ecosystem health and natural resources) and social (human well-being and human health) (Taelman et al. 2020). The indicators involved capital, operational and end-of-life expenses and revenues, eutrophication, ozone and fossil depletion, global warming, particulate matters, human toxicity, urban space consumption, odour, landscape disruptions, etc. (Iodice et al. 2021).

The results showed that although five times more expensive than traditional, selective demolition and high-quality recycling may contribute up to 88% of savings in CO_2-eq per tonne of CDW (Iodice et al. 2021). However, one of their limitations concerns the data on CDW composition that may be underestimated. Their analysis and comparison were based on the data obtained from traditional demolition practices where CDW is mostly classified as mixed, so they used literature-based assumptions and best-guess estimates for the composition.

A review of CDW management's sustainability assessment studies conducted and described in this subchapter (Subchapter 2.6) revealed several gaps in the knowledge base. First, the majority of CDW management assessment studies based their evaluations on statistical data of CDW quantities, scientific literature or expert-based estimations from practitioners. However, the CDW composition data is often missed in these estimations as CDW is recorded, looked and estimated as bulk waste (mixed waste). Additionally, developing countries may lack statistics on CDW generation, or the statistics may be insufficient or inadequate for better judgments in CDW management decision-making.

The second gap that was noted was in the scope of waste recovery and treatment and the number of individual waste streams for which the sustainability assessment studies were performed. Namely, studies were mainly devoted to the treatment of either the mixed or concrete CDW stream, which implies the need to extend the scope of the studies to include other notable CDW streams such as metal, wood, brick, glass, etc. Also, special attention needs to be devoted to the presence of hazardous substances in the CDW streams.

A compelling number of studies examined CDW management scenarios that involved only recycling and the disposal of waste. Other CDW waste treatments such as energy recovery and especially preparation for reuse were inadequately addressed. This shortage becomes more significant as the circular economy gains more attention, and only reuse and recycling may enable closing the loop and returning of the recovered material back into the economy for further use. This implies that the circular economy approach remains yet to be investigated and evaluated in sustainability assessment studies.

The third gap in the CDW management domain is related to the social performance of CDW management scenarios. To the best of the author's knowledge, only six studies attempted to assess the social performance either as a stand-alone impact or simultaneously with the economic and the environmental impacts. However, only one of them was on a national scale, and quantification of CDW in that study was based on the WGR, and possible treatments included only recycling and disposal. For that reason, a considerable number of scientists urge more studies that will address sustainability from a holistic perspective and facilitate benchmarking of CDW management practices in different economies.

2.7 Summary

This chapter presented the state-of-the-art and scientific background on the most important aspects of construction and demolition waste management. It started with the definition of construction and demolition waste, its physical and chemical characteristics and possible treatment options for different streams. Examination of key stakeholders, their roles in CDW management and motivation for better treatment practices followed. Special attention was given to the investigation of factors affecting best management practices as well as the investigation of CDW management practices in developed countries with high rates of CDW recovery. The chapter ends with the overview and identification of knowledge gaps in the existing methodologies for the estimation of CDW quantities and the evaluation of CDW management sustainability performance.

3 Methodology

3.1 Introduction

This chapter describes the detailed methodology that was adopted as the solution to the CDW management problem identified in the previous chapters. The chapter begins with a clarification of principles and criteria that guided the choice of the appropriate methodologies integrated into the model for the quantification and evaluation of sustainability performance. It continues with a short description of the model's aim, structure and data required for model development, followed by a detailed explanation of methods used for the model integration. The chapter ends with a description of the procedure adopted for model validation.

3.2 Methodological Approach

The search for the appropriate methodology for the quantification of CDW and the assessment of different management alternatives was guided by several principles. First and foremost is that it needs to be a model since it will represent a real-life waste management system. The second principle is that the model needs to be simple, easily understood, and user friendly as it is intended for decision-makers' use. Most of the decision-makers come from a political science background and lack training in complex financial, economic and technical analysis. The third principle is that model needed to be data-intensive to facilitate more informed decision-making in the CDW management domain. Additionally, the model needed to be appropriate for the intended use and to include all possible aspects that may affect the outcome. And finally, the model needed a certain degree of flexibility and adaptiveness to eventual input changes.

Based on these principles, a thorough literature review of the existing CDW quantification and sustainability assessment methodologies was conducted in Subchapters 2.5 and 2.6. The following chapters will address the methodological approach used to overcome the knowledge gaps identified during the literature review process.

3.2.1 Selecting the CDW Quantification Methodology

The quantification of the CDW method proposed in this model was selected on the basis of the results that this part of the research needed to deliver. In terms of CDW quantification, one of the main objectives of this research was to estimate the composition of the material types embedded in buildings. The second main objective was to forecast the amounts and the composition of waste that will be generated in the process of renovation or demolition of these buildings. Both the composition and the amount of an individual CDW stream highly depend on the structure and the type of the construction; therefore, this information had to be considered. In addition, these estimates had to be done at a national level. And finally, the choice of the methodology depended on the availability, the reliability of data and the overall feasibility of use in a given case study.

The above preconditions directed the choice of the appropriate quantification models. The first ones to be excluded were: field observation and computer-based models. Field-observation models were excluded since direct measuring and separation of CDW streams on-site may only be feasible for project-level estimations. On-site sorting and measuring are usually short terms, and the amount and composition of waste may also depend on the construction technology that was used at the time of measurement. Computer-based models were also excluded for practical reasons; national scale GIS maps would be difficult to process as they require large data sets; the application of information models (BIMs) is limited by the fact that the majority of the existing building stock would require reconstruction and development of BIMs from architectural plans or by photogrammetric or laser scanning of buildings at a national scale.

Although commonly used, WGR-based field observation-based models were immediately excluded based on the fact that this research required a more accurate model, especially in terms of the composition of waste. The author considered that WGR indicators might be appropriate when they already exist in handbooks or case studies conducted in a particular country, as transferring from countries with different political, economic and cultural backgrounds and construction practices may lead to misestimation of CDW quantities. On the other hand, calculation of these indicators based on statistical records may provide more accurate estimations only in countries with developed statistics on construction, renovation and, more importantly, demolition activities. Particularly, demolition statistics may underestimate the amounts of waste, as most construction companies in developing countries do not record and report the quantities and the composition of CDW. Even when they exist, these statistics report the activity of the entire building in its gross building area and volume rather than its inventory. For instance, the latter would help to obtain the estimations of indicators such as WPA, WPC and WPCT for individual CDW streams.

Due to the facts stated above, none of the approaches was suitable for use in estimating CDW quantities and composition at a national level. Consequently, only material stock-based models were left to be considered for this research. In terms of material stock-based model types, the bottom-up approach was considered more appropriate for the building stock. In contrast to the top-down approach that uses information on material sales and consumption without clear distinction in what type of construction material is embedded in buildings, the bottom-up model contains information on typical buildings, their construction elements and materials, the materials' service life and renovation and demolition rates. The author considered that only the bottom-up model might provide more accurate data on CDW streams that could be further used for sustainability assessments of different treatment options.

The bottom-up approach to material stock models defragments the entire building stock into construction elements and materials from which they were built. In this way, these models facilitate a deeper analysis and understanding of the economic, environmental and social effects on all levels, from construction elements to buildings and building stocks. This approach yields a robust base for further processing in the scenario and multi-criteria analyses. A trade-off to this robustness is that they need expert knowledge to identify and establish representative models of buildings, i.e., building types, and they also typically deal with a large amount of data that makes them very exposed to assumptions.

3.2.2 Selecting the CDW Management Assessment Methodology

Considering that a decision support system underpins this model and that the sustainability aspect may be observed from three different domains that often conflict with each other, scenario and multi-criteria analyses were employed to facilitate the choice of optimal CDW treatment for this research. In this respect, several MCDM techniques were considered (AHP, VIKOR, TOPSIS, ELECTRE and PROMETHEE), but the widely used AHP (Analytical Hierarchy Process) was selected. Aside from being simple and flexible, this method proved to be best suited for the choice of optimal, i.e., the most sustainable alternative. The hierarchical approach (goal, criteria and alternatives) of this method also enables a structured definition of the decision problem. The only issue that may pose a challenge during the implementation is the choice of specific criteria and sub-criteria.

The choice of criteria and methods for their evaluation depended on the sustainability aspect that needed to be addressed. An overview of commonly used methods based on sustainability aspects that they considered is given in Subchapter 2.5. Considering that this research adopted a holistic approach to sustainability, all three aspects had to be included.

It was noted that the existing studies that included all sustainable aspects had several limitations. The most important limitation concerned the source of CDW quantities and composition data that were used further in MCDM analysis, their availability and quality in particular. The studies used either WGRs, statistical data or field observation data, which all have several disadvantages that were explained in previous chapters. This research aims to overcome these disadvantages by adopting the material stock-based approach and by integrating this approach into the overall methodology.

Other limitations were related to the temporal and spatial scope of the studies, the scope of waste treatment and the number of different waste streams. When it comes to time horizon, studies evaluated the past performance of CDW management alternatives (up to twelve years), and no forecasts of future effects were conducted. The integrated model proposed in the following chapter plans to overcome this by using dynamic building stock modelling in the estimation of future CDW quantities and compositions and the effects of their management on society.

In terms of geography, only one out of five studies evaluated the sustainability performance of CDW management options at the national scale. However, this study, as most of the others, was limited to recycling and disposal as the only waste treatment options that were considered as alternatives. When it comes to waste streams, the studies considered only mixed CDW and concrete. The methodology proposed in this research wants to overcome these shortcomings by including all treatment options from reuse to disposal (including illegal dumping) and the majority of waste streams, such as metal, wood, masonry, etc. Adding more treatment options and waste streams into these assessments directly allowed the implementation of circular economy principles and potentials that are still missing in previous assessments.

3.3 Model Breakdown

3.3.1 Aim of the Model

The main purpose of the proposed model is to assist the decision-makers to bring optimal sustainable decisions when it comes to the development of new or improvement of existing management of CDW. Sustainability in decision-making is reflected in considering all three aspects and their impacts on society. In the process of decision-making, both the decision-maker and the society better understand the implications of one CDW treatment alternative when it is expressed in monetary terms. This is the main approach behind the proposed model. Meaning that apart from the economic, both the environmental and the social impacts were indicated in monetary units. Yet, to be able to discuss and consider treatment potentials and impacts on society, the expected amount of particular CDW streams in the future needed to be estimated.

Based on the above, more specific objectives of the proposed model are to:

1. Set up a database of construction materials incorporated in typical residential buildings (Material Stock Database);
2. Develop different renovation activities and CDW management alternatives;
3. Estimate the quantity and the composition of CDW streams that might be generated when these materials become waste during renovation or demolition activity, depending on different alternatives;
4. To assess the economic, environmental and social performance of these alternatives;
5. To rank the CDW management alternatives under different decision-making scenarios and choose the optimal alternative.

These five items served as the base for the methodological approach that led to the decision-support model development. This methodological approach follows the sustainability assessment framework developed by the author of this thesis and published in a paper by Nadazdi, Naunovic, and Ivanisevic (2022). The following Subchapters 3.3—3.5 will explain the principles of the framework, the structure and the procedure of the modelling process, as well as its validation in more detail.

3.3.2 Model Structure

As one may expect, the methodological approach to reach these specific goals and the problem stated in Subchapters 1.2 and 1.3 is threefold. To simplify, this is a process of transforming various input data utilizing different methodologies into valuable output data that are then used in the next stage of the process, as shown in Figure 2.

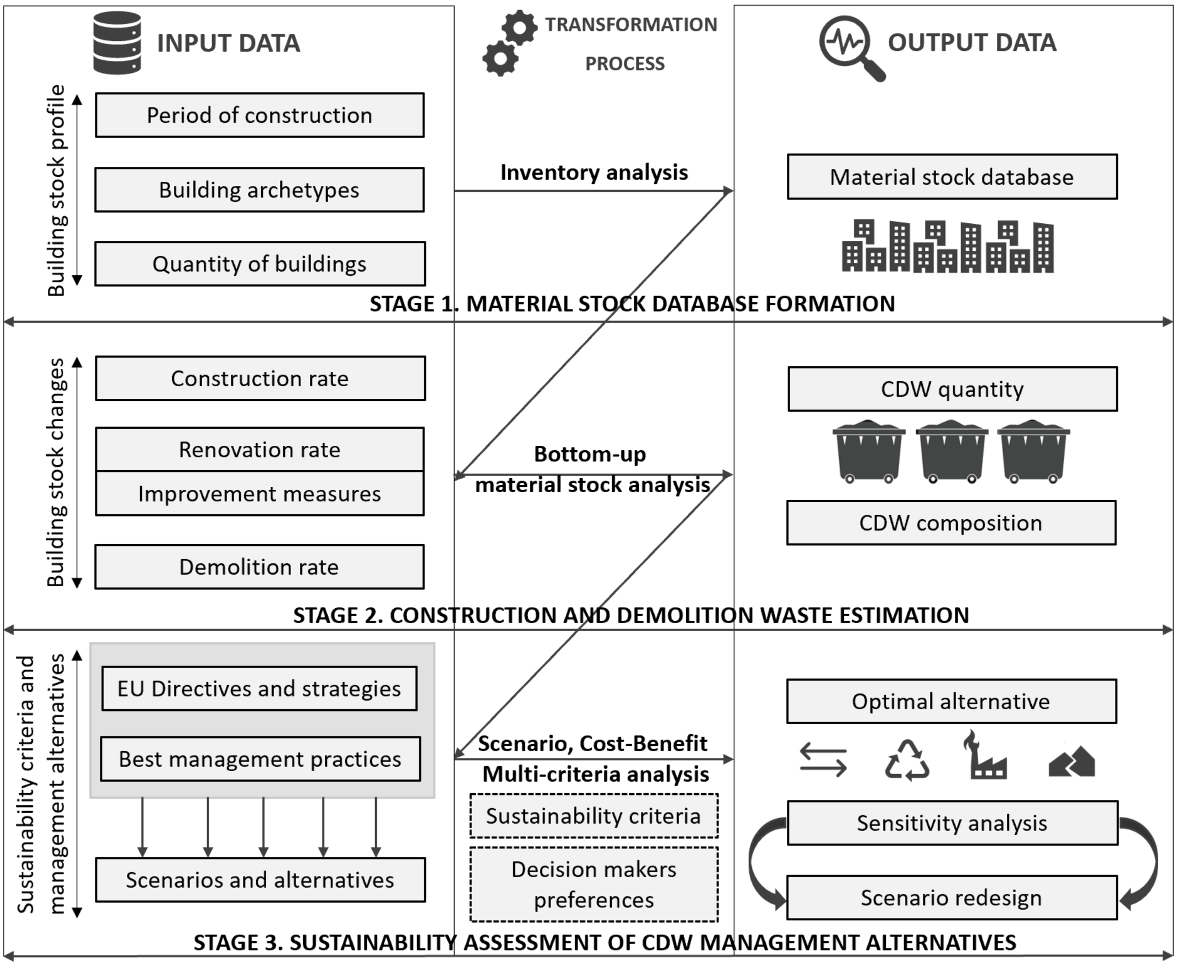


Figure 2 Overall methodological approach to sustainability assessment of CDW management alternatives (Nadazdi, Naunovic, and Ivanisevic 2022)

The results of the model are highly sensitive to input data as it builds upon the data on building typologies, current CDW management practices and possibilities for their improvements.

The first stage of the proposed model is to estimate the quantity and type of construction material incorporated in buildings (Material Stock). This is done through inventory analysis which facilitates the information on the physical characteristics of typical buildings' elements and the types of materials from which are they made. This information is acquired from national building typologies, such as the ones for residential buildings developed for two European projects, Tabula and Episcope (Institute Housing and Environment GmbH (IWU) 2016) or the one proposed for rapid earthquake loss estimation in (Stojadinović et al. 2021).

If this typology does not exist for a particular country or a building type, a new typology must be developed, and it should include the layouts and cross-sections of typical buildings from different construction periods and the information on the material type embedded in them as a minimum.

A Material Stock (MS) Database is developed within this inventory analysis and is then carried to the second stage. The second stage is construction and demolition waste estimation. This estimation uses dynamic building stock modelling to estimate the quantity of buildings to be demolished or renovated (renovation and demolition rates). These rates are used to estimate the future quantity and composition of waste from renovation and demolition activities.

The final stage of the model development included three steps: formulation of several CDW management alternatives, the assessment of their sustainability performance and the choice of the optimal alternative for CDW management based on different decision-making scenarios.

These alternatives should include treatment recovery pathways and rates of particular waste streams obtained in the second stage, as well as relevant CDW management measures. Aside from capital and operational costs and revenues from particular CDW treatments, these alternatives should cover potential regulatory and economic instruments such as carbon and landfill taxes that may influence sustainability performance.

The sustainability assessment of each alternative is performed with Cost-Benefit Analysis which results in two important indicators: financial and economic net present values. The financial net present value is used to indicate the measure of financial sustainability, while the economic net present value is used to indicate the measure of environmental and social sustainability. The alternatives that have positive net present values are declared as sustainable options for CDW management.

The choice of the optimal alternative is achieved by Multi-Criteria Decision-Making Analysis which includes the comparison of sustainability indicators of all alternatives with respect to different decision-making scenarios. Sixteen sustainability indicators (criteria) and four decision-making scenarios are considered: economic, environmental, social and holistic.

The first step in the MCDM analysis is to compare the criteria. While the decision-makers in the first three decision-making scenarios give a significant advantage to one of the sustainability aspects, the holistic decision-making scenario has equal significance assigned to all three aspects.

For instance, the decision-makers that have economic preferences favour economic indicators such as capital and operational costs and revenues from treatment over avoided GHG emissions and land consumption.

Similarly, the decision-makers who favour environmental indicators give the advantage to avoided GHG emissions over the economic and social indicators. This step includes the comparison of all criteria and their weighting for each of the different decision-making scenarios. These weights indicate the significance of each criterion in a particular decision-making scenario.

The next step is to calculate criteria values for different alternatives in each of the proposed decision-making scenarios in order to calculate their weights and compare them. CDW alternatives are finally ranked, and the optimal alternative is determined.

3.4 Modelling

3.4.1 Modelling the Material Stock

In this chapter, a material stock model, i.e., a methodology to specify the material type and to estimate the quantity of materials embedded in buildings, is presented. This methodology uses the classification of building built in a certain period (cohort) into typical buildings, which are representatives of particular building cohorts.

The classification of buildings should include building layouts, cross-sections, descriptions and schemes of thermal envelops of a typical building that represents one period of construction and building type similar to typologies developed for 21 European countries under two European projects, Tabula and Episcope (Institute Housing and Environment GmbH (IWU) 2016).

As mentioned before, if this typology does not exist for a particular country or a building type, a new typology must be developed.

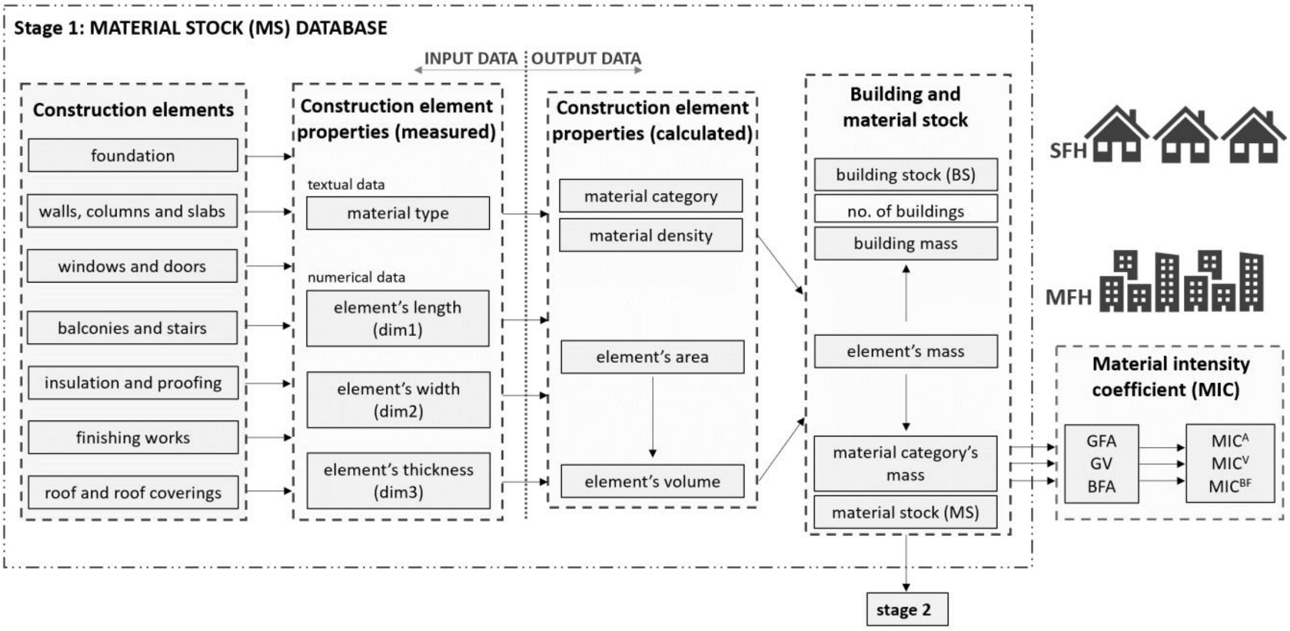


Figure 3 Methodological framework for MS database composition and calculation of MICs

The aim of this stage is to compile and calculate the inventory of construction elements and embedded materials (MS Database) from the architectural data on typical buildings and to calculate the material intensity coefficients (MICs). This is done following the methodological framework depicted in Figure 3 and the procedure outlined in Table 8. Each step is explained in detail in the text that follows.

Table 8 Procedure for calculation of the MS Database composition and MICs calculation

1. MS Database composition and calculation
a. Creation of buildings inventory (per type and per period of construction) b. Creation of elements' inventory for each building type (slabs, walls, etc.) c. Identification of material types for each element d. Classification of material types into material categories e. Identification of dimensions for each element f. Calculation of element's physical characteristic (area, volume, mass) g. Calculation of a typical building's mass per material category h. Calculation of entire building stock mass (material stock)
2. Calculation of MICs
a. Areal material intensity coefficient (MIC^A) b. Volumetric material intensity coefficient (MIC^B) c. Building footprint material intensity coefficient (MIC^{BF})

To create a unique inventory of construction elements, data on typical buildings and their elements are used and inserted into the MS database. The MS database contains sets of textual and numerical data.

As seen in Table 9, the textual data that is extracted and inserted into the database are building type, period of construction, typology coding, building element location, function and material type. Typology coding is inserted for easier reference between the two databases, the typology database and the MS database. From C to F, each letter corresponds to the period (a cohort) in which the buildings were built. Numbers from 1 to 6 indicate the type of residential building that was built in that decade. For instance, numbers 1 and 2 indicate SFH buildings, and 3, 4, 5 and 6 indicate types of MFH buildings: free-standing, lamella, in a row and high-rise, respectively.

Table 9 Overview of MS database template with textual data input and their sources

Type of building	**Period of construction**	**Typology coding**	**Building element location**	**Building element function**	**Material type**
SFH MFH	as in typology	as in typology	B GF 1st-top floor Roof	as in Table 10	as in Table 11

A breakdown of building elements is made for each building type. The location and function of each element are also recorded in the database. The list of elements is presented in Table 10 in alphabetical order. However, the order of the MS database filling is different. It starts from the bottom to the top of the buildings with the data on the foundation slab (including sub-base), floor coverings, openings, walls and wall coverings, stairs, ceiling coverings, slabs, balconies and railings for each floor and roof structure and coverings at the end. The location of the element has to be inserted to ease the calculation of the total number and mass of building elements and the materials.

On the other hand, a function has to be inserted to differentiate the elements when eventual waste treatment options are considered. Namely, in the future prefabricated elements such as slab and wall panels or even bathrooms may be considered for reuse instead of recycling.

Table 10 List of building elements and their functions

Elements		
Balconies	Openings – doors and windows	Slab
Ceiling coverings	Openings – frames	Slab base (incl. subbase layer)
Columns (incl. tie-columns)	Railings	Stairs
Floor coverings	Roof structure	Walls
Gutters	Roof coverings	Wall coverings

A material type is assigned to each construction element indicating the main material from which the element was made. For example, in most cases, reinforced or prefabricated concrete was the main material type for slabs, columns and stairs, clay brick for walls, steel for railings, wood for frames and glass for windows, etc. At a later stage, the information on the material type serves to obtain the material density needed to calculate the mass of each element.

For easier estimation of the MS and CDW and an easier comparison between the existing studies, these materials are classified into 18 categories defined in Table 11. These categories mostly correspond to the EWL (European Commission 2014b). The largest categories, as may be expected, belong to mineral-based materials, i.e., concrete and plaster.

Table 11 List of typical materials, their categories and the location within the building

Material type category	Material type	Elements
Asbestos-cement based	Asbestos-cement sheets (corrugated)	Wall and roof coverings
Bitumen based	Bitumen, bitumen sheets, asphalt, florbit, tar paper, bitumen putty	Floor coverings, water-proofing, vapour barrier
Cement-based	Fibre-cement sheets (eternit)	Floor and wall coverings
Clay-based	Bricks, blocks, tiles, roof tiles	Walls, slabs, floor and roof covering
Concrete based	Concrete, reinforced concrete, prefabricated concrete (IMS), semi-prefabricated slabs (Omnia, Avramenko, Standard), terrazzo, magnesite screed (blindit), autoclaved aerated concrete (aac) blocks, durisol blocks, hollow core slab, perlit concrete, tarolit, woodcrete	Walls, slabs, columns, tie-columns, stairs, balconies, railings, floor, wall and roof coverings
Copper-based	Copper sheets	Roof coverings
Glass-based	Window and door glass, glass blocks, glass wool	Doors and windows, railings, thermal insulation
Gypsum-based	Plaster, board, blocks	Walls, wall coverings, roof coverings
Lime-sand-based	Silicate bricks	Walls
Metal-based	Steel, sheet metal, Al foil, metal lath	Window and door frames, railings and gutters, wall and ceiling coverings, fire escape stairs
Organic – misc.	Cardboard, kraft paper, mud and husk, reed	Doors, floor, walls and ceiling coverings
Plaster based	Lime-sand plaster, cement-sand plaster, screed, aggregate plaster, cement roof tiles, pebbledash, perlite plaster, sand, termon plaster	Wall and ceiling coverings, screed
Plastic-based	Vinyl flooring, PVC foil, PE foil, vinyl-asbestos tiles	Floor and roof coverings
Polystyrene-based	EPS panels	Thermal insulation
Slag-cement-based	Blocks, concrete	Walls, floor coverings
Soil-based	Rammed earth, mud	Floor and ceiling coverings
Stone-based	Stone, stone tiles, gravel, rock wool	Subbase layer, floor, wall ceiling and roof coverings, thermal insulation

Wood-based	Beams, battens, boards, parquet, panels, cork panels, plywood, kombi panels (heraklit)	Window and door frames, roof structure, floor and ceiling coverings, railings, thermal and sound insulation

A numerical set of data that is inserted into the database contains data on the quantity and physical dimensions of building elements: width, length and thickness, expressed in meters (m) (Table 12). Considering that different elements have different orientations in buildings, these dimensions are renamed dim1, dim2 and dim3 to make the extraction of these elements easier. Two dimensions (length and height) are measured directly from the architectural drawings, while the thickness is taken from the technical description in the typology. This data is placed in a spreadsheet as the final input of the MS database. Other elements of the database, such as the area, volume and mass of building elements, have to be calculated. These elements are expressed in m^2, m^3, and kg, respectively.

Table 12 Overview of the MS database template with numerical data input and their sources

Qty. (pcs.)	Dimensions			A (m^2)	V (m^3)	ρ (kg/m^3)	Mass per pcs. (kg)	Total mass (kg)	Material category
	d1 (m)	d2 (m)	d3 (m)						
architectural drawings				calculations		as in Table 13	calculations		as in Table 11

Qty. – Quantity; pcs. – pieces; A – area, V volume, ρ - density

Three ways are used to calculate the area that the construction element enclosed. The first is with the use of a "*measure area*", an integrated function in the CAD drawing software. This option is used mostly for slab and floor areas in buildings with complex layouts or in the calculation of areas covered with plasters. In these cases, database inputs for dimensions 1 and 2 are not provided. Instead, a n/a abbreviation is used. The second and third options involve simple mathematical operations. The second option in most cases follows Equation 3.1, which is based on multiplying dim1 (width, in most cases) and dim2 (length, in most cases) of the elements with rectangular bases, or dividing the product of width and length for triangle bases of elements. The final third option is a modification of the second, and it is used when there are openings in slabs or walls. These openings have to be subtracted from the original slab or wall area (Equation 3.2).

$$A_{e,b} = dim1_{e,b} * \ dim2_{e,b}; or\ A_{e,b} = \frac{dim1_{e,b} * dim2_{e,b}}{2} \tag{3.1}$$

$$A_{e,b} = dim1_{e,b} * \ dim2_{e,b} - dim1o_{e,b} * \ dim2o_{e,b} \tag{3.2}$$

where: $A_{e,b}$ – is the area of element *e* in typical building b; $dim1_{e,b}$ – is the first dimension (width) of element *e* in typical building *b; $dim2_{e,b}$* – is the second dimension (height) of element *e* in typical building *b; $dim1o_{e,b}$* – is the first dimension of the opening in element *e* in typical building *b*; $dim2o_{e,b}$ – is the second dimension of the opening in element *e* in typical building *b.*

The volume of the construction elements is calculated by multiplying the area and dim3 (Equation 3.3).

$$V_{m,c,e,b} = A_{e,b} * \ dim3_{e,b} \tag{3.3}$$

where: $V_{m,c,e,b}$ – is the volume of material *m*, which belongs to category *c*, from which element *e* in typical building *b* was made; $A_{e,b}$ – is the area of element *e* in typical building *b*; $dim3_{e,b}$ – is the third dimension (in most cases the thickness) of element *e* in typical building *b.*

The next step is to calculate the mass of a single construction element and all elements within the building made from a single material. These are obtained by using Equations 3.4 and 3.5, i.e., by multiplying the volumes of the elements with the densities of the materials from which the elements were made. The total mass of a construction element, i.e., the material from which the element was made, is obtained by multiplying the mass of a single element and the number (frequency) of this element within the building.

$$M_{m,c,e,b} = V_{m,c,e,b} * \ D_{m,c} \tag{3.4}$$

$$M_{M,c,e,b} = n_e * V_{m,c,e,b} * \ D_{m,c} \tag{3.5}$$

where: $M_{M,c,e,b}$ – is the mass of material $m,$ which belongs to category c, from which elements e in typical building b were made$;V_{m,c,e,b}$ – is the volume of material m, which belongs to category c, from which element e in typical building b was made; $D_{m,c}$ – is the density of material m, which belongs to category c, n_e – is the number of elements in a typical building.

The majority of materials' densities are adopted from the online database MASEA (Fraunhofer Institute for Building Physics in Holzkirchen et al. n.d.). Considering that this database predominantly focuses on thermal insulation materials, walls, floors and covering materials, it lacks several data on material densities. These have to be searched in building constructions and construction materials textbooks and, in a few cases, manufacturer's technical data sheets. A detailed list of materials and their densities is available in Table 13.

Table 13 Classification of typical building materials and their densities (in kg per m^3)

Asbestos-cement based					
Asbestos-cement sheets	1675				
Bitumen-based					
Asphalt	2100(1)	Bitumen putty	1500(1)	Florbit	770
Bitumen	1500(1)	Bitumen sheets	1200	Tar paper	929
Cement-based					
Fibre-cement sheets	1860(2)				
Clay-based					
Clay bricks	1800(1)	Clay blocks	1000(2	Clay tiles	1800(1)
Clay bricks - facing	1300	Clay roof-tiles	1644		
Concrete-based					
Autoclaved aerated concrete (aac) blocks	550	Durisol blocks 20	420(2)	Reinf. concrete (1)	2400
Concrete	2400(1)	Hollow core slab	1360(2)	Tarolit	350(1)
Durisol blocks 60	830(2)	Magnesite screed	1100	Terrazzo	2500
Durisol blocks 30	530(2)	Perlite concrete	500(1	Woodcrete	1000
Durisol blocks 25	420(2)	Prefab. concrete (1)	2400		
Copper-based					
Copper sheets	9000				
Glass-based					
Glass	2580	Glass blocks	950	Glass wool	130(2)
Gypsum-based					
Gypsum board	732	Gypsum plaster	1043		
Lime-sand-based					
Silicate bricks	1900				
Metal-based					
Aluminium foil	2800(1)	Sheet metal (1)	7860		
Metal lath	179(2)	Steel (1)	7860		

Organic – misc.					
Cardboard (honeycomb)	5,8(2)	Mud	400	Reed	150
Kraft paper	648	Mud and husk	400		
Plaster-based					
Cement-sand plaster	2100(1)	Lime-sand plaster	1800(1)	Sand	1300
Cement screed)	2100(1	Pebbledash	1800(1)	Termon plaster	280
Cement roof tiles	2104	Perlite plaster	338		
Plastic-based					
PE foil	940	Vinyl flooring	2152(1)		
PVC foil	1400(2)	Vinyl-asbestos tiles	2152(1)		
Polystyrene-based					
Eps panels	53				
Slag-cement-based					
Slag-cement blocks	790	Slag-concrete	790		
Soil-based					
Earth	400				
Stone-based					
Gravel	1850	Stone	2670(1)		
Rock wool	160	Stone tiles	2690		
Wood-based					
Cork panels	150	Wood panels	455	Wooden floor boards	455
Kombi panels	460	Heraklit	460	Wood	455
Plywood	427				

(1) Construction materials textbooks; (2) Manufacturer technical data sheets; densities without a superscript were obtained from the MASEA database

In the end, the total mass of a material category within a single typical building (Equation 3.6) and the mass of all materials incorporated in a typical building (Equation 3.7) can be calculated.

$$M_{c,b} = \sum_{m,e} M_{M,c,e,b} \tag{3.6}$$

$$M_b = \sum_{c} M_{c,b} \tag{3.7}$$

where: $M_{c,b}$ – is the mass of material category c in typical building b; $M_{M,c,e,b}$ – is the mass of material m, which belongs to category c, from which elements e in typical building b were made; M_b – is the mass of material incorporated in typical building b (mass of a typical building).

The next step is to calculate the total mass of the entire building/material stock. The multiplication of the mass of an entire typical building that represents a certain period with the number of buildings built in the corresponding period gives the mass for the entire building type (Equation 3.8), while the aggregation of these gives the mass of the entire material stock (Equation 3.9).

$$M_B = n_{bc} * M_b \tag{3.8}$$

$$Ms = \sum_{B} M_B \tag{3.9}$$

where: M_B – is the mass of the entire building cohort, n_{bc} – is the number of typical buildings b built in a certain period c (cohort); M_b – is the mass of material incorporated in typical building b (mass of a typical building); Ms– is the mass of material used for the construction of buildings.

From here, the calculation of the MIC may be done in several ways depending on in which units the MIC will be expressed. Most studies expressed it in kg (tonnes) per m^2 of gross building area or even in kg (tonnes) per m^3 of gross volume of the buildings. Studies that use spatial analysis (GIS) for the estimation of material stock express it in kg (tonnes) per m^2 of the building footprint area or kg (tonnes) per km^2 of the occupied area. In this research, the MIC is calculated by dividing the mass of each material category of a single building type by the gross floor area (Equation 3.10) and the gross volume area (Equation 3.11) of the building and therefore expressed in kg per m^2 and kg per m^3. To compare it with other studies, the MIC is also calculated and expressed in kg per m^2 (of building footprint area) (Equation 3.12).

$$MIC_{c,b}^{A} = \frac{M_{c,b}}{GFA_b} \tag{3.10}$$

$$MIC_{c,b}^{V} = \frac{M_{c,b}}{GV_b} \tag{3.11}$$

$$MIC_{c,b}^{BF} = \frac{M_{c,b}}{BFA_b} \tag{3.12}$$

where: $MIC_{c,b}^{A}$ – is the areal material intensity coefficient of material category c in typical building b; $M_{c,b}$ – is the mass of material category c in typical building b; GFA_b – is the gross floor area of a typical building b; $MIC_{c,b}^{V}$ – is the volumetric material intensity coefficient of material category c in typical building b; GV_b – is the gross volume of a typical building b; $MIC_{c,b}^{BF}$ – is the building footprint material intensity coefficient of material category c in typical building b; BFA_b – is the building footprint area of a typical building b.

3.4.2 Modelling the Estimation of Construction and Demolition Waste

At this point, the quantity of all materials built in typical buildings is known. The next step is to estimate the amount and the composition of the renovation and demolition waste. This is represented as stage two of the methodology.

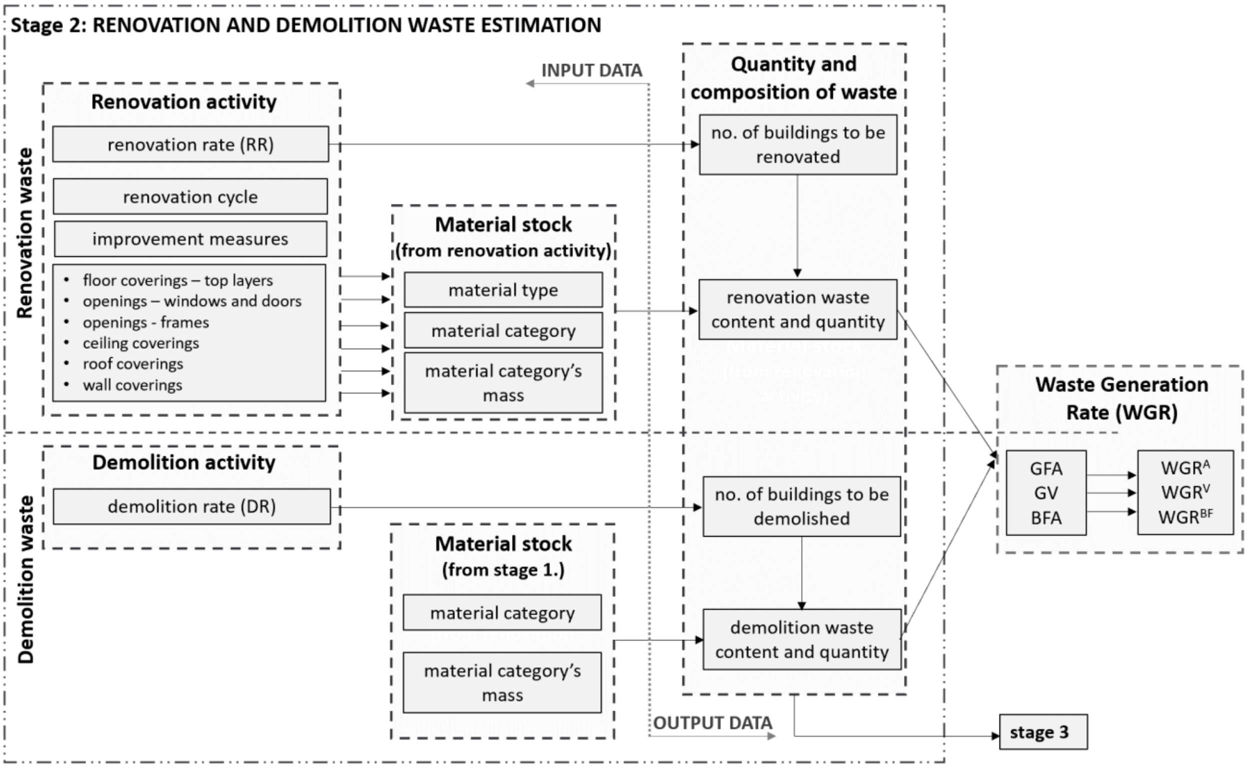


Figure 4 Methodological framework for the estimation and calculation of waste

This stage follows the procedure depicted in Figure 4, and in more detail, it includes the selection and adoption of renovation and demolition profiles for typical buildings and applying them to the material stock calculated in the previous stage. In this way, the number of buildings to be renovated and demolished in a particular year may be calculated as well as the content and the quantity of waste that comes out from these activities.

The renovation profile includes the adoption of a renovation rate, improvement measures and cycle(s) in which these renovation measures will be taken, while the demolition profile includes the adoption of appropriate demolition rates. The renovation and demolition rates are the shares of building stock that will be renovated or demolished annually in a given period.

In this thesis, these rates follow the probability equations (Equations 3.13 and 3.15.) developed and applied for the dynamic building stock model in Norway (Sandberg, Sartori, and Brattebø 2014; Sartori, Sandberg, and Brattebø 2016), and ten other European countries (including Serbia) (Sandberg et al. 2016). The latter uses the following equation to calculate the annual number of demolished buildings:

$$D_{dem}(i) = D_0(i) + (p_{DEM} * D_{new})(i) \tag{3.13}$$

where: $D_{dem}(i)$ – is the number of buildings demolished in a year (i); $D_0(i)$ – is the sum of demolition of initial stock; p_{DEM} – is the demolition probability function; D_{new} – is the number of new buildings (modelled).

In contrast to demolition, which happens once in a building's lifetime, renovation is a cyclic activity and requires a renovation profile to be defined (Equation 3.14.). This is a cyclic repetition of the renovation activity weighted against the building's lifetime (Sandberg et al. 2016), and it is calculated as follows:

$$p_{REN_{cycle}} = \sum_{k=1}^{K} p_{REN}(k) * \quad L_{DEM} * L(\tau) \tag{3.14}$$

where: $p_{REN_{cycle}}$ – is the renovation profile; $p_{REN}(k)$ – is the renovation probability function; K – defines cyclic repetitions; $L(\tau)$ – is the lifetime shifted by years τ – the probability of a building lifetime.

The number of renovated buildings is then calculated following this equation:

$$D_{REN}(i) = R_0(i) + (p_{REN_{cycle}} * D_{new})(i) \tag{3.15}$$

where: $D_{REN}(i)$ - is the number of buildings renovated in a year (i); $R_0(i)$ – is the renovation of the initial stock; $p_{REN_{cycle}}$ – is the renovation profile; D_{new} – is the number of new buildings (modelled).

It is important to note that the annual values of the renovation and demolition rates represented the total amount of buildings to be renovated or demolished, irrespective of the period when they were constructed. However, to be applied to this model, these rates have to be segmented and applied to cohorts (Equations 3.16a and 3.16b.). The model uses rates that are segregated to follow the share of particular cohorts in the entire stock.

$$dr\_seg_c(i) = dr(i) * \frac{n_{bc}}{\sum n_{bc}};\; rr\_seg_c(i) = rr(i) * \frac{n_{bc}}{\sum n_{bc}} \tag{3.16a; 3.16b}$$

Where: $dr\_seg_c(i)$, $rr\_seg_c(i)$ – are the annual demolition and renovation rates segmented to cohorts; $dr(i), rr(i)$ – are the annual demolition and renovation rates of the entire building stock; n_{bc} – is the number of typical buildings b built in a certain period c (cohort).

These segmented rates are applied to appropriate cohorts to obtain the number of buildings to be renovated and demolished in a certain year (Equations 3.17a and 3.17b.). These numbers have to be calibrated, i.e., rounded to the nearest whole digit, to avoid decimals numbers in the numbers of buildings.

$$n_{db}(i) = dr\_seg_c(i) * n_{bc};\ n_{rb}(i) = \ rr\_seg_c(i) * n_{bc} \qquad (3.17a; 3.17b)$$

Where: $n_{db}(i), n_{rb}(i)$ – are the number of buildings to be demolished and renovated in a year (i); $dr\_seg_c(i)$, $rr\_seg_c(i)$ – are the annual demolition and renovation rates segmented to cohorts; n_{bc} – is the number of typical buildings b built in a certain period c (cohort).

The final action in this stage of the methodology is to calculate the amount of waste from renovation and demolition activities. There is a slight difference in calculating these. Demolition waste is calculated using Equation 3.18a, where the number of buildings to be demolished is multiplied by the masses of particular material categories calculated in the previous methodological stage via Equation 3.6 or Equation 3.18b to calculate the amount of waste within the building.

$$M_{dw,c,b}(i) = n_{db}(i) * M_{c,b};\ M_{dw,b}(i) = \sum_c M_{dw,c,b}(i) \qquad (3.18a; 3.18b)$$

Where: $M_{dw,c,b}(i)$ – is the mass of material category c demolished within building type b; $n_{db}(i)$ – is the number of buildings to be demolished in the year (i); - $M_{c,b}$ - is the mass of material category c in typical building b; $M_{dw,b}(i)$ – is the mass of demolished building type b (i.e., the demolished waste from typical building b).

On the other hand, renovation waste requires the calculation of its material stock (Equations 3.19. and 3.20.).

$$M_{rw,c,b}(i) = n_{db}(i) * M^r_{c,b}\ , M^r_{c,b} \subset M_{c,b,dw,b} \qquad (3.19)$$

$$M_{rw,b}(i) = \sum_c M_{rw,c,b}(i) \qquad (3.20)$$

Where: $M_{rw,c,b}(i)$ - is the mass of material category c demolished during a renovation of building type b; $n_{db}(i)$ – is the number of buildings to be renovated in the year (i); - $M^r_{c,b}$ - is the mass of material category c demolished during renovation in building type b; $M_{rw,b}(i)$ – is the mass of demolished waste from the renovation of building type b (i.e., the renovation waste from typical building b).

The material stock applied to renovation activity is calculated by the extraction of materials and their masses from the original material stock database. This extraction is based on the improvement measures often suggested for the appropriate building types. These measures are focused on the improvement of the thermal envelope of buildings and, in most cases, include windows and doors replacement (from wooden frames to PVC frames) and adding layers of thermal insulation on floors, walls, ceilings and roofs. All these activities include some sort of demolition or a building element's removal. Apart from the removal of windows and doors, most of the demolition happens when there is a need to remove top layers of floors or roofs to install thermal insulation. In other cases, thermal insulation is placed on the existing elements (or layers) without any demolition.

Finally, the annual amounts of demolition and renovation waste are obtained with the following equations:

$$M_{dw}(i) = \sum_{b} M_{dw,b}(i)\,;\; M_{rw}(i) = \sum_{b} M_{rw,b}(i) \qquad (3.21a; 3.21b)$$

Where: $M_{dw}(i), M_{rw}(i)$ – are the annual masses of the demolition and renovation waste; $M_{dw,b}(i), M_{rw,b}(i)$ – are the masses of demolition and renovation waste from buildings type b.

Considering that the renovation waste in this thesis consists only of the demolition activity during renovation, the sum of Equations 3.21a and 3.21b gives the total annual mass of waste from demolition (demolition waste) (Equation 3.22), which is then used in the next stage of the methodology.

$$M_{DW}(i) = M_{dw}(i) + M_{rw}(i) \qquad (3.22)$$

Where: $M_{dw}(i), M_{rw}(i)$ – are the annual masses of the waste from demolition and renovation activities, respectively; M_{DW} – is the annual mass of waste from demolition.

When the amount of waste from demolition and renovation activities is known, the WGR may be calculated. Once again, depending on the units in which the WGR is to be expressed, this may be done in several ways. To follow the rules set for the calculation of the MIC, the WGR is calculated in three ways: by dividing the mass of each demolition and renovation waste material category of a single building type with the gross floor area (Equation 3.23), building footprint area (Equation 3.24) and gross volume area (Equation 3.25).

$$WGR_{c,b}^{A} = \frac{M_{dw,c,b}(i) + M_{rw,c,b}(i)}{GFA_b}; \qquad (3.23)$$

$$WGR_{c,b}^{V} = \frac{M_{dw,c,b}(i) + M_{rw,c,b}(i)}{GV_b}; \qquad (3.24)$$

$$WGR_{c,b}^{BF} = \frac{M_{dw,c,b}(i) + M_{rw,c,b}(i)}{BFA_b}; \qquad (3.25)$$

where: $WGR_{c,b}^{A}$ – is the areal waste generation rate coefficient of material category c in typical building b; $M_{dw,c,b}(i), M_{rw,c,b}(i)$ – are the masses of material category c demolished during renovation and demolition activities in typical building b; GFA_b – is the gross floor area of a typical building b; $WGR_{c,b}^{V}$ – is the volumetric waste generation coefficient of material category c in typical building b; GV_b – is the gross volume of a typical building b; $WGR_{c,b}^{BF}$ – is the building footprint waste generation rate coefficient of material category c in typical building b; BFA_b – is the building footprint area of a typical building b.

3.4.3 Modelling the Sustainability Assessment of Construction and Demolition Waste Management

3.4.3.1 Designing the Construction and Demolition Waste Management Alternatives

The overall objective of methodological stage 3 is to assess the alternatives for managing the construction and demolition waste and to choose the optimal strategy depending on several criteria and decision-makers' preferences. This is achieved by using a combination of methods that are most often used in decision-making analysis: the MCDM analysis coupled with scenario analysis and, finally, the CBA. The detailed framework follows the procedure set out in Table 14 below.

Table 14 Procedure for the assessment of waste management alternatives

1. Definition of CDW management alternatives
a. Aggregation of material categories into waste streams
b. Calculation of waste stream masses
c. Definition of treatment rates for different treatment options and different alternatives
d. Calculation of waste stream masses subjected to particular treatments
2. Calculation of criteria values for different decision-making scenarios and alternatives
a. Identification of the economic, environmental and social criteria and sub-criteria
b. Formation of the Criteria Judgment Matrix
c. Calculation of criteria values for each alternative
d. Formation of the Alternative Judgment Matrix
e. Final Aggregation of alternatives related to each sub-criterion

The first step in this methodological stage is the aggregation of material categories into waste streams and the calculation of their masses (Equation 3.26).

$$M_{DW,ws}(i) = \sum_{ws} M_{DW,ws}(i)\ ;\ M_{DW,ws} \subset M_{DW} \tag{3.26}$$

Where: $M_{DW,wc}(i)$ – is the annual mass of waste stream (ws); M_{DW} – is the annual mass of waste from demolition.

For this step, material categories listed in Table 11 and Table 13 (bitumen-based, cement-based, etc.) that are used to estimate the quantity and content of the waste in the previous stage were grouped. The reason for this is that several material categories, when they become waste (i.e., waste streams), may share the same treatment options. For instance, it was important to differentiate the material categories that contain hazardous substances (asbestos, bitumen, gypsum) when estimating the content and the quantity of the waste, but for assessing waste managing alternatives, as they will be treated in the same way, these material categories may be merged into one waste stream (hazardous). A full list of the waste streams and their material categories used in this stage is provided in Table 15.

Table 15 List of waste streams used for alternative development

Waste stream	Material categories	
Glass-based fractions	Glass-based	
Hazardous fractions	Asbestos-cement-based Bitumen-based	Gypsum-based
Mineral fractions	Cement-based Clay-based Concrete-based Lime-sand-based	Plaster-based Slag-cement-based Stone-based
Metal-based fractions	Copper-based	Metal-based
Organic fractions	Organic – misc.	Textile-based
Plastic-based fractions	Plastic-based	
Polystyrene-based fractions	Polystyrene-based	
Soil-based fractions	Soil-based	
Wood-based fractions	Wood-based	

The next step is to separate the waste streams' masses into different treatment options and different alternatives. To separate the waste streams into different treatment options and different alternatives, treatment rates for different alternatives are defined. Apart from current treatment rates that are taken from the official statistic records (Eurostat 2021b), future treatment rates need to be assumed. This is done by following several conditions identified in Table 16.

Table 16 Set of conditions for waste stream treatment limits

Conditions	Values	Source
Waste stream treatment options	From reuse to illegal dumping	WFD; literature (as described in Chapter 2)
Current treatment rates	Mineral fraction of CDW	Eurostat (Eurostat 2021b)
Average treatment rates in the EU	Mineral fraction of CDW	Eurostat (Eurostat 2021b)
Maximum share of waste streams	Calculations from stage 2	(as described in Subchapter 3.4.2)
Legal requirements	Recovery of 70% of non-hazardous CDW; Respecting waste treatment hierarchy and CE principles	EU directives, strategies, and action plans (as described in Chapter 2)

The future treatment rates are split into two different alternatives: the first with the goal to reach the EU average treatment rates for 2018 and current WFD requirements (The European Parliament and the Council of the European Union 2008), and an alternative called “EU28" (2018), and the second to follow the circular economy principles as set out in New Circular Economy Action Plan (European Commission 2020a), an alternative called “CE”. When deciding on future waste treatment options, the main boundary is the share of waste streams in the amount of waste and available and probable options for that particular waste stream. This means that in most cases, the mineral fractions and the metal-based waste stream would be subjected to recycling, the wood-based waste stream to recycling and incineration, etc. The distribution of these treatment rates through the years in this methodology is assumed to be linear.

The definition of treatment rates allows the calculation of the waste stream quantities that are subjected to different waste treatments. This is done following Equation 3.27.

$$M_{t,ws}(i) = tr_t(i) * M_{DW,ws}(i); tr_t(i) \in (tr_{ru}(i), tr_{rc}(i), tr_{dc}(i), tr_{er}(i), tr_{lf}(i), tr_{id}(i)) \qquad (3.27)$$

Where: $M_{t,ws}(i)$ – is the annual mass of a waste stream (ws) subjected to a particular treatment (t); $tr_t(i)$ – is the annual treatment rate that may assume values $tr_{ru}(i)$ - reusing treatment rate, $tr_{rc}(i)$ – recycling treatment rate, $tr_{dc}(i)$ – downcycling treatment rate, $tr_{er}(i)$ – energy recovery treatment rate, $tr_{lf}(i)$ – is the landfilling treatment rate and $tr_{id}(i)$ – is the illegal dumping treatment rate; $M_{DW,ws}(i)$ - is the annual mass of a waste stream (ws).

3.4.3.2 Modelling the Sustainability Assessment of CDW Management Alternatives

Three indicators are calculated to measure the long-term performance and stability of each waste management alternative: the net present value, the rate of return and the b/c ratio. To calculate these, an annual difference between the total revenues and costs (cash flow balance) for a certain number of years is required. This reference period is usually a period of 20, 25 or 30 years for waste management assessments. The difference is also known as the “cash flow”. Those money changes over time need to be discounted at a certain rate – the discount rate. Discounting means that to sum these cash flows over time, they need to be calculated for the same point in time – the present. This method is referred to in the literature as discounted cash flow analysis (Capehart, Turner, and Kennedy 2020), and the monetary amount of cash flow in the present time is referred to as the net present value (NPV). Depending on the nature of revenues and costs observed and evaluated, the analysis may be financial and economic. The financial analysis considers strictly the financial performance and calculates the financial net present value (FNPV), while the economic analysis considers the contribution to environmental and social welfare and calculates the economic net present value (ENPV) (European Commission 2014a). Another important difference is that the former uses constant market prices, net of VAT and before direct taxes, and the latter uses shadow prices instead. These prices reflect the distortion of market prices, which is reflected in the opportunity costs and often include government subsidies, duties on imports, wages taxation, etc. (European Commission 2014a) (Equations 3.28a and 3.28b).

$$FNPV = \sum_{i=1}^{n} \frac{TR_i - TC_i}{(1+fdr)^i}, where\ (TR_i and\ TC_i = f(p_k)) \qquad (3.28a)$$

$$ENPV = \sum_{i=1}^{n} \frac{TR_i^e - TC_i^e}{(1+sdr)^i}, where\ (TR_i^e and\ TC_i^e = f(sp_k), sp_k = c_k * p_k) \qquad (3.28b)$$

Where: $FNPV\ and\ ENPV$ – are the financial and economic net present values; $TR_{i,}TR_i^e$ – are the total revenues of the project in the year *i*; TC_i, TC_i^e – are the total costs of the project in the year *i*; *fdr* and *sdr* – are the financial and social discount rates; p_k – is the standard market price of a good or a service *k*; sp_k – are the shadow price of a good or a service *k*, c_k – is the conversion factor.

Apart from the financial and the economic present value, which are used for the economic, environmental and social performance, the long-term stability and profitability of the project are calculated using a rate of return (of the project investment). For that reason, the financial (FRR) and the economic rates of return (ERR) are calculated as rates that produce a zero FNPV and ENPV (European Commission 2014a), following the Equations 3.29a and 3.29b:

$$0 = \sum_{i=1}^{n} \frac{TR_i - TC_i}{(1+FRR)^i}, 0 = \sum_{i=1}^{n} \frac{TR_i^e - TC_i^e}{(1+ERR)^i} \qquad (3.29a); (3.29b)$$

Where: $TR_{i,}TR_i^e$– are the total revenues of the project in the year *i*; TC_i, TC_i^e– are the total costs of the project in the year *i*; $FRR\ and\ ERR$ – are the financial and economic rates of return.

Both the NPVs and the RRs carry information on future investment from different perspectives. While the NPVs are expressed in monetary terms and hence closely connected to the project, the RRs allow for comparison between other projects or applied rates of return, i.e., if these rates are lower than the applied, the revenues generated on the project will not cover the costs incurred (European Commission 2014a). However, in some cases, the RRs may be difficult to calculate (eighter as multiple values or not defined); therefore, another non-dimensional indicator was calculated following Equations 3.30a and 3.30b. This is the B/C ratio, i.e., the ratio between the discounted benefits and costs (European Commission 2014a).

$$\frac{B}{C}(F) = \frac{\sum TR_i}{\sum TC_i}; \frac{B}{C}(E) = \frac{\sum TR_i^e}{\sum TC_i^e} \qquad (3.30a); (3.30b)$$

Where: $\frac{B}{C}(F), \frac{B}{C}(E)$ – are the financial and economic b/c ratios; $TR_{i,}TR_i^e$-– are the total revenues of the project in the year *i*; TC_i, TC_i^e– are the total costs of the project in the year *i*; $FRR\ and\ ERR$ – are the financial and economic rates of return.

3.4.4 Ranking of CDW Management Alternatives and Selecting the Optimal Alternative

The next step in this methodological stage is the evaluation of different waste treatment alternatives that are performed to determine the optimal option.

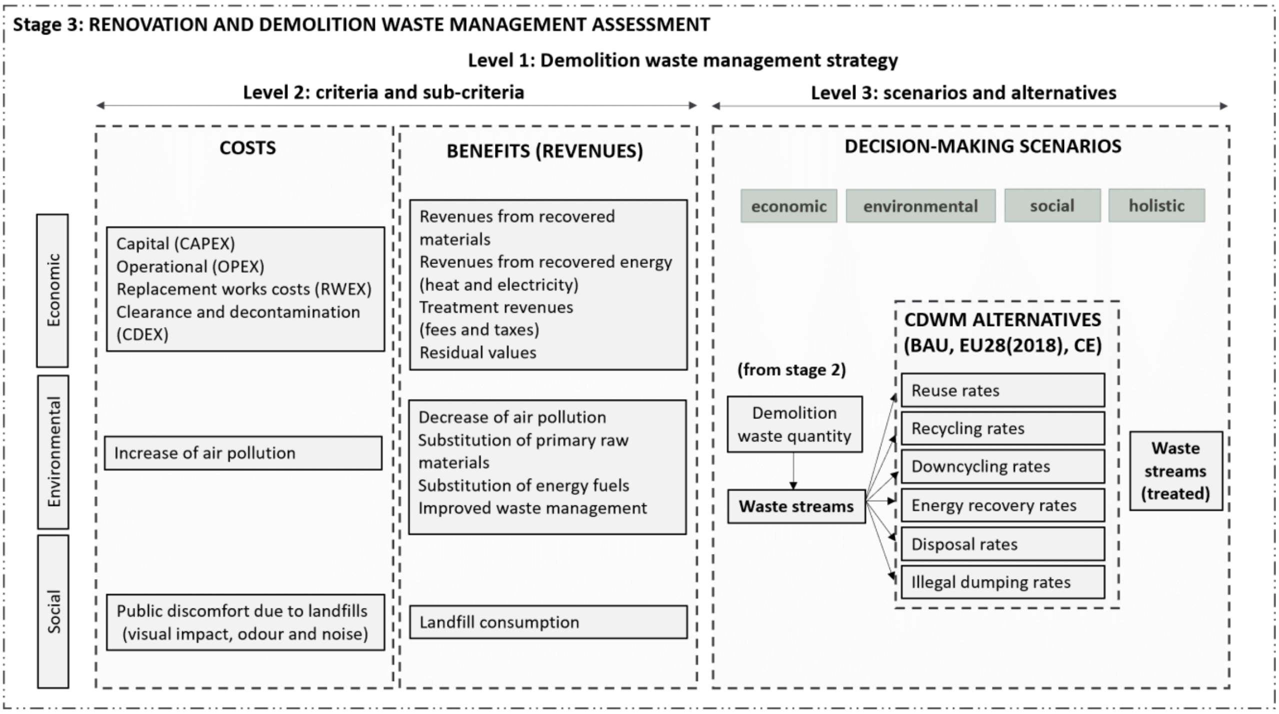


Figure 5 Methodological framework for demolition waste management assessment

As mentioned before, different alternatives to waste management with respect to several criteria and sub-criteria (depicted in Figure 5) are analysed and compared. As seen in Figure 5, an evaluation of each criterion (indicator) is performed. These indicators may yield either cost (often referred to as expenses, expenditures) or revenues (often referred to as benefits) to the waste management alternative during its life cycle. Indicators that are gathered from the literature serve to depict the entire sustainability domain and are grouped as economic, environmental and social to alleviate easier comparison.

In more detail, the economic criteria consider capital expenditures (CAPEX) such as land acquisition, costs for design and permits, costs for construction works and equipment costs. Labour wages, administration and insurance costs, cost of electricity and diesel consumption and maintenance, costs of waste treatment, etc., are included as costs of operation (OPEX). And finally, the analysis considers the cost of equipment replacement (RWEX) and clearance and decontamination costs (CDEX) at the end of the service life of treatment facilities.

On the other hand, project revenues in the economic criteria group that are considered come from different sources. The direct revenues come from secondary raw material sales, sales of recovered energy and heat, gate fees and landfill taxes that are assumed for different alternatives. A special category of direct revenues is the residual value of the treatment facility, which represents the value at the end of its life cycle.

The environmental criteria that are considered in this methodology are acquired by considering the externalities that waste management alternatives may have to the environment. These externalities may be positive - beneficial to the environment or negative – to incur additional costs. The positive ones are achieved through decreased GHG emissions from the avoidance of primary raw materials usage, energy recovery from incineration, and an improvement in waste management. The negative ones refer to the increase in GHG emissions from current waste treatment options such as landfilling and illegal dumping and possible future options such as recycling and energy recovery. These negative externalities are often significantly less than the positive; hence they are referred to and indicated as revenues.

The social criteria consider the effects that waste management alternatives may have on society. These are reflected in the social adjustment of the economic cost and revenues to include customs, taxation, labour wages and unemployment rates on one side and public discomfort and land degradation caused by landfills and illegal dumping on the other side.

To summarize, in total, 19 indicators, three criteria and 16 sub-criteria are used in the analysis. An elaborated list of these indicators, as well as the methods used for the calculation of their values, are provided in Table 17.

Table 17 List of sustainability indicators and their calculation methods

Indicator	Type	Treatment	Calculation method
ECONOMIC			
Capital expenditures (CAPEX)	C	RC, ER, D	RC, D – as in Waste Management Program for the Republic of Serbia for the period 2022—2031 (Government of the Republic of Serbia 2022b) ER - as in Tsilemou and Panagiotakopoulos (2006)
Operational expenditures (OPEX)	C	RU, RC, ER, D	RC, D – as in as in Waste Management Program for the Republic of Serbia for the period 2022—2031 (Government of the Republic of Serbia 2022b) and Lotfi et al. (2017) ER - as in (Tsilemou and Panagiotakopoulos 2006) Transport costs, as in Zhang et al. (2019)
Replacement works expenditures (RWEX)	C	RC, ER	RC – as in Coelho and de Brito (2013b) ER – as calculated in Nikolic, Mikic, and Naunovic (2017)
Clearance and decontamination expenditures (CDEX)	C	RC, ER, D, ID	RC, ER – 4% of Capex (European Commission 2014a) D, ID – as in Waste Management Program for the Republic of Serbia for the period 2022—2031 (Government of the Republic of Serbia 2022b)
Sale of secondary raw material+	R	RU, RC	(Di Maria, Eyckmans, and Van Acker 2018) Network of environmental managers for waste and recovered materials exchanges available at www.borsinorifiuti.com Personal investigation
Sale of recovered heat and electricity	R	ER	As calculated in Nikolic, Mikic, and Naunovic (2017)
Gate fees and landfilling taxes	R	RC, ER, D	RC – as calculated in (Di Maria, Eyckmans, and Van Acker 2018) ER – as calculated in (Nikolic, Mikic, and Naunovic 2017) The Confederation of European Waste-to-Energy (The Confederation of European Waste-to-Energy (CEWEP) 2021)
Residual value (RV)	R	RC, ER	Calculated with the annual depreciation rate of 15% for recycling and 10% for energy recovery facilities as per the Rulebook on Depreciation (Tax Administration of the Republic of Serbia (RS) 2019)
ENVIRONMENTAL			
GHG emissions	R	RU, RC, ER	**Avoided GHG through secondary raw material recovery** Quantity of material recovered * GHG emission from primary raw material extraction and processing taken from the literature (André Coelho and de Brito 2013a; Schmitz et al. 2011; Van Ruijven et al. 2016; Weiler, Harter, and Eicker 2017)* cost of CO_2-eq per tonne **Avoided GHG through energy recovery** as calculated in Nikolic, Mikic, and Naunovic (2017) * cost of CO_2-eq per tonne **Avoided GHG through improved waste management** (Quantity of waste from RU+RC+ER) * sum of GHG emission Sum of GHG emission=(emission from landfills and illegal dumping – (emission from RU+ RC+ER)) * cost of CO_2-eq per tonne Cost of CO_2-eq per tonne as suggested in The World Bank (2021)

SOCIAL			
Capital expenditures – social (CAPEX_SOC)	C	RC, ER	Economic values with conversion factors applied (c_k). Conversion factors (c_k) are calculated as in European Commission (2014): SCF (value of import and export from the National Statistics (Statistical Office of the Republic of Serbia n.d.), custom tariffs from the Customs Administration Fact Sheets 2021 Customs Administration (2021) SW (wages for skilled and non-skilled workers, wage taxation, unemployment rate from National Statistics Office (Statistical Office of the Republic of Serbia n.d.)) Share of conversion factors in costs and revenues as suggested in Nikolic, Mikic, and Naunovic (2017)
Operational expenditures – social (OPEX_SOC)	C	RU, RC, ER, D	
Replacement works expenditures -social (RWEX_SOC)	C	RC, ER	
Clearance and decontamination expenditures - social (CDEX_SOC)	C	RC, ER, D	
Public discomfort due to landfill presence	C	D	Hedonic price method (European Commission 2014a) The average surface area of properties in rural areas was calculated from the National Statistics Office (Statistical Office of the Republic of Serbia n.d.); the number of landfills taken from the Ministry of Environmental Protection Republic of Serbia - Environmental Protection Agency (2020)
Residual value - social (RV_SOC)	R	RC, ER	Economic values with conversion factors applied (c_k)
Arable land consumption	R	RU, RC, ER	As calculated in (Nikolic, Mikic, and Naunovic 2017) Price of land as reported in the Republic Geodetic Authority (2021)

C – Costs; R – Revenues; RU – reusing; RC – Recycling; ER – Energy recovery; D – Disposal; ID – Illegal dumping

Following the AHP method (Saaty 1990), the next step of the methodology is to perform a pairwise comparison of the criteria and sub-criteria and form their judgment matrices (Equations 3.31).

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & & a_{2n} \\ \vdots & \vdots & \ddots & \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \tag{3.31}$$

Where: a_{ij} – is a descriptor of relative significance between either criteria or alternative *i* or *j*. It is expressed on a scale from 1 to 9, determined by Saaty (1990), where 1 represents equally significance, 3 moderate significance, 5 strong significance, 7 very strong significance and 9 presents the extreme significance of one criterion or alternative over another, while values 2, 4, 6 and 8 serve to refine the judgment.

Based on the same principle, the sub-criteria and alternatives are compared down to the lowest levels of the hierarchical structure, and their judgment matrix is formed. The alternatives are valued with respect to each sub-criterion and based on the methodology described in Table 17.

The next step is to determine the relative weights of matrices' elements of steps. The procedure then follows Equation 3.32 and is the same for each element (criteria, sub-criteria and alternatives). As developed by Saaty (1990), the goal behind this is to derive the vector of priorities (weights) by finding the eigenvalue λ_{max} and eigenvector *W* of matrix *A.*

$$A * W = n * W = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & & a_{2n} \\ \vdots & \vdots & \ddots & \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} * \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \lambda max * \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{3.32}$$

Where: a_{ij} – is a descriptor of the relative significance between either criteria or alternative i or j – the ratio comparison; λ_{max} – is the largest eigenvalue of matrix A; $w_1, w_2, \dots w_n$ – is the priority vector, the vector of weights.

When the vector of criteria weights and vector of alternative weights is known, the optimal alternative is obtained through the ranking of the overall weights of the alternatives. This ranking is achieved through the aggregation of the weight of the alternatives with respect to the criteria and the weight of the criteria with respect to the goal.

3.4.5 Key Limitations and Assumptions for Model Development

To start with, the high levels of uncertainty in the model results stem from the generalisation of the building stock archetypes and the assumed rates of renovation and demolition activities. As these data are used at the very beginning of the calculations, these uncertainties then propagate and accumulate through each step of the calculation.

The building archetypes in this model are used for deriving important features (dimensions and material types) that represent the entire cohort of buildings constructed in certain periods, which does not imply that these features are the same for every building in that cohort. However, in the case of the building archetypes, it is important to note that there can be a high degree of confidence in the specific archetypes from one construction period. This confidence is related to the similarity of the structural and major non-structural elements, as construction techniques and materials follow similar trends through the years and even decades. On the other hand, non-structural walls, building finishes, thermal envelope layers and even balconies undergo renovations by the end-users that are often unrecorded; therefore, the renovations that are already performed are not taken into account.

Also, one of the limitations of the model results comes from the fact that foundation works, excavated soils and installation works are not included, which may underestimate the CDW quantities and the composition results, especially in quantities of specific materials, such as plastic, metal, asbestos, etc.

In terms of demolition and renovation activities, the renovation and demolition rates variables are theoretical in this study due to two reasons. There is no reliable data on these activities, and the decision to renovate and demolish individual residential buildings is rarely made because of their age and state. Therefore, for the quantifications of CDW and the sustainability analysis of CDW management options, calculations of these rates are inevitable.

The lack of data on non-residential building archetypes limits the material stock and CDW quantity estimation results to residential buildings only. In addition, civil engineering works such as bridges, tunnels, dams, or roads are rarely demolished and renovated. Construction waste is also excluded from the study, as it is assumed that its quantities are not very significant in comparison to demolition waste.

Additionally, several other assumptions related to sustainability assessment may limit the model results. These include assumptions on advanced recycling technologies and environmental indicators other than GHG emissions. The former is related to advance recycling technologies with the ADR system that is included in alternative CE, which is at the moment only applied in the laboratory environment. The latter limits the environmental impact only to GHG emission as the most significant, while other indicators, such as eutrophication, acidification, toxicity, etc., remained unexplored.

Even though the methodology and alternatives are mostly based on widely used variables and factors from the scientific literature worldwide and European regulations and CDW practices, there are many variables aside from CDW quantities and compositions that are country related. These are the sustainability assessment variables, and they include the financial and social discount rates, elements that constitute operational costs such as energy and labour costs, insurance and administration costs, willingness-to-pay for gate fees and recovered materials, etc. Most of these variables are assumed in the sustainability analysis.

And finally, the majority of these limitations and assumptions will be covered with the development of different alternatives and the verification and validation of case study results.

3.5 Model Verification and Validation

All the assumptions and limitations explained in the previous chapter may lead to various uncertainties in the interpretation of the results. As it may be seen from the previous chapter, they come from a lack of data and the use of intervals in the calculations. Concerning this, there are two major sources of uncertainties in this model. The first is related to the homogeneity of data on residential building types, where an entire residential building stock is represented by several building types. While there is a high degree of accuracy in the calculation of the quantities and the compositions of materials for these 20 building types, the calculation for the entire stock would be an approximation, as the characteristics of one building cannot simply be transferred to the entire cohort.

The second source of uncertainties is connected to the renovation and demolition rates, i.e., the number of buildings renovated and demolished and the particularities of the waste treatment options. When it comes to the number of buildings renovated and demolished, this number is based on the assumption that the share of building types in cohorts corresponds to the share in renovation and demolition rates. However, this might not be the case in real life, where renovation and demolition activities do not follow a particular pattern. Similarly, the waste treatment rates may not follow a linear distribution in real life. These rates may depend on the local waste management policies, the network and the capacity of treatment facilities, the public attitude towards CDW management, etc.

In an attempt to overcome these and the uncertainties caused by other assumptions explained in the previous subchapter, verification and validation of the model are proposed. This is usually performed through a series of tests in order to demonstrate the robustness of a model, measure the goodness of its representation and finally increase the confidence in the results. The verification tests show whether the model uses the assumptions correctly and whether the model serves its intention, while the validation tests show whether these assumptions are reasonable and whether the model represents the real-life system with enough confidence (Hillston 2017). These tests include boundary adequacy, structure assessment, dimension consistency for verification and extreme condition tests, sensitivity analysis and the comparison of results with real or theoretical data for the validation of the model. The tests applied for verification and validation of this model are briefly described in the following text, while the details of these processes are provided in Chapter 5.

Firstly, verification of whether the model structure corresponds to the descriptive knowledge of the real-life system needs to be performed. This is done through a structure assessment test. Secondly, the boundary adequacy test is performed to establish whether the variables that are included in the model are appropriate for the research problem. These dimensions (units of measure) of these variables should be consistent throughout the entire model. This is tested with a dimension consistency test.

Model validation starts with the extreme conditions test. This test is performed to verify the behaviour of the model when its variables assume extreme values. The results obtained through this simulation are compared with anticipated real-life situations, and in order to pass this test, the model results have to be logical and consistent. It was then followed by a sensitivity analysis that examined the sensitivity of results and model behaviour when key variables change their values. Normally, the sensitivity is expressed through elasticity, a percentage of change in the value of the output for a change in the percentage of an input variable. And finally, to test the consistency of the model results with real data, a comparative test is conducted. When real data are not available, analytical data from the literature are used.

3.6 Summary

This chapter delivers the methodological approach that guided the integrated model development for the estimation of the quantity and composition of CDW and the evaluation of the sustainability performance of CDW treatment. It starts with the principles that lead to the selection of the appropriate methodologies for the estimation and evaluation, followed by the structure of the three-stage model that integrates these methodologies: the MS database, CDW estimation and the sustainability performance assessment of CDW treatment alternatives. Each stage of the model is explained in detail, including the input variables and their sources, the processes and the analysis used for their transformation into output variables. Several model limitations and the assumptions that had to be made were also described. Finally, the chapter concludes with an explanation of the verification and validation that was performed to alleviate these limitations and assumptions and increase the overall confidence in the model.

4 Case Study Results

4.1 Introduction

This chapter starts with the description of the main selection criteria for the choice of the case study that will be used for the implementation and validation of the model developed in the previous chapter. In addition, detailed background information related to population, geography, economy, political aspirations and the existing buildings stock is also provided. Following this, three alternatives for CDW management are developed and explained. This chapter is then divided into three more parts. The first two consist of the results related to the material stock and the quantity and composition of waste for each alternative, while the third is related to the evaluation of the sustainability performance of each alternative. And finally, the results of the alternative comparisons are provided at the end of the chapter.

4.2 Case Study Description

The Republic of Serbia (Serbia) is a country located mostly within the Balkan Peninsula in southeast Europe. It has a population of approximately 6.9 million that inhabits an area of 88499 km^2 (Statistical Office of the Republic of Serbia (RZS) 2021). This area is divided into five statistical regions and 30 districts with 29 cities and 168 municipalities (Statistical Office of the Republic of Serbia (RZS) 2021).

With a GDP per capita of 6,783 euros (or 7,742 dollars) in 2020 (Statistical Office of the Republic of Serbia 2021), the Serbian economy is labelled by the UN as an economy in transition between the developing and developed economies (United Nations Department of Economic and Social Affairs 2022).

Serbia is also in transition to the EU. Accession to the EU has been the top priority goal for all government institutions in Serbia ever since an EU membership request was submitted in 2009 (Government of the Republic of Serbia 2011). An EU candidate country status was granted to Serbia in 2012, and the negotiations began in 2014 with the opening of two out of 35 chapters divided into six clusters (European Commission 2021). Since then, the Serbian government has constantly declared its devotion to adopting EU values and achieving EU standards required for membership.

In terms of environmental protection and climate change, the recently opened chapter 27 is relevant. Through the negotiation process in this chapter, environmental protection and waste management legislation will be fully harmonized with the EU legislation. So far, this has been done for the EU legislation on waste management (National Assembly of the Republic of Serbia 2018) and landfill disposal (Government of the Republic of Serbia 2010), waste categories (Government of the Republic of Serbia Ministry of Environmental Protection 2021) and waste statistics.

On its way to the EU path, Serbia signed the Sofia Declaration on the Green Agenda for Western Balkan 2021—2030, which endorses the EU's Green Deal strategy and the New Circular

Economy Action Plan (Regional Cooperation Council (RCC) 2020). In this document, Serbia commits to work towards decarbonization, transition to a circular economy, decrease pollution, sustainable agriculture and biodiversity (Regional Cooperation Council (RCC) 2020).

The Action plan for the implementation of the Green Agenda for Western Balkan 2021—2030 included 58 objectives, among which are prioritisation of energy efficiency, support of private and public buildings renovation schemes, development of circular economy strategies, improvement of waste management infrastructure for cities and regions, etc. (Regional Cooperation Council (RCC) 2021). To support this as well as the entire accession process of the Western Balkans countries, the EC plans to mobilize up to 9 billion euros through 10 key investment flagships, among which are the expansion of the renovation wave strategy and regional waste management systems in Albania, Montenegro, North Macedonia and Serbia (European Commission 2020c).

In addition to the Green Agenda, Serbia has adopted a Roadmap for Circular Economy that serves as a guideline in the transition process from the linear to the circular economy. A set of recommendations for the construction sector includes harmonising procedures for monitoring CDW, establishing the dialogue between key stakeholders, enacting the legal framework, promoting sustainable construction and adapting and reconstructing buildings in line with the CE principles (Government of the Republic of Serbia Ministry of Environmental Protection 2020).

However, investments in the environment in Serbia are insufficient (Coalition 27 2021). National expenditure on environmental protection is far from the EU average, which was relatively stable (1.8—2.0% of GDP) for the past fifteen years (European Commission 2022). In 2019, the EU Member States spent 1.9% of GDP on average (European Commission 2022) on environmental protection, while Serbia allocated only 0.3% of GDP from budget expenditures (Krunić-Lazić 2021). Another 0.08% and 0.01% of GDP came from loans and donations (Krunić-Lazić 2021). More than a third of these expenditures went on subsidies and incentives (0.08% of GDP), mainly for the reuse of waste (Krunić-Lazić 2021).

On the other hand, the real estate and construction sectors were one of the major contributors to the GDP with 7% and 5.4% in 2020 (Statistical Office of the Republic of Serbia 2021). Driven by the demand due to economic growth, the construction industry in Serbia continued its rise in the past five years, both in terms of the value of works and the number of completed dwellings (Statistical Office of the Republic of Serbia 2021). Consequently, the consumption of building materials also increased in 2020, especially the consumption of masonry elements, cement and aggregates for concrete, steel, timber etc. (Statistical Office of the Republic of Serbia 2021).

At the same time, the construction industry generated 0.73 million tonnes of waste in 2020 that was mainly deposited in landfills (Statistical Office of the Republic of Serbia 2021). Serbia has ten regional sanitary landfills and 138 non-sanitary landfills that need to be closed in the next years (Đorđević et al. 2021). In addition, three regional sanitary landfills are under construction.

Considering that there are no records on the waste inflows on 59 non-sanitary landfills and that local municipalities reported 2642 illegal landfills with huge amounts of waste deposited, the above quantity of waste is largely underestimated (Đorđević et al. 2021). This is further supported by the fact that the CDW contributed only 1.29% to the total amount of waste in Serbia, while the EU average is approximately around 35% (Eurostat 2021a).

In addition, except for one study related to the quantity of asbestos (Zoraja et al. 2021) there are no studies or statistical records on the composition of the CDW stream and particular waste streams quantities in Serbia. For this reason, the integrated model for the quantification of CDW and the assessment of the sustainability performance of CDW management developed in the previous chapter (Chapter 3) will be implemented on the national scale for Serbia.

The author of the thesis hopes that this will contribute to the identification of the future amounts and composition of CDW that may go under the radar and/or be mismanaged. Considering that waste in Serbia is currently managed at the local scale, the performance assessment analysis was done from the waste operator perspective, which is, on most occasions, a public company owned by the local government.

The author decided to exclude civil engineering works (infrastructure works) from this case study as these are structures with a low demolition probability. Even in the case of demolition, roads would generate plenty of soil with a low possibility for high-grade application in CDW management. On the other hand, the demolition of residential buildings abounds with a lot of different materials that are more reusable and recyclable than soil. Residential buildings are in the spotlight for two reasons: the availability of data on building types and the fact that the majority of buildings that will be renovated or demolished in the future belong to this type.

When it comes to activities, the literature review showed that demolition works generate the greatest quantity of waste, while renovation works generate a higher quantity of waste than new construction. For these reasons, the focus of this study is on renovation and demolition works only.

It is expected that renovation and demolition activities will increase in the future in Serbia since most of the buildings in Serbia were built after World War II and before 1980, i.e. approximately 70% of the entire building stock in Serbia for the period before 2011 was built before 1980 (Jovanović-Popović et al. 2013). This means that these residential buildings, especially the ones built in the aftermath of World War II, will soon reach the time when their demolition is probable.

The temporal scope of the study was also determined to cover the age of buildings between 50 and 100 years, based on the fact that either renovation or demolition activity must occur in this period. In addition, the CBA guideline recommends a reference period of 25—30 years for waste treatment studies. Therefore, this model will include buildings constructed in the period 1946—1990 to calculate the potential quantities and the composition of CDW and the period 2021—2046 for the evaluation of the sustainability performance of the CDW management alternatives.

A detailed explanation of residential building types constructed in Serbia in the period 1946—1990 will follow in the next chapter.

4.2.1 Types of Residential Buildings (Building Stock) in Serbia

In this period, a total of 26 building types described and depicted in the National Typology (Jovanović-Popović et al. 2013)were analysed. Eight of these building types were SFH building types, both free-standing and in a row, while the other 16 were MFH building types, and they included free-standing buildings, lamella, in a row and high-rise buildings. An overview of these building types is provided in Table 18.

As shown in the table, these types of buildings represent 72.3% of the entire building stock in the period 1946—2011. The highest contributors to this number are SFH buildings, with a share of 70.3%. When looking into individual periods and building types, the highest number of SFH buildings were built between 1971 and 1980 (475,529), with similar numbers of SFH buildings in periods 1981—1990 (406,726) and 1961—1970 (399,385). In contrast, the highest number of MFH buildings were built in 1971—1980 (14,732), followed by 1981—1990 (14,200).

Table 18 An overview of residential buildings types for the period 1946—1990 and their main characteristics (adapted from the National Typology (Jovanović-Popović et al. 2013))

No.	Building type	Period of construction	Area (m^2) *	No. of floors	Floor structure	No. of Buildings	Type frequency (%)
Single-family house buildings							
1.	C1	1946—1960	76	1	Gf	286,259	12.74
2.	C2		257.3	1	Gf	12,034	0.54
3.	D1	1961—1970	209.7	3	B+Gf+1	376,057	16.74
4.	D2		110.1	2	B+Gf	23,328	1.04
5.	E1	1971—1980	223.4	3	B+Gf+1	454,893	20.25
6.	E2		260.4	2	Gf+1	20,636	0.92
7.	F1	1981—1990	167	2	Gf+1	386,958	17.23
8.	F2		233.1	3	B+Gf+1	19,768	0.88
Multi-family house building							
1.	C3	1946—1960	673.9	4	B+Gf+3	2,013	0.09
2.	C4		962.7	4	B+Gf+3	1,175	0.05
3.	C5		1,191.4	5	B+Gf+4	1,344	0.06
4.	C6		4,081.3	12	B+Gf+11	34	0.002
5.	D3	1961—1970	1,814.3	5	B+Gf+4	5,624	0.25
6.	D4		1,727.3	5	B+Gf+4	2,113	0.09
7.	D5		1,704.	6	B+Gf+5	1,661	0.07
8.	D6		4,847	14	B+Gf+13	242	0.01
9.	E3	1971—1980	1,218.5	4	B+Gf+3	8,104	0.36
10.	E4		3,609.6	8	B+Gf+7	4,377	0.19
11.	E5		1,424.6	6	B+Gf+5	1,876	0.08
12.	E6		7,443.2	16	B+Gf+15	415	0.02
13.	F3	1981—1990	2,789.7	5	B+Gf+3+A	7,837	0.35
14.	F4		1,892.6	7	B+Gf+4+2A	4,176	0.19
15.	F5		1,732.7	5	B+Gf+3+A	2,024	0.09
16.	F6		6,472.8	14	B+Gf+13	163	0.01

* These values are measured from architectural drawings and may differ from values in the National Typology;
B – Basement, Gf – Ground floor, A – Attic

When it comes to the number of floors and floor structures, most of the SFH buildings have two or three floors, i.e., two above-ground floors and optionally a basement. On the other hand, all MFH buildings have a basement and a ground floor, while the number of above-ground floors varies with the type of MFH building (high-rise buildings have between 11 and 15 floors).

However, aside from the geometry of the building types, the greatest value of the National Typology is the identification of construction materials embedded in these buildings, especially in their thermal envelope, that enabled the calculation of the MS Database for residential buildings in Serbia presented in Subchapter 4.4.

In addition, the National Typology also recommended a set of thermal envelope improvement measures that were used for the estimation of waste generated during renovation.

4.2.2 Alternatives' Description

The methodology that was proposed in Chapter 3 will be implemented in three CDW management alternatives in Serbia. These alternatives were developed on the basis of current and future management practices. While the current CDW management practice was easy to establish and describe, the future practices were developed in line with several legal, economic, environmental, social and technical assumptions.

These assumptions are identified in several strategic documents issued by the EC and the Serbian government, especially strategies, action plans and programs regarding waste management, circular economy and renovation activities. It can be argued that these alternatives are policy and technology-based alternatives as they are driven by the EU directives and strategies and best management practices in the EU.

The assumptions were based on future renovation activities, shares of selective demolition (deconstruction) in demolition activities, treatment routes for each waste stream, recovery rates for each CDW treatment and a set of possible legal instruments that may be promoted by the government to support better CDW management practices.

An overview of these assumptions is provided in Table 19, while full details and descriptions of the alternatives that were developed are given in the following subchapters (Subchapters 4.2.3—4.2.5).

Table 19 A comparison of CDW management alternative' particulars

Alternative particulars	**S1 – Business as Usual** **2021—2046**	**S2 – Achieving the EU28 (2018) Average** **2021—2046**	**S3 – On the Road to Circular Economy** **2021—2046**
Renovation rates (%)	0.58—0.65	0.58—1	0.58—2
Share of deconstruction (%)	1	6	20
Recovery rates of CDW (%)	62%	72%	81%
Gate fees (euro per tonne)			
Recycling	0	0	2
Energy recovery	0	42.6, from 2024	42.6, from 2024—70
Disposal	9.4—16.5	9.4—16.5	9.4—24
Landfill tax (euro per tonne)	0	0—11 starting from 2031	0—30.5 starting from 2031
Cost of CO_2 (euro per tonne)	0	0—17 starting from 2032	0—34 starting from 2032

One of the main differences between the alternatives is in the share of selective demolition that occurs during the renovation or demolition activity. The share of deconstruction activity was based on the CDW composition. For instance, the maximum share of metal or wood-based waste streams was 1.2% and 2.2% in all three alternatives. Therefore, the share of selective demolition for these fractions was limited by these numbers.

Notably, the higher the share of deconstruction is, the greater the potential for high-quality recovery of particular CDW streams. This is because a higher share of deconstruction also raises the number of individual CDW streams and enhances the number of potential CDW treatments.

An overview of CDW management alternatives (treatment routes and destinations) is provided in Figure 6. This overview is only to note the general difference between treatment routes, while a detailed description of the alternatives and the particularities will follow in the next Subchapters 4.2.3—4.2.5.

It has to be noted that although disposal remains a possible treatment option for all CDW streams, it is not indicated in this figure, except in the case when it is the only option or when the major share of a particular waste stream is treated this way. Illegal dumping is excluded from routes as it is not an acceptable waste treatment practice. However, the effects of this waste mismanagement are evaluated in the sustainability assessment.

Similar to the share of selective demolition, recovery rates for each of the CDW streams were also based on the CDW composition and the technological capabilities of recovering facilities. Thus, in addition to CDW management recovery rates in 2021, recovery rates were limited by the assumption that 20% of CDW in Serbia is currently disposed of at illegal landfills (Statistical Office of the Republic of Serbia 2021), while the recovery rates in 2046 were limited by the quantity of particular waste streams and the level of recycling infrastructure development.

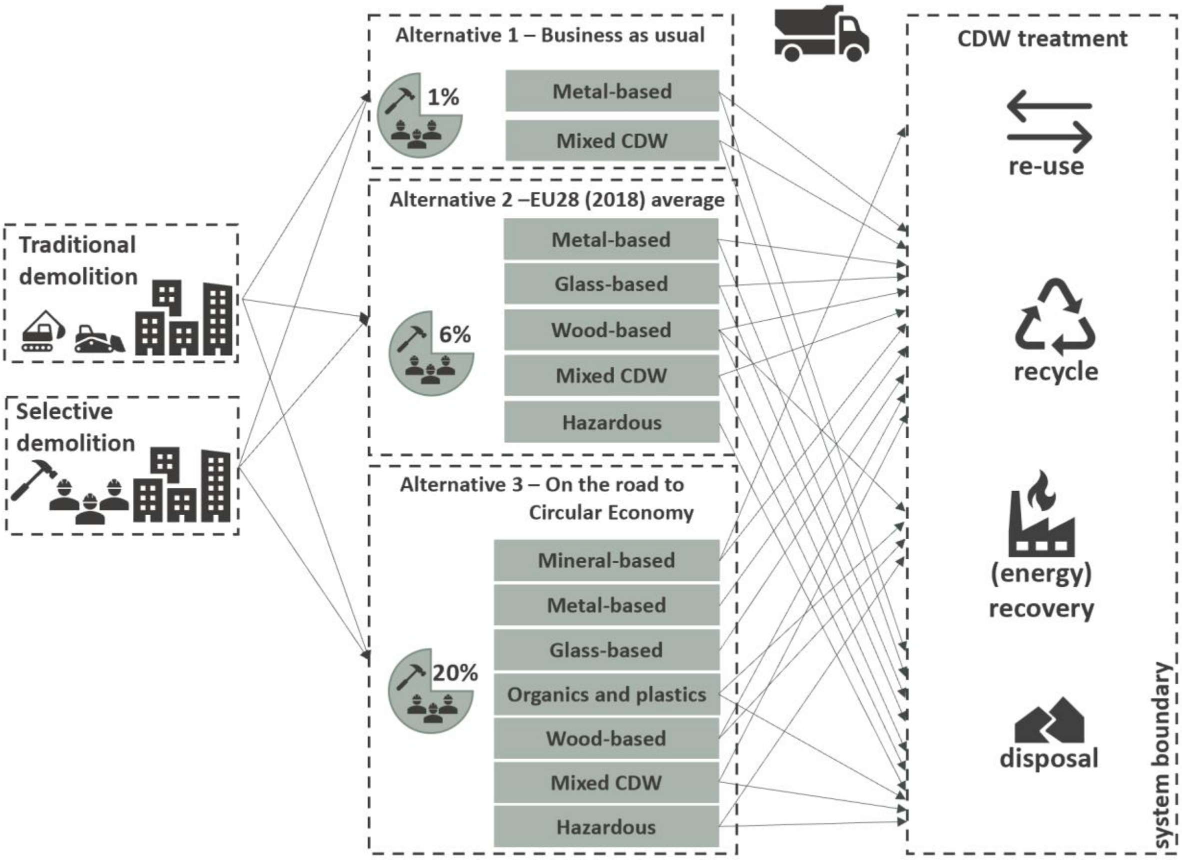


Figure 6 An overview of waste streams' treatment routes and destinations for different management alternatives

The set of legal instruments was based on current legal frameworks and the best CDW management practices in the EU. These instruments included higher gate fees and the introduction of landfill and carbon (CO_2 emission) taxes. Other instruments which could not be monetised in this calculation and that also lead to better CDW management practices, such as landfill bans or green public procurement thresholds, were also included in the alternatives and will be explained in the next subchapters.

4.2.3 Alternative 1 Description – Business as Usual

As mentioned before, the "Business as Usual" alternative represents the current renovation, demolition and CDW management practices. While the details on CDW management practices were easily obtained from national statistic records and reports of the Serbian Environmental Protection Agency, the prediction of renovation and demolition activity was a bit more complicated.

While predictions of construction activity based on construction permit records can be fairly reliable, this is not the case for the renovation or demolition activities, and renovation and demolition permits where national statistics are underdeveloped. For that reason, dynamic building stock modelling needed to be considered.

The model that was used to simulate the changes in the residential building stock in this thesis was developed by Sandberg et al. (2016). It is based on the population needs for housing as well as renovation and demolition probability. They assumed a renovation cycle of 40 years, 40 years of the initial period without demolition, an average lifetime of buildings of 120 years and that 5% of buildings will not be demolished to preserve national heritage. Their results for Serbia are shown in Figure 7.

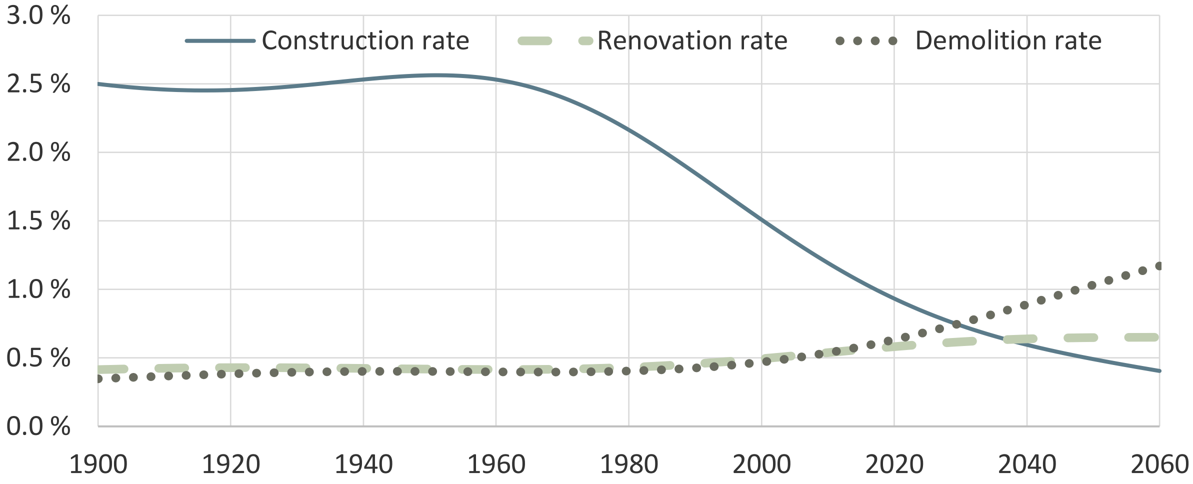


Figure 7 Renovation and demolition rates in Serbia, modified from (Sandberg et al. 2016)

Figure 7 depicts just a fraction of the period in which the share of building stock in Serbia has been modelled. However, if an entire period is looked at, it may be seen that the renovation probability function follows a normal distribution, while the demolition probability function follows a Weibull distribution. The methodology for the estimation of CDW presented in this thesis used these demolition rates in all three alternatives, while the renovation rates were used just in this alternative.

The following assumptions concerned the current CDW management practices as this alternative predicts that no change in the current practice will happen in the next 26 years. In general, this alternative is characterised by immature CDW management practices with almost no selective demolition, low level of recycling infrastructure development, low gate fees, the majority of CDW downcycled rather than recycled, significant disposal of CDW at landfills and high rates of illegal dumping.

In Serbia, reporting related to waste generation and treatment, according to Waste Management Act, is an obligation of generators, owners, treatment facilities and landfill operators. They collect daily reports on waste but submit annual reports to the Serbian

Environmental Protection Agency (National Assembly of the Republic of Serbia 2018). Although the number of reports has been gradually increasing since 2017, it is far from satisfactory. Namely, the Serbian Environmental Protection Agency revealed that 15,806 reports were submitted for the year 2020 (Đorđević et al. 2021), which is only 18% of the total number of enterprises in Serbia (Statistical Office of the Republic of Serbia 2021).

Waste in Serbia is currently managed at a local scale. As mentioned before, the existing waste collection and treatment infrastructure of waste in Serbia is immature. It faces many challenges: lack of primary sorting, the inadequacy of transport routes, lack of treatment facilities such as recycling and incineration facilities, a large number of non-sanitary landfills and illegal dumping areas, etc. (Government of the Republic of Serbia 2022b).

Although the National Waste Management Program foresees 26 Regional waste management centres in Serbia, only 13 are currently established. In addition, regional sanitary landfills are constructed and fully operational in 10 of these centres. However, waste is also disposed of at non-sanitary landfills and illegal dumping areas.

Whit an exception of a few mobile CDW recycling facilities, there is no systematic CDW recycling in Serbia (Government of the Republic of Serbia 2022b). The only organised recycling that happens is the recycling of metal-based waste streams that are driven by the economic benefits and the existence of a secondary market for the recovered waste materials. Therefore, the share of selective demolition in this alternative will be set to 1%, which is approximately the share of the metal-based waste stream in the total CDW quantity. Setting the selective demolition to 1% reflects the fact that only metal-based (excluding steel rebars for concrete) waste is being recycled at the moment.

In terms of quantities of mineral CDW that are subject to different waste treatments, Serbia has reported that in 2018, 81% of mineral CDW fraction was used in backfilling, i.e., downcycled, while 19% of this waste was deposited at landfills (Eurostat 2021b). In addition, 20% of the total waste goes under the radar as this is the share of waste that is illegally dumped in Serbia annually. Therefore, the reported recycling rates will be transferred into Alternative 1 after taking into account the illegal dumping rate and the consequential adaptation of backfilling and disposal rates. This means that the adapted recovery rate of CDW in Serbia in 2018 was set at 62%.

Ending with 2021, Serbia has no economic instruments that could support better CDW management practices. For instance, the instruments that are applied in other countries to efficiently divert waste from landfills to recycling are landfill taxes or bans. Also, the delayed introduction of the carbon tax hinders the public's awareness of CO_2 emissions in Serbia.

Currently, in addition to the economic benefits of backfilling, only the gate fees for non-hazardous CDW disposal that are paid at several regional sanitary landfills contribute to this diversion of CDW from the disposal. These fees range from 9.4—24 euros per tonne. This alternative predicts that a disposal gate fee starts from 9.4 euros per tonne owing to the fact that at the moment, most of the CDW in Serbia is deposited on both sanitary and non-sanitary landfills without any charge. The fee starts to increase from 2035, at the time when the alternative predicts that all regional sanitary landfills will be constructed, to finally reach the 16.5 euros per tonne fee in 2046. This is the average gate fee for the disposal of non-hazardous inert waste at regional sanitary landfills in Serbia.

However, sustainable CDW management practices clearly need more support. The following chapters will identify all these instruments and calculate their effects on CDW management.

4.2.4 Alternative 2 Description – Achieving the EU 28 (2018) Average

Guided by the assumption that the service life (lifetime) of buildings and that the population behaviour related to housing will not change significantly from Alternative 1, this alternative keeps the same demolition rates. Contrarily, in an attempt to achieve the EU average recovery rates, the renovation rates will change in Alternative 2. This alternative predicts an almost double renovation rate by the end of 2046.

The prediction is further supported by the Government's proposal of the Strategy on National Housing for the period 2022-2032, which in terms of renovation of the stock, sets the specific goals for renovation of up to 30% of the buildings whose amortization time expires in 2032. Considering that buildings depreciate at a rate of 2.5% (Tax Administration of the Republic of Serbia 2019), this goal will include buildings built before 1992.

Due to the fact that the Strategy planned to achieve this goal through regulatory measures and to raise awareness actions, the author of the thesis decided to reduce this percentage by a third in this alternative. In other words, in the period 2021—2046, Alternative 2 predicts a linear growth of recycling rates from 0.58 to 1%; by 2032, the rates will accumulate to 8.1% of buildings built between 1946—1990 or 11% if we look at all buildings built before 1990.

The main characteristics of this alternative are related to the objective of achieving the EU average CDW management practices. These include higher shares of deconstructions and primary separation for particular waste streams, mineral CDW recycling infrastructure at a basic level, more strict control of illegal dumping and several economic instruments such as landfill and carbon tax to support better practices.

When it comes to CDW waste streams, the previous alternative included only the valorisation of metal-based waste due to the existing demand for these materials and clear economic benefits. However, aside from metal, i.e., reinforced steel, consumption of other building materials, such as bricks, concrete and aggregates for concrete, gravel and sand in the past five (Statistical Office of the Republic of Serbia 2021) imply that there is an increasing need for these products. This need can indirectly create a demand for the development of a secondary market for the placement of high-quality recycled concrete aggregate.

Furthermore, the extraction of aggregates, especially river gravel and sand, although legally well-regulated, is poorly implemented in reality. The extraction from river beds in Serbia is often performed illegally and uncontrollably, causing detrimental consequences to the environment in terms of resource depletion, the use of arable land and potential risks from flooding. Implementation of higher extraction taxes or even bans may also drive the secondary market to the use of recycled aggregates.

Therefore, this alternative will involve the valorisation of mineral, glass and wood-based material in addition to metal-based and mixed CDW, which were treated in Alternative 1. For that reason, the share of selective demolition in this alternative is set to 6%. This number took into account the composition of the waste and the fact that the above-mentioned streams will be recovered. Physically, the above number includes the soft stripping of metal, wood, and glass products and removing of hazardous waste (bitumen, asbestos, gypsum) and other impurities such as soil that may decrease the recovery rate of the mineral CDW fraction before the traditional demolition of the entire building structure. It was assumed that the remaining mineral CDW fraction will achieve the EU average recovery rates for recycling, backfilling and disposal, provided in Figure 8, by the end of 2046.

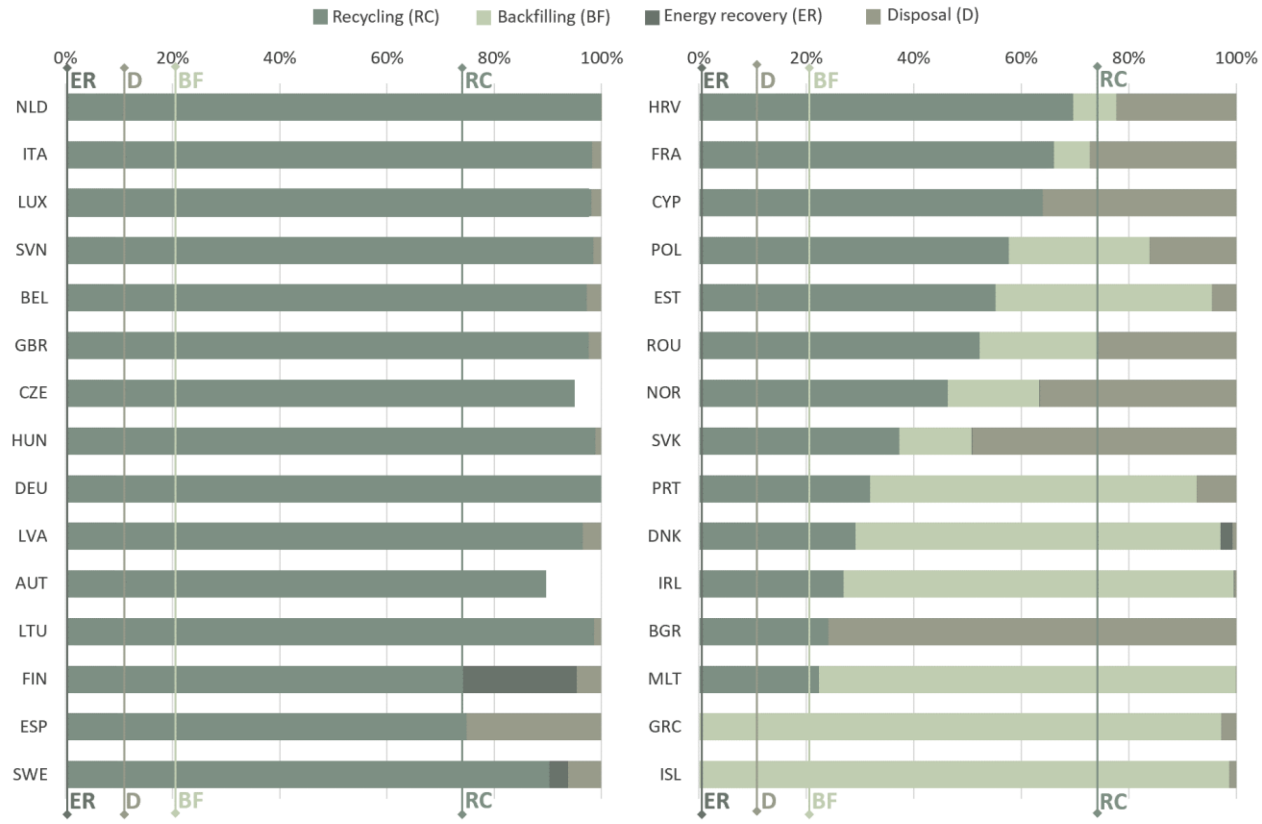


Figure 8 Mineral CDW stream treatment rates in the EU (data from Eurostat for 2018)

Once again, these rates needed to be adapted for the entire quantity of CDW, and the rates also needed to include the amount of illegally dumped waste. In other words, this alternative predicts that more stringent control by the local authorities and higher penalties will decrease the rate of illegally dumped CDW to 5% by 2046, meaning that the total recovery rate in this alternative will reach 72%.

The assumptions made on the economic instruments were based on industry reports and national statistics where these were available, or they were taken from the literature. The gate fee for energy recovery was previously calculated by the author in the Nikolic, Mikic, and Naunovic (2017) study. The energy recovery fee has a delayed start, i.e., the application starts in 2024 when the incineration facility reaches its operational phase. Similar to Alternative 1, the predicted disposal gate fee of 9.4 euros per tonne till 2030 was used, which will then gradually increase to 16.5 euros per tonne.

And finally, Alternative 2 introduces two economic instruments: landfill and carbon tax. The former tax serves to divert CDW from landfills, and it will gradually increase from 2031 to 2046 to 11 euros per tonne for non-hazardous mineral waste. This is the minimum value of current landfill taxes in Serbia's neighbouring countries: Bulgaria, Greece, Hungary, Italy, Romania, and Slovenia, which range between 11 and 50 euros per tonne (The Confederation of European Waste-to-Energy (CEWEP) 2021). On the other hand, in Alternative 2, the carbon tax implementation starts in 2032, and it gradually increases its value to 17 euros per tonne of CO_2-eq (approximately 20 dollars per tonne of CO_2-eq), which is the current price that Slovenia pays for CO_2 emissions (World Bank 2021).

4.2.5 Alternative 3 Description – On the Road to Circular Economy

While the demolition rate remains the same as in the two previous alternatives, the renovation rate will increase two and four times in comparison to Alternative 2 and Alternative 1. In line with the Green Deal and Renovation Wave strategies, this alternative predicts achieving a renovation rate of 2% by 2046. It was assumed that the pace of renovation would be linear, and it would reach 10.7% of the 1946—1990 building stock by 2032, or 15% if we look at all buildings built before 1990.

These numbers also correspond with the recently adopted (February 2022) Long-term Strategy for Encouraging Investments in the Renovation of the National Building Stock of the Republic of Serbia by 2050 (Government of the Republic of Serbia 2022a). To decrease CO_2 emission by 31% by 2050 in comparison to the 2020 values, this strategy anticipates an annual renovation rate of 0.5% of the total SFH buildings' area. The percentages are doubled for MFH buildings built before 1960 and tripled for MFH buildings built from 1961. When these rates are applied to the 1946—1990 building stock, the total number of buildings to be renovated annually amounts to 8,524 buildings. Similarly, when the Renovation Wave Strategy rate is applied, the total number of buildings to be renovated gradually increases from 2,414 to 8,338 in 2046. The author chose the latter renovation alternative with a gradual increase as it seems more realistic than the one with fixed annual values.

The main characteristics of this alternative are related to the objective of adopting the CE principles and CE oriented strategies in CDW management practices. This means obligatory deconstruction and primary separation of particular waste streams, the introduction of green public procurement, advanced recycling facilities for mineral CDW, no disposal of reusable and recyclable waste at landfills, elimination of illegal dumping practices, higher rates of gate fees for disposal and energy recovery and higher landfill and carbon taxes and an introduction of a landfill ban at the end of the period. Additionally, and following the National Waste Management Program, management of waste will be transferred from local to regional scale (Government of the Republic of Serbia 2022b).

Alternative 3 predicts separate treatment and valorisation of even more streams. Aside from hazardous, metal, glass and wood-based streams and mixed CDW fractions, mineral, organics and plastic-based waste streams were added. To achieve this separation, the share of selective demolition was increased to 20%. In addition to the removal of metal, wood, glass products and hazardous waste or other impurities, selective demolition share includes a deconstruction of bricks that will be prepared for reuse before the traditional demolition.

In terms of particular waste streams, the objective of Alternative 3 is to eliminate both disposal and illegal dumping of the recyclable CDW fractions (mineral, metal, glass and wood) by 2046. By doing this, the alternative achieves a recovery rate of 81%. These rates correspond with the specific recovery goal for non-hazardous waste of 40% by 2029 and 70% by 2034 set in the National Waste Program (Government of the Republic of Serbia 2022b). To support this goal, the Program suggests the following infrastructure: 26 mobile recycling facilities (one in each regional waste management centre) and at least one stationary recycling centre with a capacity of 200,000 per year. In terms of driving the demand for recovered aggregates, the Program advises the formulation and implementation of quality standards for recycled aggregates and the establishment of the mandatory use of recycled aggregates in public procurement works (green procurement) with a threshold of 10% (Government of the Republic of Serbia 2022b). The treatment routes for other waste streams include a higher share of wood recycling, energy recovery from organics, plastics and wood and recycling of glass-based streams. After removal, asbestos and gypsum will be deposited at regional sanitary landfills with special landfill cells for hazardous waste disposal, while a significant share of bitumen-based waste materials will be sent to energy recovery.

Generally, the regulatory and economic instruments are crucial for the realisation of the CDW Management Alternative 3. The alternative predicts the introduction of a recycling gate fee that is set to 2 euros per tonne (Di Maria, Eyckmans, and Van Acker 2018) to stimulate the generators of CDW to recycle rather than dispose of this waste. This recycling gate fee is set to be lower than the minimal gate fee for disposal in Europe, which should make recycling a more preferable option than disposal. The energy recovery gate fee remained the same as in Alternative 2 as it is based on the amount of money that users are willing to pay (Nikolic, Mikic, and Naunovic 2017). In addition, the maximal gate fee for disposal of CDW is significantly higher (45%) than in Alternative 2.

In comparison to Alternative 2, Alternative 3 doubles and triples the carbon and landfill tax by 2046, respectively. By doing this, the carbon tax will reach the lower limit of the current World Bank recommendation on carbon pricing (World Bank 2021), while the increase of landfill tax to the average of current landfilling taxes in Serbia's neighbouring countries (The Confederation of European Waste-to-Energy (CEWEP) 2021) should prepare the ground for the introduction of a landfill ban on recyclable and reusable CDW.

4.3 Data Required for the Case Study Calculations

Considering that models are usually highly sensitive to the input data, only data from credible sources were employed in this model. An overview of these data and their sources are provided in Table 20, while only the most significant sources are further explained in the text.

Naturally, the Statistical Office of the Republic of Serbia was a major source of the data used in this study. Statistical records were used both directly and indirectly through the National Typology publication, which will be explained later. Most of the data that was used came from the publication "Census of Population, Households and Dwellings in Serbia" (Census), which has been carried out approximately every ten years since 1948 (Statistical Office of the Republic of Serbia 2014). The Census that was supposed to be published in 2021 was postponed for October 2022 due to the COVID-19 pandemic (Government of the Republic of Serbia 2021), making the 2011 Census the last available data. And it was the results from this Census that was used as initial data in this thesis, particularly the results that are related to dwellings and, to a lesser extent, the population and geographical data.

Based on these results, a group of authors built the aforementioned "National Typology of Residential Buildings" (National Typology) (Jovanović-Popović et al. 2013). The National Typology was a result of two European projects, Tabula and Episcope (Institute Housing and Environment GmbH (IWU) 2016), which focused on residential building stocks and energy refurbishment. In addition to the Census data, field research was conducted by the professors and associates from the Faculty of Architecture in Belgrade, in which they surveyed 6,000 single-family buildings and 13,000 multi-family buildings, amounting to 19,000 residential buildings in total. Depending on the period of construction, the building stock was divided into seven cohorts: before 1919, 1919—1946, 1946—1960, 1961—1970, 1971—1980, 1981—1990, and 1991-2011. The stock also differed in the types of residential buildings in the single-family house (SFH) and multi-family house (MFH) buildings. These types were further divided into six sub-types. SFH buildings distinguished between *freestanding* and *in a row* house sub-type, while MFH buildings had two more sub-types: *lamela* and *high-rise*. A combination of these cohorts, types and sub-types yielded 35 representative building types.

In addition to the statistical data that existed in some form in the National Statistical Office (period of construction, building types, number of dwellings, floor area, etc.), Jovanović-Popović et al. (2013) calculated the number of buildings per building type and gathered physical characteristics of these building types. The data were used the most in this analysis as they included details on the thermal envelope layers, such as types of external walls, ground floor and roof (or attic) slabs, their insulation and coverings, type of windows and external doors, etc. These were presented as schemes of different walls' and slabs' layers with thicknesses of these layers indicated. Digital versions of the drawings allowed the discovery of the exact position of these elements within the building and the extraction of their precise quantity and other two dimensions (width and length). Finally, the authors of the typology recommended numerous renovation measures directed toward buildings' thermal envelop improvement. These measures were specifically designed for each building type and each construction element (Jovanović-Popović et al. 2013).

Table 20 Overview of data and their sources required for the integrated model development

Data	Source
Material stock estimation	
Building types Period of construction	Textual and tabular presentation from the National Typology published by Jovanović-Popović et al. (2013)
Number of buildings (per building type)	Tabular presentation in the National Typology published by Jovanović-Popović et al. (2013)
Building element's characteristics (location, function, quantity and dimensions)	Architectural drawings and layout plans made available by the authors of National Typology of residential buildings in Serbia
Building element's characteristics (material type)	Textual and schematic presentations from the National Typology published by Jovanović-Popović et al. (2013)
Density of material	MASEA online database - Material data collection for energy-efficient renovation (Fraunhofer Institute for Building Physics in Holzkirchen et al. n.d.) Building construction and Construction materials textbooks (Muravljov 2007) Manufacturer's technical data sheets
Population and population projections	Statistical office of the Republic of Serbia (Statistical Office of the Republic of Serbia (RZS) 2014) (Statistical Office of the Republic of Serbia 2011)
Estimation of CDW	
Renovation measures	Textual and schematic presentations from the National Typology published by Jovanović-Popović et al. (2013)
Renovation rates Demolition rates	Results of the dynamic building stock of 11 European countries published in a study by (Sandberg et al. 2016), Renovation Wave Strategy (European Commission 2020b)
Assessment of CDWM	
Labour wages and labour taxation	Statistical office of the Republic of Serbia – Average monthly earnings by division of activity (Statistical Office of the Republic of Serbia n.d.)
Unemployment rate	Statistical office of the Republic of Serbia – Unemployment rates by sex, region and age (Statistical Office of the Republic of Serbia n.d.)
Value of export, import	Statistical office of the Republic of Serbia – Export and import total, by months (Statistical Office of the Republic of Serbia n.d.)
Customs tariffs	Customs Administration Fact Sheets, Republic of Serbia (The Republic of Serbia Customs Administration 2021)
Inflation rates, exchange rates	Eurostat (Eurostat n.d.) National Bank of Serbia (National Bank of Serbia n.d.)
Social and discount rates	Ministry of Finance, Republic of Serbia (Government of the Republic of Serbia Ministry of Finance 2021)
Waste generation rates	Eurostat – Waste generation (Eurostat 2021a) Serbian Environmental Protection Agency (Ministry of Environmental Protection Republic of Serbia - Environmental Protection Agency 2020)
Waste treatment rates	Eurostat – Waste treatment (Eurostat 2021b)

Gate fees and landfilling taxes	Landfill taxes and bans The Confederation of European Waste-to-Energy (The Confederation of European Waste-to-Energy (CEWEP) 2021) Gate Fees Report (Waste Resource Action Programme (WRAP) 2021)
Carbon pricing	World Bank (World Bank 2021)
The average cost of arable land	Geodetic Authority (The Republic of Serbia Republic Geodetic Authority 2021)
Number of landfills	Environmental Protection Agency, Republic of Serbia (Ministry of Environmental Protection Republic of Serbia - Environmental Protection Agency 2020)

Other data from the National Statistical Office that were used were mostly employed in the assessment stage. These were data on labour wages and taxations, unemployment rates, values of import and export, etc. In addition to the Serbian Statistical Office, records from Eurostat were also used, especially records on current waste generation and treatment rates that later served for the alternative's development.

Specialized organizations, institutions and online databases were addressed when particular and specific data were needed. One of the major sources of specialized data was the MASEA Database. The database was made to support the energy refurbishment of old buildings, especially to facilitate their hygrothermal simulation. Two German institutes and one centre, the Fraunhofer Institute for Building Physic, the Institute for Building Climate and the Centre for Environmentally Conscious Building, joined their forces to collect information on construction material properties. The database included 474 entries organised into 13 categories of materials that are usually being incorporated into the thermal envelope of a building (Fraunhofer Institute for Building Physics in Holzkirchen et al. n.d.). These are paints, plasters, bricks, stones, cementitious materials, insulating materials, boards, wood, facade cladding, floor, roof covering, etc. The number of properties such as density, specific heat capacity porosity, sorption, diffusion resistance, etc., were determined for each entry. In this thesis, the MASEA database was used for data on construction material density. Even though it provided a lot of significant information, for the data that was missing, a Serbian textbook on construction materials was used (Muravljov 2007). The latter was chosen since it was assumed that they followed Serbian standards and construction practices and norms from the past. In the cases when there was no information on the density of a particular material, the manufacturer of this material was contacted.

Other specialised data mostly came from various government agencies. Serbian Environmental Protection Agencies provided additional data on existing waste management practices, the number and location of treatment facilities, illegal dumping areas, etc., while the Republic Geodetic Authority provided information on the price of land and precise location of treatment facilities. Finally, on rare occasions, when the necessary data for the model was not available, personal contact and investigations were used to obtain them, or similar data which best fitted the analysed phenomenon was used.

4.4 Material Stock Results

The methodology described in Subchapter 3.4.1 and the MS Database provided in Appendix A and Appendix B allowed for the estimation of the residential buildings' material stock quantity and composition of CDW that they may generate during renovation or demolition. More than 60 material types classified into 18 categories were recorded in the MS database. As mentioned previously, the quantity and the composition of the materials depend on the building type and period of construction. Therefore, as SHF buildings constituted the majority of the building stock in the period 1946—1990, they also contributed the most to the materials stock. The total calculated weight of the material embedded in residential buildings built in this period is 714.6 million tonnes, out of which 601.1 million tonnes are embedded in the SFH buildings and 113.5 million tonnes of materials are embedded in MFH buildings.

The compositions of these materials, both total and divided per building type, are shown in Figure 9a, Figure 9b and Figure 9c. The materials are sorted by EWC codes for easier referencing. As expected, mineral fractions (17 01 and 17 05) were the major contributors in both building types, with a share of more than 80%. This is due to the fact that most of the buildings built between 1946 and 1990 used concrete, bricks and blocks for their structure. For the same reason, there were five times more stone and soil materials in SFH than in MFH buildings.

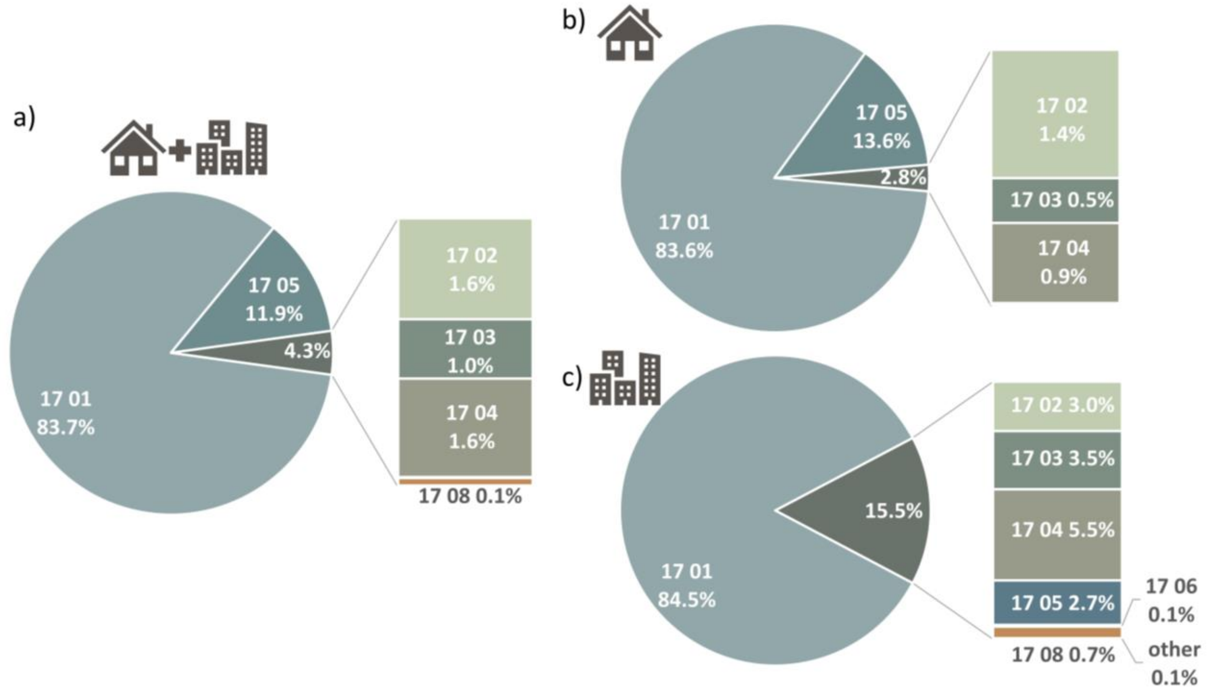


Figure 9 Share of material types embedded in residential buildings (a) single-family (b) and multi-family (c) house buildings built in the period 1946—1990

17 01 – concrete, bricks, tiles and ceramics, 17 02 – wood, glass and plastics, 17 03 – bitumen mixtures, 17 04 – metals, 17 05 – soil and stone, 17 06 – insulation material (polystyrene) and asbestos, 17 08 – gypsum, other – textile and organics.

On the other hand, with 12.8% in contrast to 2.8%, MFH buildings were richer in non-mineral fractions than SFH buildings. The content of wood, glass and plastic material (17 02) was more than doubled, while the quantity of metals and bitumen mixtures were significantly higher (five and seven times respectively) in MFH than in SFH buildings. The other fractions with notable quantities, especially in MFH buildings, were gypsum, insulation materials and asbestos and textile and organics, but these fractions contributed to the entire quantity of materials with less than 1%.

Figure 10 and Figure 11 provide a closer look at the compositions of the mineral (Figure 10) and non-mineral fractions (Figure 11) of SFH and MFH buildings in different periods of construction. It may be seen that the quantity of mineral materials changed over time. The peak in quantity for SFH buildings was reached in the period 1971—1980 (225.2 million tonnes), while the peak of 46.8 million tonnes for MFH buildings was reached in the next period (1981—1990).

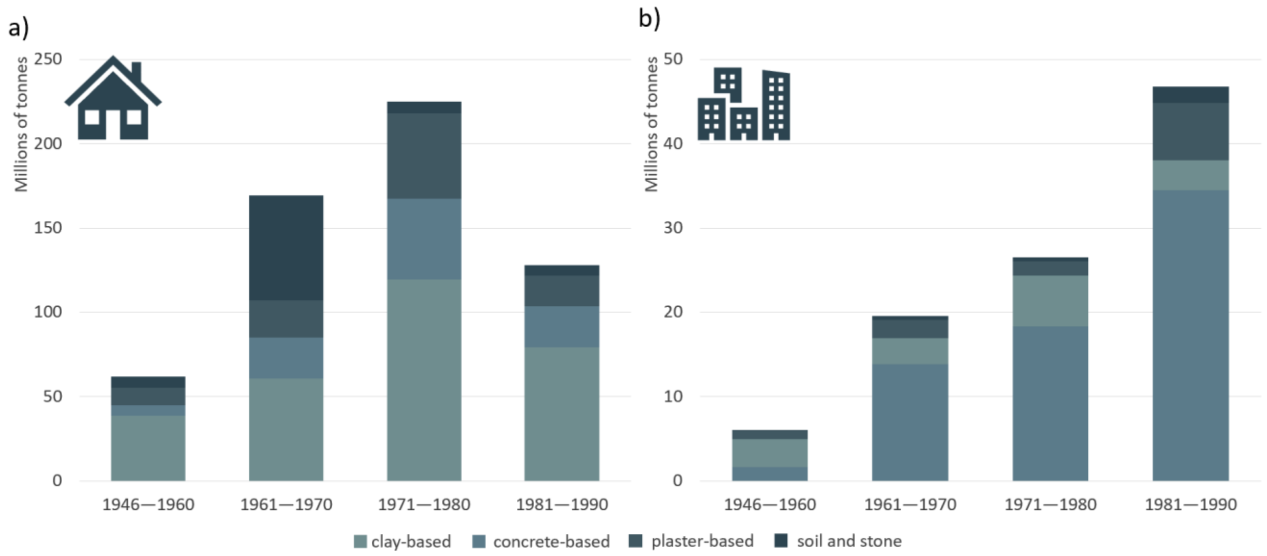


Figure 10 Composition of mineral fraction materials (17 01 and 17 05) in single-family (a) and multi-family (b) house buildings

The building types also differed in the composition of mineral materials. Clay-based materials dominated the SFH building stock in all periods in contrast to concrete-based materials in the MFH building stock. Similar to this, the amount of stone and soil was higher in SFH buildings, especially the ones built between 1961 and 1970, than in MFH buildings. Both figures also show the significant amounts of plaster (mostly cement and lime-sand plaster) that were used for masonry and wall and ceiling coverings.

Figure 11 shows the amount and the composition of non-mineral fractions. Similarly to the mineral fractions, the highest quantity of non-mineral fractions built-in SFH buildings was in the period 1961—1970 (5.9 million tonnes), while the highest quantity in MFH buildings was built in the period 1971—1980 (6.8 million tonnes). Metals in combination with wood, glass and plastic materials in SFH buildings and bitumen mixtures in MFH buildings contribute the most in non-mineral fractions with 81 and 93%, respectively.

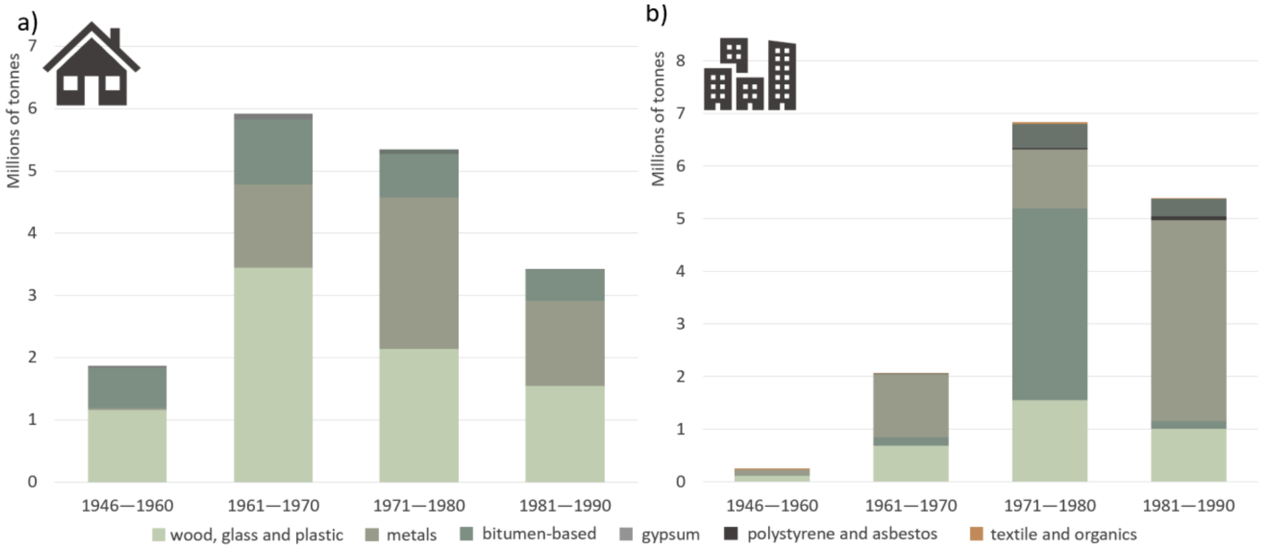


Figure 11 Composition of non-mineral fractions materials in single-family (a) and multi-family (b) house buildings

According to the figures above, it may be noted that gypsum-based materials were not used before 1960. In addition, gypsum was used more in MFH buildings, with shares around 10 and 11% in the ’70s and ’80s, while the share of gypsum in the buildings built before 1990 was below 2%. Similarly to gypsum, polystyrene and asbestos were not used for insulation in SFH buildings before 1990, while their use in MFH buildings was in the range of 1 and 3%.

It has to be noted that there are several material types that, due to their quantities, are not clearly visible in figures but are present in both stocks. These are the textile and organic materials that had small shares in the total amount of non-minerals, i.e., these materials were in the range of 0.1—2.7% in SFH buildings and 0.6—6.7% in MFH buildings.

4.5 Estimation of CDW Quantities and Composition

This subchapter includes the result of the estimation of CDW quantities and their compositions for the period 2021—2046, as well as the sustainability performance of alternatives for the management of this waste in all three alternatives. The results in each alternative include the estimation of the number of buildings that will be demolished or renovated in this period, the estimation of CDW quantities and composition and the calculation of sustainability indicators. The results of the MCDM analysis are provided in a separate chapter.

4.5.1 Alternative 1 – Business as Usual

The assumptions on the renovation and demolition rate for Alternative 1 described in Subchapter 4.2.3 and the methodology described in Subchapter 3.4.1 allowed the calculation of the number of SFH and MFH buildings that will be demolished and renovated in the period 2021—2046 per each cohort. These numbers are shown in Figure 12a and Figure 12b.

It may be seen that at the beginning of this period, the total number of buildings that will be demolished or renovated is approximately 2,500 buildings (2,652 for demolition and 2,415 for renovation activity). Then, the number of buildings that will be demolished by 2046 increases by 52% to 4,044, while the number of buildings that will be renovated increases only by 12% and reaches 2,693.

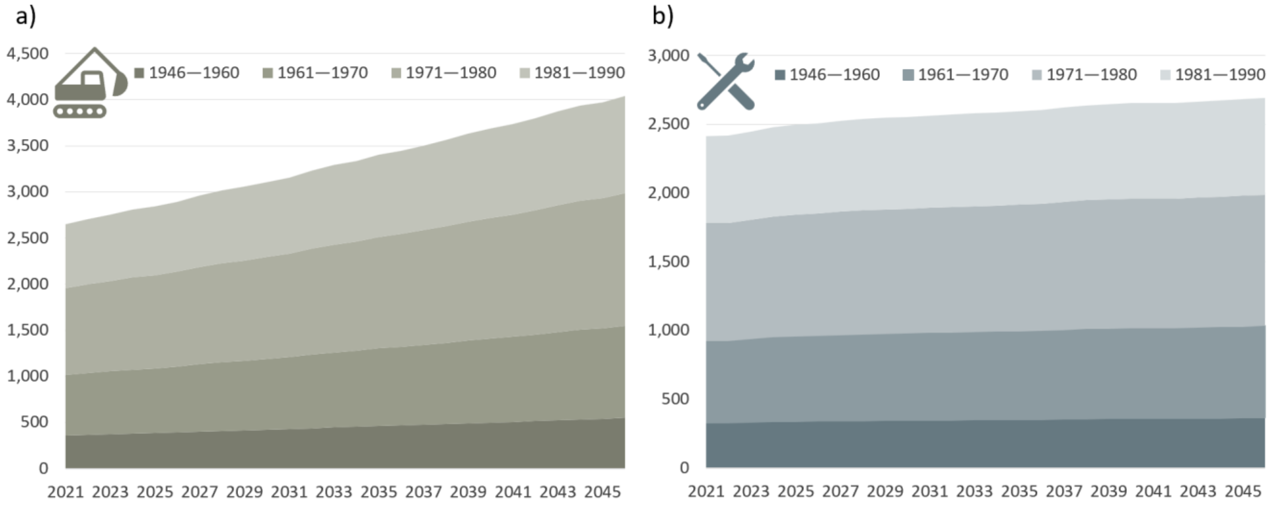


Figure 12 Estimated number of demolished (a) and renovated (b) buildings in Alternative 1

When it comes to individual cohorts, the highest share in the total number of buildings (more than 60%) belongs to buildings from the period 1961 to 1980, which will have between 51 and 85 years at the time of their renovation or demolition.

Based on the estimated number of buildings to be renovated and demolished and the material stock calculated in Subchapter 4.4, the quantity and the composition of CDW for Alternative 1 may be calculated. The total cumulative amount that may be generated from demolition and renovation activity for the period 2021—2046 is 40.2 million tonnes, i.e., if we look at the annual amounts, they steadily increase from 1.25 in 2021 to 1.88 million tonnes in 2046. As expected, due to the high content of clay and concrete-based material, the mineral fraction of CDW contributes the most to these quantities. For practical reasons, the mineral and non-mineral fractions are shown in two figures (Figure 13 and Figure 14).

Figure 13 illustrates the distribution of CDW mineral fractions' quantities and the composition in Alternative 1. The quantities ranged from 1.17 million tonnes in 2021 to 1.78 million tonnes in 2046. The clay and concrete-based materials account for approximately 67% of the total quantity of the mineral CDW fractions. The clay-based waste stream that includes brick, block waste, tiles and ceramics with the range of 0.53—0.81 million tonnes is the major contributor to the total quantity of mineral CDW. It is followed by the concrete-based waste stream that ranges from 0.3 to 0.45 million tonnes. The other waste streams belong to the plaster (0.2—0.3 million tonnes) and the stone-based (0.13—0.2 million tonnes) waste streams, but their quantities are not as significant as is the case with the clay and the concrete-based waste streams.

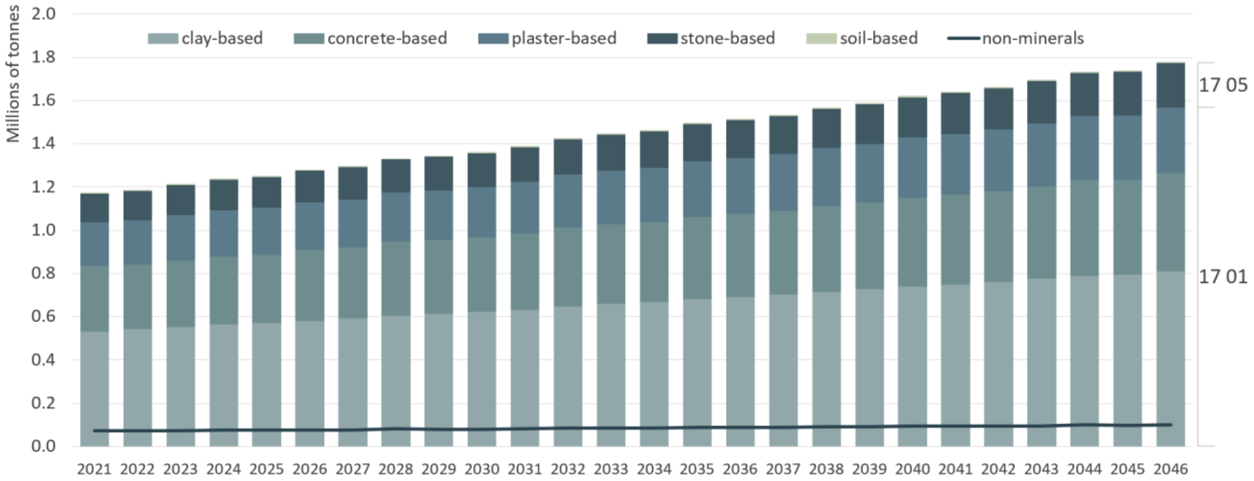


Figure 13 Quantity and composition of mineral CDW (17 01 and 17 05) from renovation and demolition activity in Alternative 1

To enable the comparison between the mineral and non-mineral CDW fractions, the quantity of non-minerals during this period is shown with a line, while their composition is illustrated in Figure 14.

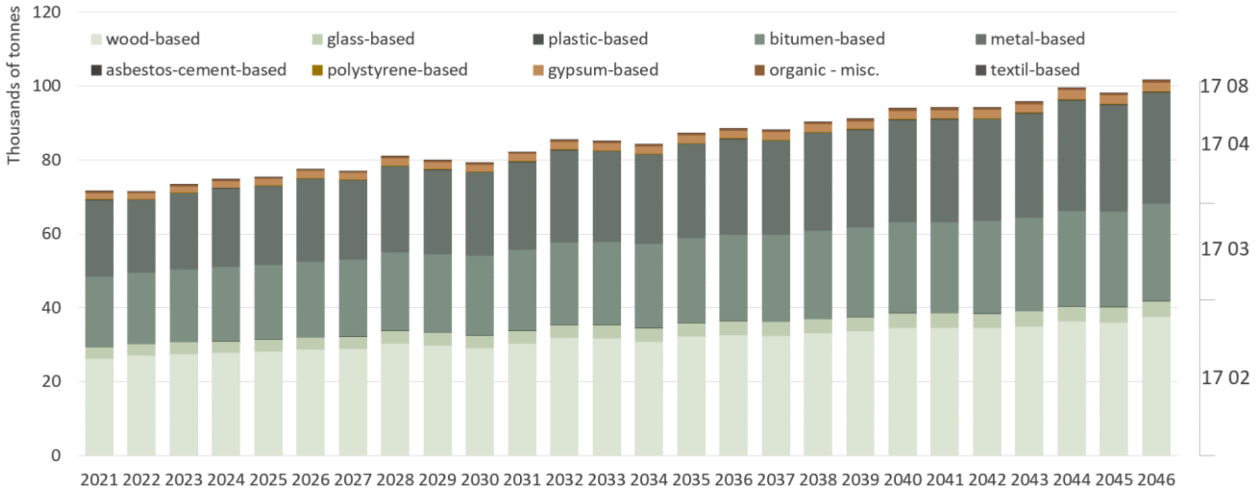


Figure 14 Quantity and composition of non-mineral CDW from renovation and demolition activity in Alternative 1

The major contributors to the non-mineral CDW fractions are wood, bitumen and metal-based materials. In the period 2021—2046, the quantity of wood-based material may go from 26.3 to 37.6 thousand tonnes, while the metal and the bitumen-based waste streams may range from 20.7 to 30.1 thousand tonnes and 19.2 to 26.3 thousand tonnes, respectively.

On the other hand, minor contributors to the quantity of non-mineral CDW fractions are glass, gypsum, organic, polystyrene and plastic-based materials. The glass, gypsum and organic-based waste streams may range from 3 to 4.1 thousand tonnes, 1.67 to 2.4 thousand tonnes and 0.5 to 0.64 thousand tonnes, respectively, while the polystyrene and the plastic waste streams may range from 0.1 to 0.2 thousand tonnes.

Although not visible in Figure 14 due to their small quantities, the asbestos and the textile-based waste streams with a range of 0.06 to 0.1 thousand tonnes and 0.01 thousand tonnes complete the non-mineral CDW fraction.

4.5.2 Alternative 2 – Achieving the EU 28 (2018) Average

While the number of buildings to be demolished remained in the same range (2,652—4,044) in Alternative 2 (Figure 15a), the number of buildings to be renovated increased by 73%, from 2,415 to 4,168 buildings (Figure 15b).

Similar to Alternative 1, the buildings that belong to cohorts 1961—1970 and 1971—1980 remained the highest contributors to the number of buildings to be renovated in the following years. The only notable difference between the two alternatives is in the number of buildings from cohort 1981—1990 to be renovated. The increase in these numbers in Alternative 2 is more than 72% in contrast to 11% in Alternative 1.

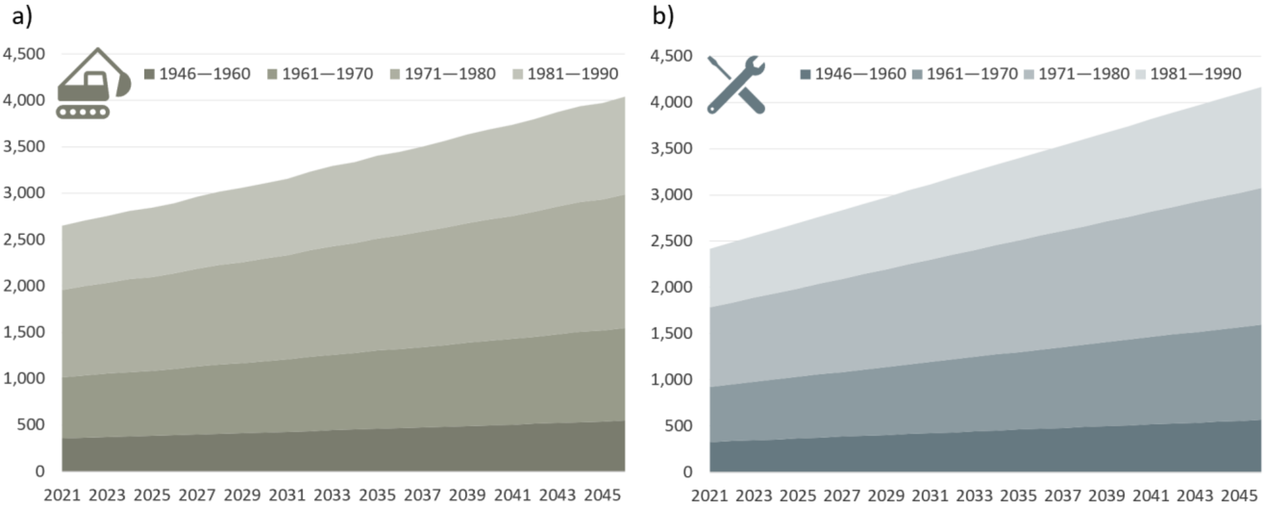


Figure 15 Estimated number of demolished (a) and renovated (b) buildings in Alternative 2

In Alternative 2, the total quantity of waste from renovation and demolition activity accumulates to 40.4 million tonnes. Similar to Alternative 1, the following two figures show the amount and the composition of mineral (Figure 16) and non-mineral (Figure 17) CDW fractions in Alternative 2. The quantities of mineral CDW fractions in Alternative 2 remained in the same range (1.17—1.79 million tonnes), while the total quantities of CDW marginally increased in 2046 from 1.88 to 1.9 million tonnes. This is mostly because the number of buildings that, when demolished, may yield significant quantities of mineral CDW fractions remained the same.

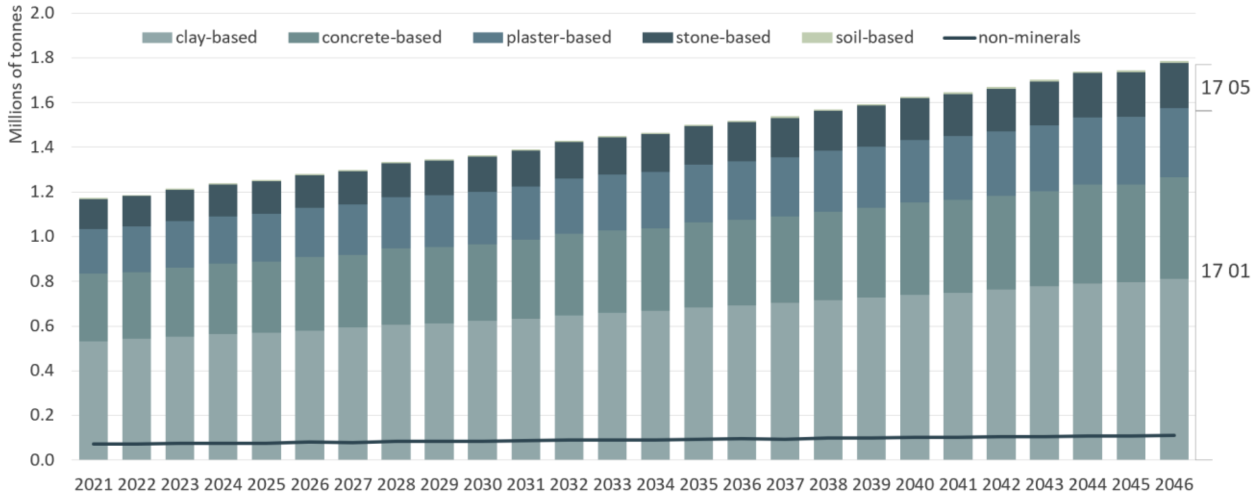


Figure 16 Quantity and composition of mineral CDW (17 01 and 17 05) from renovation and demolition activity in Alternative 2

Consistently, clay and concrete-based materials remained the major contributors with a share of 67% in the total quantity of mineral CDW fractions (Figure 16). In Alternative 2, the quantity of the clay, concrete-and stone-based waste streams kept their Alternative 1 ranges of 0.53—0.81 million tonnes, 0.3 to 0.45 million tonnes and 0.13—0.2 million tonnes, respectively. However, the rest of the mineral fraction waste stream, the plaster-based waste, increased its quantity to 0.31 million tonnes in 2046.

On the other hand, due to excessive renovation activity, the non-mineral CDW fraction experienced a significant change in quantity and composition. As shown in Figure 17, the total quantity of non-mineral CDW fractions in 2046 increased by 10%, from 101.6 thousand tonnes in Alternative 1 to 111.7 thousand tonnes in Alternative 2.

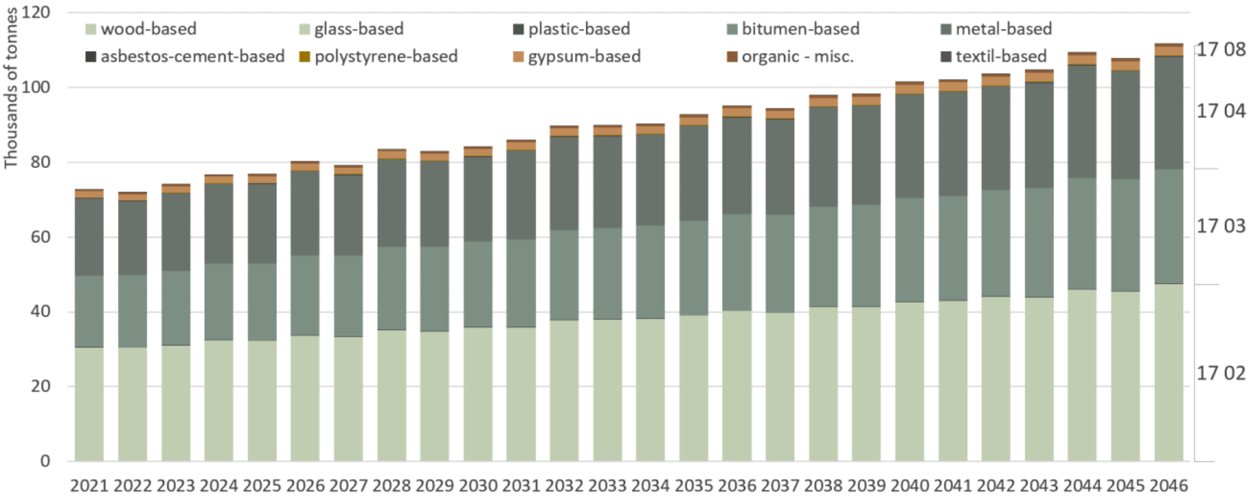


Figure 17 Quantity and composition of non-mineral CDW from renovation and demolition activity in Alternative 2

Wood, bitumen and metal-based materials remained the major contributors with a slight increase in absolute quantities in comparison with Alternative 2. For instance, in 2046, the quantity of the wood-based waste stream may amount to 42.6 thousand tonnes, while the bitumen and the metal-based waste streams may reach 30.6 and 30.2 thousand tonnes, respectively. All other waste streams have the same quantities as in Alternative 1 except for glass and organic-based waste, which slightly increased their quantities to 4.8 and 0.73 thousand tonnes, respectively.

4.5.3 Alternative 3 – On the Road to Circular Economy

Alternative 3 is characterised by significant renovation activity. As seen in Figure 18, the number of buildings to be demolished remained the same as in the previous two alternatives, while the number of buildings to be renovated in 2046 in Alternative 1 (2,693) tripled in Alternative 3 (8,338). The figure also shows that all four cohorts may experience a rise in the number of buildings. However, growth in cohorts 1961—1970, 1971—1980 and 1981—1990 are three times higher than in 1946—1960.

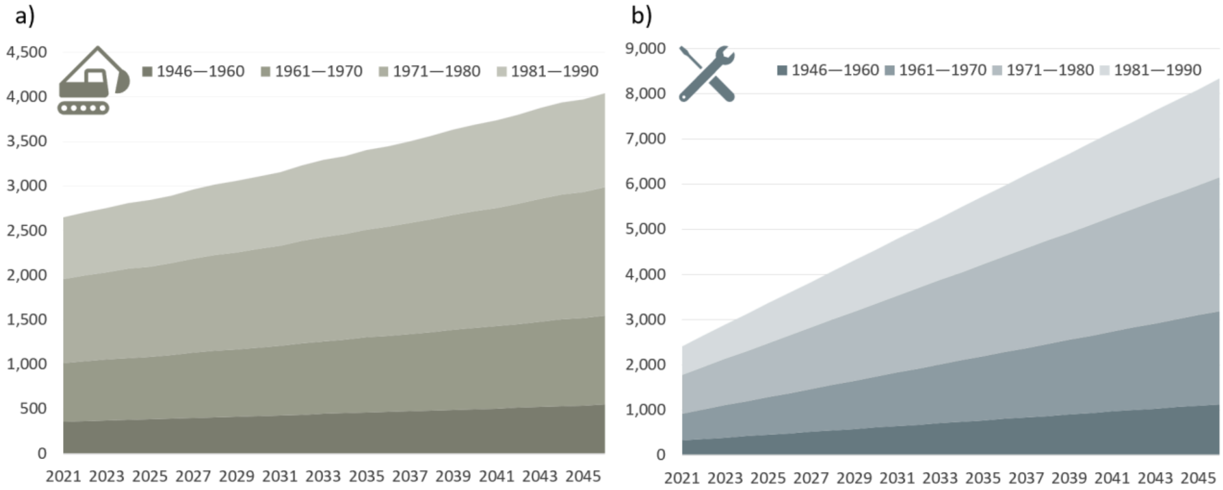


Figure 18 Estimated number of demolished (a) and renovated (b) buildings in Alternative 3

Similarly to Alternative 2, no significant growth is expected in the total quantity of CDW in Alternative 3. The cumulative quantity in this alternative increased from 1.6% and 2.2% in comparison with Alternatives 2 and 1. This annual quantity in this alternative may range from 1.25 to 1.95 million tonnes, which is an increase of just 50 thousand tonnes in comparison to Alternative 2 or 67 thousand tonnes in comparison to Alternative 1. No significant changes may be expected in the mineral CDW fractions as well. According to Figure 19, the range of mineral waste streams remained between 1.17 and 1.8 million tonnes. All mineral waste streams maintained the quantities from the two previous alternatives; however, the share of the mineral CDW major contributor, clay-based material, is expected to decrease to 65% in 2046.

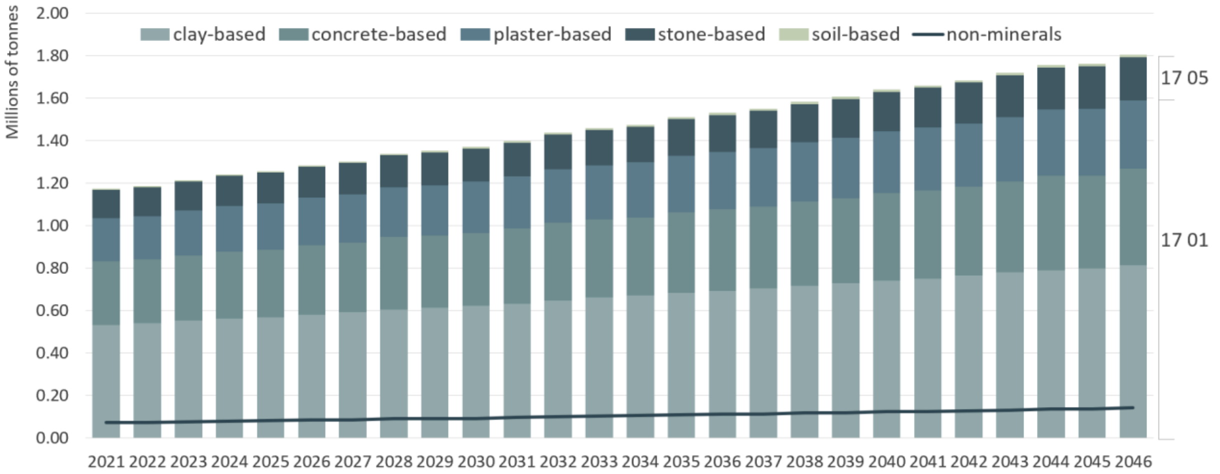


Figure 19 Quantity and composition of mineral CDW (17 01 and 17 05) from renovation and demolition activity in Alternative 3

As may be expected, more than a tripled number of buildings to be renovated led to a significant increase in the quantity of non-mineral CDW fractions. Figure 20 shows that this increase may reach 142.4 thousand tonnes in 2046, which is an increase of 27 and 40% from Alternative 2 and Alternative 1, respectively.

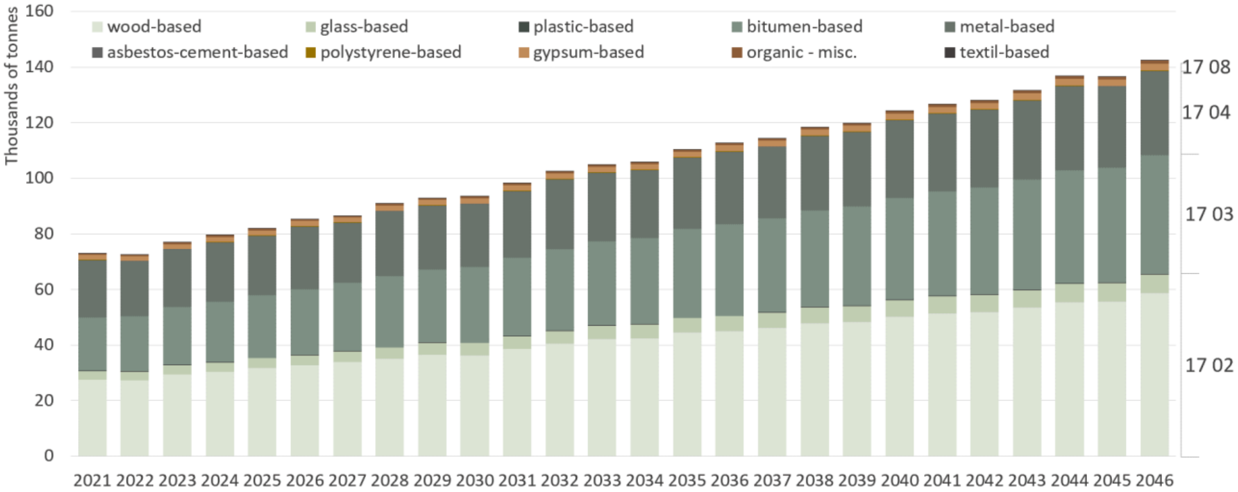


Figure 20 Quantity and composition of non-mineral CDW from renovation and demolition activity in Alternative 3

Except for asbestos, polystyrene, gypsum and textile-based waste streams, all other streams may experience an increase, particularly for the wood, the bitumen and the metal-based streams. For instance, in Alternative 3, wood, bitumen and metal-based waste may increase their quantities to 58.7, 42.6 and 30.4 thousand tonnes, respectively. The remaining waste streams, glass, plastic and organic-based, may experience a minor increase in the range of 0.07 to 2 thousand tonnes.

4.6 Sustainability Assessment of CDW Management Alternatives

The sustainability assessment presented in the following subchapters was based on quantities and the composition given in the previous subchapter and the methodology for the evaluation of sustainability performance described in Subchapter 3.4.3.

For each of the CDW management alternatives, a total of 16 indicators under all sustainability aspects, both in the category of costs and revenues (alternative outflows and inflows) were financially and economically analysed and calculated. This analysis differed according to the type of prices that were used. The financial analysis used market prices, while these prices were converted into shadow prices for the economic analysis. Upon evaluation, the indicators were used as criteria and sub-criteria in the MCDM Analysis that was conducted to evaluate the optimal CDW management alternative.

In addition to this, three more indicators in the financial and economic analyses were estimated for each of the alternatives. These were the net present value, the rate of return and the b/c ratio. These indicators were analysed and calculated as a measure of if and to what extent the investment in each alternative may benefit the owner and the society.

4.6.1 Alternative 1 – Business as Usual

The calculation of sustainability indicators in this alternative was performed under the assumptions of the current CDW management practice described in Subchapter 4.2.3. These assumptions included disposal at sanitary and non-sanitary landfills as the preferable options for almost all waste streams and high rates of illegal dumping. This alternative predicts that the same practices will be followed until 2046. The recovery rates and treatment routes of each particular stream are given in Table 21. The mixed CDW is a portion of all other waste streams that will be generated during the demolition activity, and that will not be treated but disposed of at landfills or illegally dumped.

Table 21 Range of recovery rates for different CDW streams in Alternative 1
(for the period 2021—2046, in percentages, zero values are not shown)

Categories	RU	RC	DC	ER	D	ID
Metal-based		63—63			17—17	20—20
Mineral-based			65—65		15—15	20—20
Mixed CDW					80—80	20—20

The calculation of economic indicators comprised the calculation of treatment costs and revenues. The treatment costs of the above waste streams included capital expenditures (CAPEX), operational expenditures (OPEX) and clearance and decontamination costs (CDEX). As there are no other treatment facilities, CAPEX was calculated only for the 16 regional sanitary landfills that, in accordance with the Waste Management Program, need to be built by 2031 (Government of the Republic of Serbia 2022b). However, this alternative prolongs this period to 2035 due to the assumption that the current pace of the construction of regional sanitary landfills will continue.

The OPEX included costs for metal recycling and the operation of landfills. As most of the local operators purchase metals and iron scrap from other companies or individuals, the metal recycling costs are presented with the average buying price of 42.5 euros per tonne. The landfill operation costs were set at 7 euros per tonne, which is an average value for both sanitary and non-sanitary landfills in Serbia. These costs gradually increase from 2036, when all regional landfills are constructed, to reach 18.3 euros per tonne, which correspond to the operating costs set in the Waste Management Program (Government of the Republic of Serbia 2022b).

The clearance and decontamination costs were also taken from the Waste Management Program as this program foresees that by 2031 80% of non-sanitary landfills will be closed. This alternative also prolonged this timeline to reflect the current pace of closing of non-sanitary landfills and illegal dumping areas.

On the other hand, revenues in this alternative may be generated through sales of the recovered materials, in this case, iron scraps and metal and disposal gate fees. The unit price for a tonne of metal waste was set at 127.6 euros, while the disposal gate fee starts at 9.4 euros per tonne, which is the minimum gate fee for mineral CDW disposal at regional sanitary landfills in Serbia.

Following the CBA guidelines, the social indicators were calculated in two ways: conversion of the market to shadow prices through the willingness-to-pay approach, standard conversion factors or shadow wages or through estimation of the externalities. Specifically, the standard conversion factors for materials and shadow wages for skilled and non-skilled workers were calculated to be 0.99, 0.62 and 0.56. Additionally, the equipment and land conversion factors were set at 1 and 1.3, respectively. These factors were then used to calculate conversion factors for each of the economic categories and their respective market price. Depending on the share of material, labour, equipment or land in the individual cost categories, the conversion factors for CAPEX and the residual value were calculated at 82 and 84% for CDEX, while the OPEX and RWEX market prices were converted into shadow prices with the factor of 87%.

The avoided landfill space and public discomfort due to landfills' presence were also calculated for this alternative. For this calculation, it was estimated that a tonne of waste occupies 0.07

square meters of surface area, and the price of land was set to 0.66 euros per square meter. Public discomfort due to landfill presence, as mentioned in Subchapter 3.4.3, was calculated with the Hedonic price method suggested by the CBA guidelines. As suggested in these guidelines, a decrease in property value of 5% was adopted for all properties within the range of 2 kilometres from sanitary and non-sanitary landfills.

Details on the calculated values for all economic and social indicators are provided in Table 22. For simplicity, these values are given as a range of annual values from 2021 to 2046. Since this alternative does not include the implementation of a carbon tax, the environmental indicator is missing from the table as there was no way to monetise it.

Table 22 Sustainability indicators' annual values and their timeline in Alternative 1
(in million euros, for the period 2021—2046)

Economic indicators				Social indicators			
SI	**Category and treatment**		**Values**	**SI**	**Category and treatment**		**Values**
E1	Capital expenditures	D	3.19 (up to 2035)	S1	Social capital expenditures	D	2.61 (up to 2035)
E2	Operational expenditures	RC	0.0006—0.0008	S2	Social operational expenditures	RC	0.0005—0.0007
		D	1.57—6.09			D	1.37—5.30
E4	Clearance and decontamination expenditures	D	1.23	S4	Social clearance and decontamination expenditures	D	1.03
		ID	0.30			ID	0.25
E5	Sales of recovered materials	RC	1.58—2.42	S5	Public discomfort due to landfill presence	D	(-1.23)—(-0.67)
E7	Treatment revenues	D	2.1—5.51	S6	Arable land consumption	D	0.04—0.05

SI – Sustainability indicator code; RC – Recycling; D – Disposal; ID – Illegal Dumping.

Finally, based on the above sustainability indicators and the annual balance between the total revenues and costs, three additional indicators were calculated (NPV, RR and B/C). Figure 21a shows this cash flow when this difference was calculated at market prices – the financial cash flow, while Figure 21b shows when this difference is calculated at shadow prices – the economic cash flow. The figures also indicate the moment in time when the cash flow balance equals zero, i.e., the moment when the initial investments in the alternative are returned.

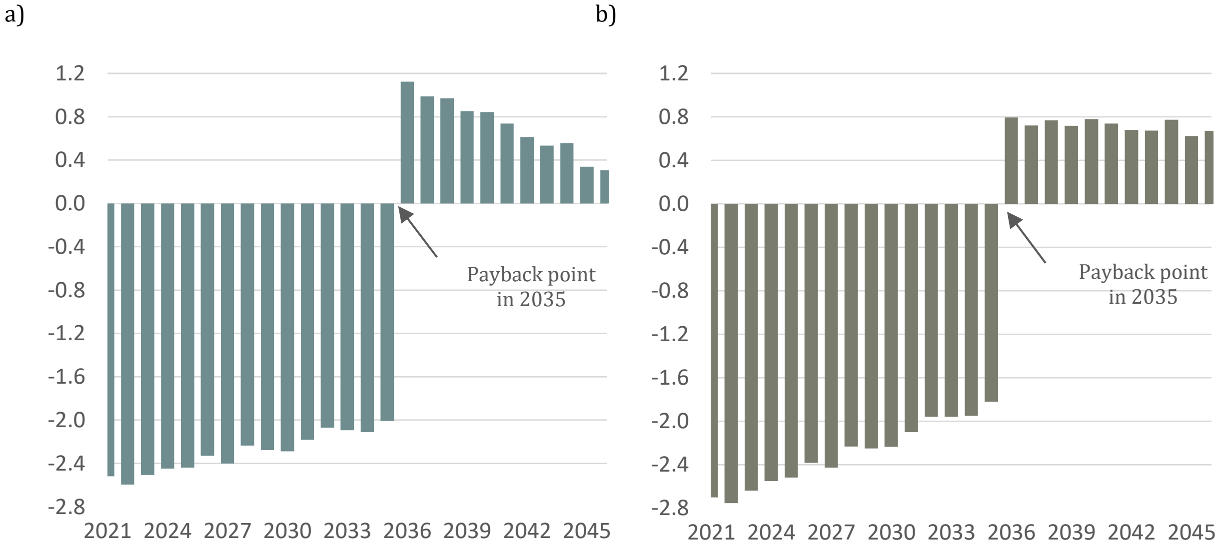


Figure 21 Financial (a) and economic (b) cash flow in Alternative 1 (in million euros)

As expected, Alternative 1 starts with a negative cash balance, meaning that in both analyses, the total costs exceed revenues. This happens until 2036, when the alternative starts to generate more revenues. The cash flow balances are almost equal in both analyses, i.e., the lowest cash flow balance in the financial analysis is -2.6 in contrast to -2.8 million euros in the economic analysis. Similarly, the highest cash flow balance in the financial analysis is 1.1 million euros, while the highest value of cash flow balance in the economic analysis is 0.8 million euros.

Discounting of these annual cash flow balances at 4 and 7% discount rates returns the FNPV and the ENPV at -22.3 and -19.7 million euros. These values will be equal to zero at the rates -12% (FRR) and -10.8% (ERR). Negative values of all four indicators imply that the investment in current CDW management improvement only through the construction of regional sanitary landfills will be neither profitable nor beneficial to society. And finally, the B/C ratio in both cases of less than one (0.8) suggests that generated benefits are lower than the costs incurred in Alternative 1.

4.6.2 Alternative 2 – Achieving the EU 28 (2018) Average

Sustainability indicators in this alternative were evaluated following the assumption that by the end of 2046, the CDW management practice will reach the EU average values of recovery rates and CDW management practices. Therefore, in line with the Waste Management Program, this alternative predicts investments in incinerators (3) and mobile recycling facilities (26) aside from the construction of new sanitary landfills. When it comes to the recycling technology, this alternative predicts the use of basic recycling technology for a mineral fraction of CDW, which involve wet processing and which, according to (C. Zhang et al. 2019), may yield approximately 52.9% of CRCA, 42.5% of FRCA and 2.6% of sludge. Therefore, instead of the EU average for recycling, backfilling, and disposal of 66, 21 and 13%, respectively, the alternative predicts that by 2046 Serbia should achieve 33% of high-quality recycling and 50% of low-quality recycling for backfilling and 12% of disposal.

In addition to the metal and the mineral CDW waste stream, this alternative predicts the recycling of glass, recycling and incineration of wood-based streams and disposal of hazardous CDW waste streams. A range of recycling rates for the mineral CDW and other waste streams in the entire time horizon are given in Table 23. These rates are set with respect to the share of individual construction products and materials and their recovery potential when they become waste.

Table 23 Range of recovery rates for different CDW streams in Alternative 2 - Achieving the EU 28 (2018) Average

(for the period 2021—2046, in percentages, zero values are not shown)

Categories	RU	RC	DC	ER	D	ID
Glass-based		0—65			80—30	20—5
Hazardous CDW					80—95	20—5
Mineral-based		0—33	65—50		15—12	20—5
Metal-based		63—65			17—30	20—5
Wood-based			0—15	0—50	80—30	20—5
Mixed CDW					80—95	20—20

As mentioned previously, the capital investment costs in this alternative are comprised of investments in regional sanitary landfills, incineration and mobile recycling facilities. Capital expenditures for one recycling facility and the necessary infrastructure were taken from the Waste Management Program. It was assumed that a basic mobile recycling facility consists of a vibrating feeder, two conveyor belts, magnets, a crusher and a vibrating screen. Only one mobile facility will be assembled per year in the first four years, and this number will double in the following eleven years.

The operational expenditure for one recycling facility included the costs of labour, maintenance, diesel and electricity consumption, the cost of disassembling, transport from one location to another and assembling and treatment of sludge. It was assumed that six workers (four skilled and two unskilled workers) are engaged in the recycling process, with an average monthly wage in the waste sector in Serbia in 2020 of 641.2 euros. The diesel and electricity consumption of a mobile recycling plant were adopted from (Jingru Li et al. 2020) study at 0.45 litre and 1.72 kWh per tonne of waste. The alternative predicts that all recycling facilities will move eight times within the corresponding region. The moving costs were adopted from the analysis made by (C. Zhang et al. 2019). Sludge that will be generated through the process will be transported to the landfill.

The replacement work costs for mobile recycling facilities included a periodic change of major components at the end of their service lives. The duration of the service life, as well as the costs of each component, was adopted from the study by (Di Maria, Eyckmans, and Van Acker 2018).

When it comes to energy recovery, it is important to note that the capital costs, as well as the operational costs, cost of equipment replacement works and clearance and decontamination for the incineration facility, included only a share of the entire costs as incinerators will be primarily constructed and used for the municipal solid waste. These costs depend on the amount of waste that will be processed annually, and the costs were based on the findings of the study by (Tsilemou and Panagiotakopoulos 2006). In terms of the construction timeline, the assumption was that all three incinerators in Belgrade, Niš and Novi Sad would be constructed in the first three years.

The capital costs of disposal and clearance and decontamination of non-sanitary landfills and illegal dumping areas remained the same as in Alternative 1, but the time horizon has been speeded up by 50%. For that reason, the operational costs slightly changed their annual value. In contrast to Alternative 1, a gradual increase in costs to reach 18.3 euros per tonne started immediately instead of in 2036.

The revenues in this alternative included earnings from the sales of recovered metal, aggregate (CRCA and FRCA), glass and wood and treatment, i.e., the gate fees for energy recovery and recycling. Unit prices of aggregates were set at 8.11 and 3.04 euros per tonne, which are approximately four times lower than the unit prices of primary raw materials. Glass recyclables and wood chips were set at 45 and 50 euros per tonne. The gate fee for energy recovery was based on the willingness-to-pay approach, and it was calculated in the previous study by the author of this thesis (Nikolic, Mikic, and Naunovic 2017). The gate fee for disposal remained in the same range of 9.4—16.5 euros per tonne as in Alternative 1. However, this alternative predicts the implementation of a landfill tax to divert CDW from landfills from 2031. This tax will then gradually increase up to 11 euros per tonne by the end of 2046; therefore, the total revenues from CDW disposal will reach 27.5 euros per tonne in 2046.

The residual values in 2046 were calculated only for the recycling and energy recovery facilities, with a depreciation rate of 15% for recycling facilities and 10% for incineration, as suggested by the Rulebook for determining depreciation (Tax Administration of the Republic of Serbia 2019).

All input parameters for the calculation of the social indicators in this alternative, especially conversion factors, remained the same as in Alternative 1. As expected, due to a decrease in the amount of waste transported to landfills and an increase in the number of closed non-sanitary landfills and illegal dumping areas, the major changes in social indicators in this alternative were noted in public discomfort due to landfill presence and the land consumption indicator.

Additionally, the introduction of the carbon tax in 2032 allowed the calculation and monetisation of the environmental indicator and avoided GHG emissions. This indicator was calculated as the difference between the generated and avoided GHG emissions, and it consisted of three components: GHG emission through material recovery, energy recovery and GHG emission induced during waste treatment processes. The values of GHG emissions used in these calculations were adopted from the literature and are provided in Table 24.

Table 24 Values of generated and avoided GHG emissions in management alternatives per one tonne of CDW

Category of GHG emission (+) generated; (-) avoided	Value (tCO$_2$eq)	Source
Secondary material recovery (-)		
Recovered bricks	0.138	(Weiler, Harter, and Eicker 2017)
Recycled aggregates CRCA	0.0018	(Marinković et al. 2017)
Recycled metal	2.05	(Van Ruijven et al. 2016)
Recycled glass	0.57	(Schmitz et al. 2011)
Recycled wood	0.168	(André Coelho and de Brito 2013a)
Energy recovery (-)		
Electricity	0.799	(Fruergaard, Astrup, and Ekvall 2009)
Heat	0.3978	(Fruergaard, Astrup, and Ekvall 2009)
Treatment process (transport excluded)		
Recycling in a mobile plant (-)	0.0515	(C. Zhang et al. 2019)
Recycling in a mobile ADR plant (-)	0.0424	(C. Zhang et al. 2019)
Energy recovery (-)	0.47—0.55	(European Commission 2014a)
Disposal (+)	0.67—0.74	(European Commission 2014a)
Illegal dumping (+)	0.67	(European Commission 2014a)

Similar to Alternative 1, details on the calculation of all sustainability indicators for Alternative 2 are provided in Table 25. In contrast to the ten indicators in Alternative 1, this alternative has six more indicators since two more treatments (recycling and incineration) of CDW were included. When it comes to incineration, it has to be noted that the replacement of the equipment in the three incinerators was foreseen in 2039 for the facility in Belgrade and 2040 for the facilities in Novi Sad and Niš. These works will last for the entire year, during which the incineration of waste will be halted.

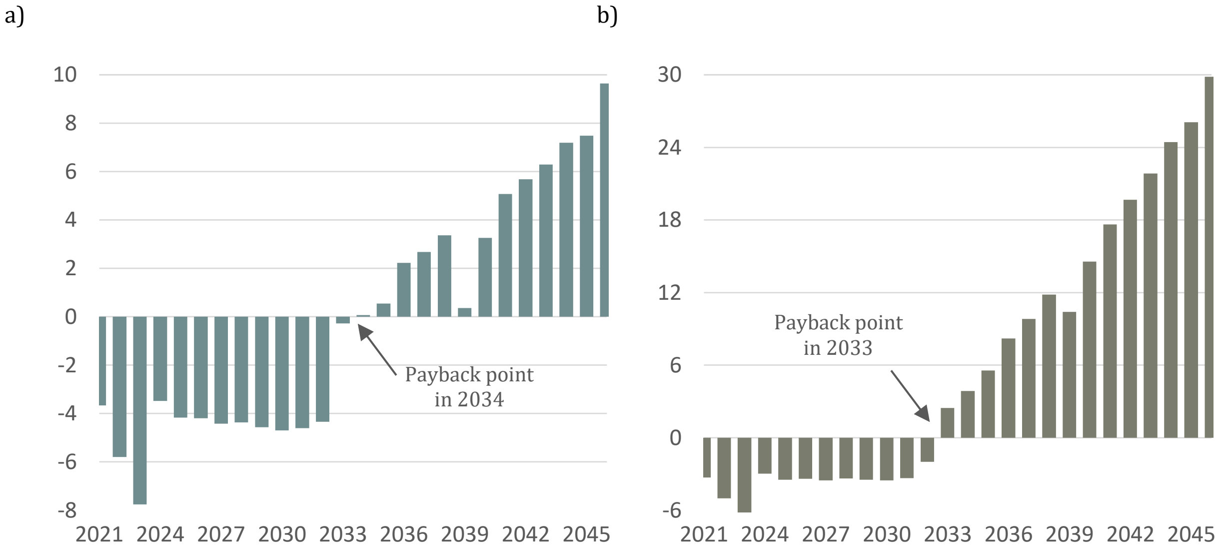
Table 25 Sustainability indicators' annual values and their timeline in Alternative 2
(in million euros, for the period 2021—2046)

SI	Category and treatment		Values	SI	Category and treatment		Values
	Economic indicators (E)				Social indicators (S)		
E1	Capital expenditures	RC	0.58 (2021—2024) 1.17 (2025—2035)	S1	Social capital expenditures	RC	0.48 (2021—2024) 0.95 (2025—2035)
		ER	0.48 (2021), 2.39 (2022), 4.30 (2023)			ER	0.39 (2021), 1.95 (2022), 3.52 (2023)
		D	3.99 (up to 2032)			D	3.26 (up to 2035)
E2	Operational expenditures	RC	0.84—4.33	S2	Social operational expenditures	RC	0.73—3.77
		ER	0.03—1.0			ER	0.03—0.87
		D	1.58—5.06			D	1.37—4.40

E3	Replacement costs	RC ER	0.005—0.21 2.55 (2039), 0.94 (2040)	S3	Social replacement costs	RC ER	0.004-0.18 2.22 (2039), 0.82 (2040)
E4	Clearance and decontamination expenditures	ER D ID	0.28 (2046) 1.84 0.44	S4	Social clearance and decontamination expenditures	ER D ID	0.23 (2046) 1.54 0.37
E5	Sales of recovered materials	RC DC	1.66—7.40 2.31—3.02	S5	Public discomfort due to landfill presence	D	(-1.23)—(-0.33)
E6	Sales of recovered energy	ER	0.07—2.28	S6	Arable land consumption	D	0.04—0.07
E7	Treatment revenues	ER D	(2024) 0.03—0.91 2.11—7.62	S7	Social residual values	RC ER	0.92 0.27
E8	Residual value	RC ER	1.12 (in 2046) 0.33 (in 2046)		**Environmental indicator (EN1)**		
				EN1	Avoided GHG emission	RC ER	1.02—20.33 (from 2032)

SI – Sustainability indicator code; RC – Recycling; ER – Energy recovery; DC – Downcycling; D – Disposal; ID – Illegal dumping.

Based on the above values, the total costs and revenues were calculated for Alternative 2. Similar to Alternative 1, their difference based on market prices is shown in Figure 22a, while their difference based on shadow prices is shown in Figure 22b. The figures indicated that the initial investment in Alternative 2 will be returned in 2034 when looked at from the waste operator's point of view or 2033 from the society's point of view.



Payback point in 2034

Payback point in 2033

Figure 22 Financial (a) and economic (b) cash flow in Alternative 2 (in million euros)

The negative values of the financial net present value and the rate of return of -21.8 million euros and -0.27%, respectively, and the B/C ratio of less than 1 (0.99) suggest that this alternative is neither financially sustainable nor profitable and hence the project within this alternative is a candidate for external financing through capital grants or loans. Moreover, the eventual loan or grant will be used for high social returns as the positive values of the economic net present value of 18.5 million euros and the rate of return of 10.3%, implying that this alternative is economically viable. In addition, the benefits of the alternative are more than 1.6 times higher than the initial costs.

Both the costs and revenues in this alternative are significantly higher than in Alternative 1, and this is also reflected in the cash flow balances. The lowest cash balances are -7.7 and -6.5 million euros in the financial and economic analysis, respectively, while the economic analysis tripled its cash flow balance to 29.8 million euros at the end of 2046. The changing point from negative to positive cash flow balance is different. The former, from the waste operator's perspective, will occur in 2034, while the latter, from the social perspective, will happen a year before.

4.6.3 Alternative 3 – On the Road to Circular Economy

The main assumption behind this alternative is that by the end of 2046, the CDW management practices should adopt and implement circular economy principles on a large scale. Therefore, the alternative predicts high shares of selective demolition, reusing and recycling rates rate of 14 and 86% (60% of CRCA and 26% of FRCA). The latter will be possible by applying advanced recycling technologies that include higher valorisation of CRCA and no by-products. In addition, the alternative predicts that illegal dumping will be eliminated and that there will be no disposal of several waste streams, such as glass, minerals, metal, wood and plastic-based streams. The range of these and the recovery rates of other waste streams in this alternative are provided in Table 26.

Table 26 Range of recovery rates for different CDW streams in Alternative 2 – On the Road to Circular Economy

(for the period 2021—2046, in percentages, zero values are not shown)

Waste streams	RU	RC	DC	ER	D	ID
Glass-based		0—100			80—0	20—0
Hazardous CDW				0—44	80—56	20—0
Mineral-based	0—14	0—60	65—26		15—0	20—0
Metal-based		63—100			17—0	20—0
Organic-based				0—49	80—51	20—0
Plastic-based				0—100	80—0	20—0
Wood-based			0—30	0—70	80—0	20—0
Mixed CDW					80—100	20—0

RU-reuse; RC – Recycling; ER – Energy recovery; DC – Downcycling; D – Disposal; ID – Illegal dumping.

The capital expenditures for most of the treatment facilities in this alternative are calculated in a similar manner as in Alternative 2 but within a different time horizon. The assumption was that the majority of investment in better CDW management practices would finish by 2031, which is in line with the current Waste Management Program. The exceptions are the costs for mobile recycling plants that in Alternative 3 have an addition of an Advance Dry Recovery (ADR) system: one mill, two conveyor belts, one rotor and one ADR knife. Due to this addition, the operational costs for this technology increased to 4.2 euros per tonne (Lotfi et al. 2017).

The operational costs for the reuse treatment were set at 31 euros per tonne of bricks. Similar to the operational costs of iron and metal scraps, the assumption was that in this alternative local waste operators would buy bricks from the demolition companies. Therefore, this price should include the costs of labour and equipment engaged in selective and traditional demolition, the costs of transport and overheads and a reasonable profit for the demolition company.

The increase in the capital and operational costs of the incineration facilities happened due to an increase in the amount of waste that will be incinerated; on average, the annual amount of waste for the incineration increased three times in this alternative. In contrast to Alternative 2, this alternative predicts that 44% of hazardous waste (mostly bitumen-based) will be sent to incineration. On the other hand, the total amount of capital costs for the construction of regional sanitary landfills and the amount of operational costs remained the same. However, the time horizon of this investment was changed to 2031, which corresponds to the Waste Management Program recommendations.

Similarly, the annual amount of clearance and decontamination costs were increased due to the time horizon change in the Waste Management Program, as this program predicts that by 2031 80% of non-sanitary landfills will be closed.

The revenues in this alternative were significantly higher, mostly due to high quantities of reused bricks and the high valorisation of quality RCA. The unit prices of recovered materials remained the same as in the previous alternative, while the price of bricks prepared for reuse was set at 55 euros per tonne. When it comes to gate fees, this alternative predicted the implementation of a recycling gate fee of 2 euros per tonne to cover a portion of the operational costs. The energy recovery gate fee remained the same, while the costs of disposal were increased due to an increase in the gate fees and the landfill tax.

In addition, both the social and environmental indicators significantly changed in Alternative 3. These changes were mostly affected by a decrease in the number of non-sanitary landfills and illegal dumping areas and the increase in the carbon tax, which in 2046 reached 33.6 euros per tonne of CO_2-eq. Similar to Alternatives 1 and 2, Table 27 indicates the range of annual values of these as well as the economic indicators in this alternative for the period 2021—2046.

Table 27 Sustainability indicators' annual values and their timeline in Alternative 2
(in million euros, for the period 2021—2046)

SI	Category and treatment		Values	SI	Category and treatment		Values
	Economic indicators (E)				**Social indicators (S)**		
E1	Capital expenditures	RC	1.38 (2021—2027) 2.07 (2025—2031)	S1	Social capital expenditures	RC	1.13 (2021—2027) 1.69 (2025—2031)
		ER	1.07 (2021), 5.34(2022), 9.61 (2023)			ER	0.87 (2021), 4.397(2022), 7.87 (2023)
		D	4.35(up to 2031)			D	3.56 (up to 2031)
E2	Operational expenditures	RU	0.21—7.78	S2	Social operational expenditures	RU	0.18—6.78
		RC	3.80—7.71			RC	3.31—6.71
		ER	0.05—2.14			ER	0.04—1.86
		D	0.7—3.28			D	0.61—2.85
E3	Replacement costs	RC	0.01—0.36	S3	Social replacement costs	RC	0.01-0.31
		ER	5.7 (2039), 2.11 (2040)			ER	4.96 (2039), 1.83 (2040)
E4	Clearance and decontamination expenditures	ER	0.63 (2046)	S4	Social clearance and decontamination expenditures	ER	0.52 (2046)
		D	4.24 (2033)			D	3.54 (2033)
		ID	0.85 (2033)			ID	0.71 (2033)
E5	Sales of recovered materials	RU	0.36—13.81	S5	Public discomfort due to landfill presence	D	(-1.23)—(-0.21)
		RC	1.66—7.40				
		DC	2.30—2.37				
E6	Sales of recovered energy	ER	0.15—6.59	S6	Arable land consumption	D	0.04—0.09
E7	Treatment revenues	RC	1.55—3.20	S7	Social residual values	RC	0.69
		ER	(2024) 0.06—2.63			ER	0.61
		D	1.06—0.92				
					Environmental indicator (EN1)		
E8	Residual value	RC	0.84 (in 2046)	EN1	Avoided GHG emission	RU	(2032) 2.25—51.40
		ER	0.75 (in 2046)			RC	
						ER	

SI – Sustainability indicator code; RU-reuse; RC – Recycling; ER – Energy recovery; DC – Downcycling; D – Disposal; ID – Illegal dumping.

The difference between the total costs and revenues and payback points for both analyses in Alternative 3 are shown in Figure 23a and 23b. While there is almost no difference between the negative cash flow balances, the difference in positive cash flow balances is significant. By the end of 2046, the economic analysis returns a value of 79.2 million euros in contrast to 26.1 million euros in the economic analysis. The negative cash flow balances are approximately the same, -18.8 million euros in the financial and -15.4 million euros in the economic analysis.

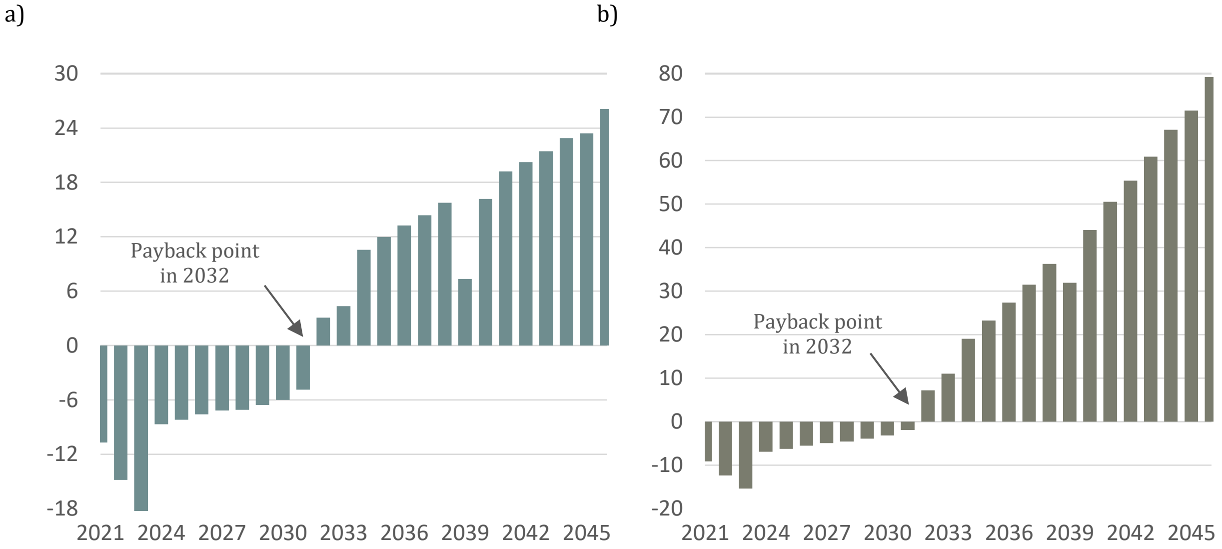


Figure 23 Financial (a) and economic (b) cash flow in Alternative 3 (in million euros)

Interestingly, the net present values in Alternative 3 in both analyses are positive 20 and 95.7 million euros for the financial and economic analysis, respectively. This implies that investments in better CDW management alternatives that adopt CE principles may benefit both the waste operator companies and society. Equivalently, the rates of return in both analyses (FRR is 5.4%, ERR is 13.9%) are higher than the discounted rates, while the B/C ratios exceed one. This means that from the waste operator's perspective, the benefits are 1.3 times higher than the costs, in contrast to the societal perspective, where benefits are 2.3 times higher than the costs.

Finally, the calculation of net present values in all three alternatives allowed the comparison of their values. Details of this comparison are provided in Table 28. The values of these three indicators imply that, guided by the current minimal costs of investment practice, waste operators might opt out of Alternative 1. However, this alternative will yield no benefits, neither to the waste operator nor to society. Also, the waste operators should not consider applying for EU grants or loans, as the EC is reluctant to spend any resources on projects that do not bring value to society.

Table 28 The comparison of financial and economic outputs of all alternatives

Alternative	Financial analysis (discount rate 4%)			Economic analysis (discount rate 7%)		
	NPV (10^6 euros)	RR (%)	B/C	NPV (10^6 euros)	RR (%)	B/C
1. Business as Usual (Total CAPEX 47.8 million euros)	-22.3	-12	0.8	-19.7	-10.8	0.8
2. Achieving the EU28 (2018) Average (Total CAPEX 57.4 million euros)	-21.8	-0.3	~1.0	18.52	10.3	1.6
3. On the Road to Circular Economy (Total CAPEX 81.8 million euros)	20	5.4	1.3	95.7	13.9	2.3

On the other hand, the increase in the initial investment of 20% may bring value to the society, but not to the waste operators. The revenues generated in this alternative will almost cover the costs incurred. To breach this financial gap, the waste operators in this alternative should consider the application for EU grants or other loans. And finally, despite the highest initial investment, Alternative 3 proves to be both financially and economically viable, but a raised socio-environmental perspective is a prerequisite for choosing this alternative.

However, alternatives' comparison based on only these three indicators might not be enough for making a sound judgment in the waste management sector. For that reason, the following subchapter will present the results of all indicators' comparison for the three sustainability pillars and under the four different decision-makers preferences (scenarios): economic, environmental, social and holistic.

4.7 MCDM Analysis of CDW Management Alternatives

4.7.1 Comparison of Sustainability Criteria in Different Decision-Making Scenarios

The first step in the MCDM Analysis was the definition of different decision-making scenarios and a comparison of all sustainability criteria per each individual decision-making scenario. The criteria were classified under the economic, environmental and social categories. The economic criteria included: capital, operational, replacement works and clearance and decontamination expenditures and revenues from recovered materials and energy, treatment and residual value. Avoided GHG emission was the environmental criterion that was compared. The social criteria that were considered and compared included the social adjustment of the economic criteria and public discomfort, and land degradation caused by landfills.

As mentioned before, it was assumed that there were four decision-making scenarios under which the criteria comparisons were made. Details of this comparison are provided in the tables Table 29—Table 32. A pairwise significance comparison of the criteria was performed, and criteria judgment matrices were formed for all decision-making scenarios.

The significance of the criteria was expressed on a scale from 1 to 9, determined by Saaty (1990), where odd values in a 1—9 range represent equally to extremely strong significance of one criterion over another, while even values serve to refine the judgment.

The criteria judgment matrices are symmetric along their diagonal; therefore, only the values above the diagonal are shown in Table 29—Table 32, while the values below the diagonal are their reciprocal values. It has to be noted that the consistency ratio (CR) was calculated for all the comparisons, and it ranged from 0.009 to 0.028, which is below 0.1. This implies that the comparisons of criteria are consistent and can be used further in the decision-making analysis.

The first scenario assumed that when faced with a choice of an optimal CDW Management alternative, the decision-makers were guided by the economic criteria. The pairwise comparison of all 16 criteria in this decision-making scenario is provided in Table 29.

As seen from the table, the highest priority was given to capital expenditures (E1), followed by operational expenditures (E2) and revenues from the treatment process (E7). Other economic criteria such as revenues from recovered materials (E5) and cost for replacement works cost (E3) are ranked as criteria with strong significance.

However, the lowest rank in this decision-making scenario belongs to the environmental and social criteria such as avoided GHG emissions (EN1) and public discomfort due to landfill presence (S5) and land consumption (S6).

Table 29 Pairwise significance comparison of sustainability criteria in the decision-making scenario with economic preferences

	E1	E2	E3	E4	E5	E6	E7	E8	EN1	S1	S2	S3	S4	S5	S6	S7
E1	1	3	5	7	5	7	3	7	9	7	7	7	7	9	9	7
E2		1	3	5	3	5	1	5	7	5	5	5	5	7	7	5
E3			1	3	1	3	1/3	3	5	3	3	3	3	5	5	3
E4				1	1/3	1	1/5	1	3	1	1	1	1	3	3	1
E5					1	3	1/3	3	5	3	3	3	3	5	5	3
E6						1	1/5	1	7	1	1	1	1	3	3	1
E7							1	5	7	5	5	5	5	7	7	5
E8								1	3	1	1	1	1	3	3	1
EN1									1	1/3	1/3	1/3	1/3	1	1	1/3
S1										1	1	1	1	3	3	1
S2											1	1	1	3	3	1
S3												1	1	3	3	1
S4													1	3	3	1
S5														1	1	1/3
S6															1	1/3
S7																1

E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

The second decision-making scenario gives the highest priority to the environmental criteria. Therefore, the avoided GHG emission has the highest intensity on the scale of significance. This criterion is followed by the social (S5 and S6) criteria that are related to public discomfort due to landfills and landfill avoidance.

All other criteria in this decision-making scenario have equal to moderate significance, except for criterion E5, treatment revenues that have strong significance. A detailed comparison of these criteria in the environmental decision-making scenario is given in Table 30.

Table 30 Pairwise significance comparison of sustainability criteria in the decision-making scenario with environmental preferences

	E1	E2	E3	E4	E5	E6	E7	E8	EN1	S1	S2	S3	S4	S5	S6	S7
E1	1	1	1	1/3	1/3	1/3	1/5	1	1/9	1/3	1/3	1/3	1/3	1/7	1/7	1/3
E2		1	1	1	1/3	1/3	1/5	1	1/9	1/3	1/3	1/3	1/3	1/7	1/7	1/3
E3			1	1/3	1/3	1/3	1/5	1	1/9	1/3	1/3	1/3	1/3	1/7	1/7	1/3
E4				1	1	1	1/3	3	1/7	1	1	1	1	1/7	1/7	1
E5					1	1	1/3	3	1/7	1	1	1	1	1/7	1/7	1
E6						1	1/3	3	1/7	1	1	1	1	1/7	1/7	1
E7							1	5	1/5	3	3	3	3	1/3	1/3	3
E8								1	1/9	1/3	1/3	1/3	1/3	1/7	1/7	1/3
EN1									1	5	5	5	5	3	3	5

S1	1	1	1	1	1/5	1/5	1
S2		1	1	1	1/5	1/5	1
S3			1	1	1/5	1/5	1
S4				1	1/5	1/5	1
S5					1	1	5
S6						1	5
S7							1

E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

The third decision-making scenario gives the highest significance to the criteria from the economic group, followed by the environmental criterion. As shown in Table 31, the highest ranks in the social criteria group belong to criteria S5 and S6, followed by criteria S1 and S2, capital and operational costs that are socially adjusted with shadow prices. Other socially adjusted costs and revenue (S3, S4 and S7) are given equal significance (strong) as the environmental criterion (EN1) in this decision-making scenario.

Table 31 Pairwise significance comparison of sustainability criteria in the decision-making scenario with social preferences

	E1	E2	E3	E4	E5	E6	E7	E8	EN1	S1	S2	S3	S4	S5	S6	S7
E1	1	3	3	3	3	3	1	3	1/3	1/5	1/5	1/3	1/3	1/7	1/7	1/3
E2		1	1	1	1	1	1/3	1	1/5	1/7	1/7	1/5	1/5	1/9	1/9	1/5
E3			1	1	1	1	1/3	1	1/5	1/7	1/7	1/5	1/5	1/9	1/9	1/5
E4				1	1	1	1/3	1	1/5	1/7	1/7	1/5	1/5	1/9	1/9	1/5
E5					1	1	1/3	1	1/5	1/7	1/7	1/5	1/5	1/9	1/9	1/5
E6						1	1/3	1	1/5	1/7	1/7	1/5	1/5	1/9	1/9	1/5
E7							1	3	1/3	1/5	1/5	1/3	1/3	1/7	1/7	1/3
E8								1	1/5	1/7	1/7	1/5	1/5	1/9	1/9	1/5
EN1									1	1/3	1/3	1	1	1/5	1/5	1
S1										1	1	3	3	1/3	1/3	3
S2											1	3	3	1/3	1/3	3
S3												1	1	1/5	1/5	1
S4													1	1/5	1/5	1
S5														1	1	5
S6															1	5
S7																1

E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

The fourth decision-making scenario assumes the holistic approach where all criteria have almost equal significance. In this scenario, it means that extreme significance is assigned to criteria from all three groups (E1, E2, E7, EN1, S5 and S6), followed by criteria with very strong significance (E4, E5, E6, S1 and S2) and finally the rest of the criteria has strong significance. More details on all criteria comparisons in this decision-making scenario are provided in Table 32.

Table 32 Pairwise significance comparison of sustainability criteria in the decision-making scenario with holistic preferences

	E1	E2	E3	E4	E5	E6	E7	E8	EN1	S1	S2	S3	S4	S5	S6	S7
E1	1	1	5	3	3	3	1	5	1	3	3	5	5	1	1	5
E2		1	5	3	3	3	1	5	1	3	3	5	5	1	1	5
E3			1	1/3	1/3	1/3	1/5	1	1/5	1/3	1/3	1	1	1/5	1/5	1
E4				1	1	1	1/3	3	1/3	1	1	3	3	1/3	1/3	3
E5					1	1	1/3	3	1/3	1	1	3	3	1/3	1/3	3
E6						1	1/3	3	1/3	1	1	3	3	1/3	1/3	3
E7							1	5	1	3	3	5	5	1	1	5
E8								1	1/5	1/3	1/3	1	1	1/5	1/5	1
EN1									1	3	3	5	5	1	1	5
S1										1	1	3	3	1/3	1/3	3
S2											1	3	3	1/3	1/3	3
S3												1	1	1/5	1/5	1
S4													1	1/5	1/5	1
S5														1	1	5
S6															1	5
S7																1

E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

Table 33 indicates the weight of each criterion in each individual decision-making scenario. As expected, the highest rank in the decision-making scenario with economic preferences had capital costs (0.24) followed by operational costs (0.14), while the lowest rank in this decision-making scenario belonged to avoided GHG emissions and public discomfort due to landfills presence and land consumption (0.01). On the other hand, avoided GHG emissions ranked the highest in the environmental decision-making scenario (0.23) in contrast to capital and operational costs and residual values, which ranked the lowest (0.02).

The highest rank in the social decision-making scenario had public discomfort due to landfill presence and land consumption (0.20), followed by social capital and operational expenditures, while operational, replacement works and clearance and decontamination costs ranked the lowest (0.01).

Table 33 Sustainability criteria weights in different decision-making scenarios

	Economic criteria								Socio-environmental criteria							
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EN1**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
ECO	0.24	0.14	0.08	0.03	0.08	0.04	0.14	0.03	0.01	0.03	0.03	0.03	0.03	0.01	0.01	0.03
ENVI	0.02	0.02	0.02	0.04	0.04	0.04	0.09	0.02	0.23	0.04	0.04	0.04	0.04	0.15	0.15	0.04

SOC	0.03	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.06	0.11	0.11	0.06	0.06	0.20	0.20	0.06
HOLI	0.11	0.11	0.02	0.05	0.05	0.05	0.11	0.02	0.11	0.05	0.05	0.02	0.02	0.11	0.11	0.02

ECO – Economic preferences in decision-making; ENVI – Environmental preferences in decision-making; SOC – Social preferences in decision-making; HOLY – Holistic preferences in decision-making; E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

On the other hand, in the holistic decision-making scenario where equal significance is assigned to all three groups of criteria, the highest rank had five criteria in total: capital and operational costs, treatment revenues, avoided GHG emissions and public discomfort due to landfills presence and land consumption. However, the weight of all these criteria is 0.11, which is significantly less than the weights in the previous scenarios. On the opposite side, the lowest weight (0.02) of the criteria in this scenario belonged to replacement works costs, residual values, social replacement works and social clearance and decontamination costs and social residual values.

4.7.2 Comparison of CDW Management Alternatives

The next step in the MCDM Analysis was the comparison of different CDW management alternatives. To facilitate this, a calculation of economic and several social criteria values for different alternatives was based on previous calculations related to sustainability assessment that was presented in Subchapter 4.6. These calculations needed to be adapted in a way so that the annual values of each criterion were discounted at appropriate discount rates (4% for economic and 7% for environmental and social criteria) to obtain the net present value of each criterion. On the other hand, avoided GHG emissions were expressed and compared in tonnes of avoided CO_2, while avoided landfill space (land consumption) was expressed and compared in m^2.

Table 34 indicates the comparison of these alternatives with respect to each criterion. Due to simplicity and the fact that there are only three alternatives, the first two rows show values of pairwise comparison between CDW management alternatives 1 and 2 and 1 and 3, respectively, while the third row shows values of pairwise comparison between CDW management alternatives 2 and 3. Similar to the criteria comparison, the consistency ratios (CR) were calculated for each of the alternative comparisons. Once again, in all cases, these values range from 0.0031 to 0.0175, which is less than 0.1, suggesting that the alternative comparisons are consistent and may be used further in the analysis.

Table 34 Pairwise comparison of CDW Alternatives for all sustainability criteria

	Economic criteria									**Socio-environmental criteria**						
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EN1**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
BAU EU28	2	3	2	2	1/3	1/4	1/2	1/2	1/4	2	3	2	2	1/2	1/2	1/2
BAU CE	3	5	5	3	1/7	1/9	1/3	1/4	1/9	3	5	3	3	1/3	1/3	1/3
EU28 CE	2	2	2	2	1/4	1/3	1/2	1/3	1/3	2	2	2	2	1/2	1/2	1/2

BAU – Business as Usual Alternative; EU28 – Achieving the EU28 (2018) Average Alternative; CE – On the Road to Circular Economy Alternative; E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

Table 35 indicates the weight of the alternatives with respect to all criteria and all CDW management alternatives. For instance, when it comes to the group of the economic criteria that are related to costs (E1—E4), Alternative 1 (BAU) has the highest rank (0.54—0.65). On the other hand, when revenues (E5—E7) are in question, Alternative 3 (CE) ranks as the best one (0.54—0.70). The same applies when alternatives are compared against environmental criterion (0.68). Lastly, Alternative 1 has the highest rank even when the alternatives are compared against the criteria from the social group (S1—S7), except when the criterion related to public discomfort due to landfill presence (S6) is observed. In the case of this criterion, Alternative 3 has the highest rank (0.54).

Table 35 Weight of CDW alternatives for different sustainability criteria

	Economic criteria								Socio-environmental criteria							
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**EN1**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
BAU	0.54	0.65	0.59	0.54	0.09	0.07	0.16	0.14	0.07	0.54	0.65	0.54	0.54	0.16	0.54	0.16
EU28	0.30	0.23	0.28	0.30	0.21	0.25	0.30	0.24	0.25	0.30	0.23	0.30	0.30	0.30	0.30	0.30
CE	0.16	0.12	0.13	0.16	0.70	0.68	0.54	0.62	0.68	0.16	0.12	0.16	0.16	0.54	0.16	0.54

BAU – Business as Usual Alternative; EU28 – Achieving the EU28 (2018) Average Alternative; CE – On the Road to Circular Economy Alternative; E1 – capital expenditures; E2 – operational expenditures; - E3 – replacement works expenditures; E4 – clearance and decontamination expenditures; E5 – revenues from recovered materials; E6 – revenues from recovered energy; E7 – treatment revenues; E8 – residual values; EN1 – avoided GHG; S1 – social capital expenditures; S2 – social operational expenditures; S3 – social replacement works; S4 – social clearance and decontamination; S5 – public discomfort due to landfill presence; S6 – land consumption (avoidance of landfills); S7 – social residual values.

The previous table shows the results from the CDW alternative comparison against each of the criteria without taking into account the weight of these criteria and the decision-makers' preferences. The latter is shown in Table 36.

Table 36 Ranking of CDW alternatives in different decision-making scenarios

Alternative	**Economic preferences**	**Environmental preferences**	**Social preferences**	**Holistic preferences**
Business as Usual	**0.418**	0.291	**0.399**	0.3628
Achieving the EU28 (2018) Average	0.272	0.277	0.283	0.274
On the Road to Circular Economy	0.309	**0.433**	0.317	**0.3634**

The results from the table suggest that Alternative 1 (Business as Usual) was the optimal alternative when decision-makers base their judgments on economic and social preferences. Contrary to the expected, the second option under the same decision-maker preferences was Alternative 3 (On the Road to Circular Economy). This is due to greater values of the recovered materials, energy and treatment revenues in Alternative 3. Additionally, Alternative 3 had the highest savings in landfill space and the lowest public discomfort. It is also important to note that both decision-making scenarios had similar rankings due to the fact that five out of seven social criteria were expressed in monetary terms and calculated on the bases of five economic criteria.

When it comes to the environmental decision-making scenario, which was predominantly guided by the environmental benefits, Alternative 3 proved to be optimal. Interestingly, this alternative was followed by Alternative 1, instead of Alternative 2, which one might expect. The reason behind this was the high values of one social criterion in Alternative 1, i.e., avoided landfill space due to backfilling, which ranked second in this decision-making scenario.

And finally, the decision-makers, under the holistic approach, opted for Alternative 3 (On the Road to Circular Economy), followed by Alternative 1. However, a very small difference between Alternatives 1 and 3 in the holistic decision-making scenario implies the need for sensitivity analysis that will be performed in the next chapter.

4.8 Summary

This chapter revealed the results of the methodology implementation. After the initial description of the case study and three alternatives for CDW management, the results were divided into four subchapters (Subchapters 4.4—4.7). The first subchapter contained information on the quantity and types of materials embedded in residential buildings built between 1946 and 1990. The second subchapter included the estimation of the renovation and demolition activity and the generation of waste during these processes for all three alternatives. The third subchapter presented the findings from the sustainability assessment of each alternative. And finally, the fourth subchapter compared these alternatives against different preferences of decision-makers.

5 Discussion and Implication of the Case Study Results

5.1 Introduction

This chapter summarises the main findings of the previous chapter and considers their implications to CDW management practices. Additionally, the chapter formulates the limitations to the model that may cause uncertainties in the results and suggests how the model can be improved. Several uncertainties are examined and discussed in the sensitivity analysis. The chapter concludes with the comparison of the main findings with the results from other CDW quantity estimations and CDW sustainability assessment studies.

5.2 Findings and Implications of the Case Study Results

The most important findings from the previous chapter are related to the quantity of materials embedded in the residential buildings' stock and waste estimation when these buildings are renovated or demolished. The quantity of construction materials embedded in buildings built in the period 1946—1990 amounted to 1,315.7 million tonnes. Therefore, the quantities of waste generated during the renovation or demolition process at the end of their service life in the following years will be enormous. However, the composition of materials, especially the high shares of the mineral fractions (concrete, bricks, tiles, and ceramics), implies an immense potential for the recovery of this waste. They account for 83.6% in SFH buildings and 84.5% in MFH buildings.

More specifically, clay-based materials contributed within the range of 36 to 62.3% in SFH buildings depending on the period of construction, in contrast to 7.6 to 55% in MHF buildings. The lower share of clay-based materials in MFH buildings waste was traded-off with concrete-based materials, which ranged from 26.7 to 73.7%, depending on the period of construction. These findings imply a great potential for the high-quality recovery of these materials when they become waste at the end of their service life, especially through reuse and recycling.

This thesis forecasts CDW quantities for the period 2021—2046 for three renovation alternatives. The alternatives included the same demolition rate and different renovation rates that corresponded to the specifics of each alternative. Depending on the alternative, the renovation rate starts at 0.58% and reaches 0.65%, 1% and 2%, respectively. The demolition rate remained the same in all alternatives (0.64—0.97%). However, the total quantities of CDW in all three alternatives are not very different. They range from 40.2 million tonnes in Alternative 1 to 41.1 million tonnes in Alternative 3, with the average annual contribution between 1.5 and 1.6 million tonnes. These small differences between the alternatives suggest that the majority of CDW consists of demolition waste, rather than renovation waste, i.e., four times increase in the renovation rate may only bring an increase of 0.9 million tonnes of CDW in total. Furthermore, the sensitivity analysis amplified this conclusion. The change in increments of 5% up to 30% may result in a significant decrease/increase of the annual waste quantities; the lower limit would be 0.89 million tonnes, while the highest would go up to 2.5 million tonnes.

The high share of the brick and the concrete-based waste streams (65—67%) suggests that there is a high potential for this waste to be recovered and cycled back into the economy. The treatment paths for these and other waste streams were then considered under three waste management alternatives.

The alternatives included management at the current and the average EU level and a level that includes a more circular approach to the CDW management. Additionally, the sustainability performance of each alternative was evaluated through a set of indicators. These indicators were then used as criteria for the ranking of these alternatives depending on different waste operators' preferences. In this way, there were two levels of sustainability performance assessment.

The first level of assessment included CBA, which resulted in several indicators, such as the net present value, the rate of return and the B/C ratio, and it defined Alternative 3 as the most sustainable alternative, i.e., the alternative with the highest net present value and rate of return for both the financial and the economic analysis. This means that in the long run, the high initial investment costs will pay off both to the waste operators and society. The second-best alternative is Alternative 2, which in terms of financial sustainability, turned negative, but in terms of economic sustainability, turned positive. This implied that high investment costs would eventually bring benefits to society. These benefits make the CDW management projects good candidates for the application for EU loans or grants or even public-private partnership projects.

If individual indicators are looked at, as expected, better CDW management practice incurred both higher capital and operational costs, mostly due to investments into recycling and energy recovery infrastructure and sanitary landfills. On the other hand, these costs were more or less compensated with the revenues from recovered materials, energy and treatment processes (gate fees). However, the comparison of the economic performances of different alternatives showed that these revenues are not sufficient for the projects to be economically viable. Only when an economic instrument, in this case, the landfill tax, was implemented these projects have experienced positive outcomes.

Evaluations of environmental and social performance are not very different from economic performance. Better CDW management practices and higher recovery rates (Alternatives 2 and 3) bring benefits both to the environment and society. This is mostly due to high amounts of GHG emissions that are avoided by diverting waste from landfills and consequently not paying a high amount of carbon tax. In terms of social indicators, public discomfort due to landfill presence proved to be the most significant indicator. Similar to GHG emission avoidance, diverting waste from landfills and closing of non-sanitary landfills and illegal dumping areas lead to a decrease in affected areas near landfills and dumps and, consequently, fewer properties sold at lower prices.

Additionally, it is important to note that high recovery rates can make a significant difference in project outcomes. For instance, a nine-percentage difference in the average recovery in Alternatives 2 and 3 yielded a difference of 47.7 million euros in net benefits. However, for this to be possible, a set of regulatory measures need to be implemented. These include obligatory primary separation, landfill bans, quality standards, and measures directed toward the development and support of the recovered materials market. Firstly, selective demolition and primary separation of CDW are imperative. Aside from the obvious benefit of avoiding hazardous fractions and impurities, these could also simplify the treatment process and decrease its costs. Therefore, governments should adopt these regulations and follow their implementation at the local and national scales. The latter is of great importance, especially for the illegal dumping practice that is still happening in Serbia at high rates.

In support of primary separation and as a measure that will divert waste from landfills, the government should also consider the implementation of landfill bans for particular fractions such as metal, mineral, glass and wood. Alternative 3 analysed the effects of this measure. This alternative predicted that from 2046 the disposal rate of these fractions would be zero, and coupled with the advanced recycling technology, 81% of CDW from 2021—2046 on average will be processed in this alternative, out of which 96% of the mineral fraction.

Two other measures that may lead to an increase in the amount of reused and recycled materials are quality standards and green procurement provisions. When it comes to quality standards, certification of the recovered material quality performance will increase confidence in their quality and may lead to greater use. At the same time, provisions in public contracts that include usage thresholds can drive the demand for high-quality recovered materials.

The research done under this thesis may offer several benefits to policymakers when they plan strategies or policies that could potentially improve current CDW practice. The knowledge of the material embedded in buildings may be used for planning the national renovation and circular economy strategies. The CDW composition analysis may be used to highlight the most significant waste streams to indicate to policymakers where to devote their efforts. The shares of particular waste streams may be used to determine specific national recovery targets and guidelines for determining thresholds for the use of recovered materials in public contracts. The simplicity of the AHP method used for ranking the alternatives allows for efficient use by the policymakers and practitioners when they need to assess the effects that a certain policy or decision might have on the environment and society.

Considering that the main motive behind this research was to assist policymakers in Serbia to make and promote efficient CDW management strategies and policies, the outputs of the research alleviated several important recommendations that need to be considered.

The first recommendation may be to improve the quality of census data to achieve more accurate representations of the existing buildings and, consequently, the quantity of materials embedded in them. For new buildings, building or usage permit designs may be considered as one of the means for quantification of embedded material and evaluation of the future CDW quantities.

In terms of regulatory instruments, policymakers should invest their efforts in the implementation of the existing regulations and the promotion of new policies. When it comes to the existing regulation, more strict control and higher penalties for illegal dumping are measures that could divert large quantities of waste from untreated to treated pathways. Similarly, reporting on waste quantities should be more efficient. The comparison with the actual and accurate CDW quantities would allow for calibration of CDW forecasts.

When it comes to new regulations, policies that include specific provisions related to CDW management should be enforced. Aside from recovery targets for each of the CDW streams, these regulations should promote selective demolition and primary separation on site.

The variables that pushed the sustainability outputs of CDW management alternatives from negative to positive ones were increased recovery rates of the mineral fractions, landfill and carbon tax and high disposal gate fees. Therefore, future measures should include these instruments. While the carbon tax should encourage efforts to decrease GHG emissions, the landfill tax and high disposal gate fees should discourage the choice of landfills as the preferable CDW treatment option. To support recovery and high-quality recycling, there has to be a demand from the market for these products. Implementation of limitations or even bans for the excavation of virgin aggregates in smaller and minor river watercourses may drive the secondary market and may even bring additional environmental benefits. In addition, reuse and recycling subsides may be considered either through the establishment of a national award system that will reward stakeholders who use recovered materials in their projects or through direct subsidies to recycling companies in order to decrease their operational costs.

In the end, to secure financing for better CDW management practices, the local waste management operators may consider public-private partnerships. In that case, this model may, with a simple change of variables, help the waste operators to evaluate how and to what extent that arrangement can be beneficial.

Practitioners in the demolition and waste management sector may use this model to increase their capacity in planning efficient construction and demolition waste management. In particular, they could develop business plans and plan potential profits from CDW treatments, make preliminary waste audits before demolition processes, create CDW treatment guidelines, etc.

For instance, the companies that consider starting a recycling business may use this model to estimate the quantities of waste, plan the number, location and capacity of the recycling facilities, optimize the preliminary sorting technology, estimate recycling gate fees, etc.

And finally, certification bodies may use this model to develop country-specific quality standards for recovered materials that would eventually serve to increase the confidence and the use of recovered materials

5.3 Limitations and Suggestions for Improvement

This subchapter provides an overview of the limitations and uncertainties in the calculations from the previous chapter that may come from different sources. Several limitations to model development were previously listed and explained in Subchapter 3.4.5. In this subchapter, only the limitations that may significantly affect the case study results were analysed.

The first two limitations related to the material stock calculation that may lead to the underestimation of the material stock concern the temporal and spatial scope and system boundaries. When it comes to temporal scope, no buildings before 1945 and after 1990 were included. This was done because the temporal horizon of the thesis was 2046, meaning that buildings built after 1990 would not undergo renovation on a larger scale. The buildings built before 1945 were excluded due to similar reasons. It was assumed that considering that these buildings have more than 76 years at the time of the analysis, they were either renovated or demolished on a large scale. The results of the thesis are limited to residential buildings in Serbia. With no prejudice to its status, Kosovo and Metohija with its districts and municipalities are excluded from the study since there has been no statistical data since 1999.

As mentioned before, the building types built in a certain period were described and depicted in the National Typology (Jovanović-Popović et al. 2013). This publication contained photos of each typical building and, more importantly, descriptions and schemes of their thermal envelopes. Building layouts and cross-sections provided in the National Typology were in a rudimentary form that limited further processing, especially measurement. For that reason, the authors of the publication were contacted, and digital versions of these drawings were acquired (CAD drawings). However, these drawings had only one building's cross-section, which led to several assumptions that had to be made mainly on the element's numbers and dimensions. A detailed list of these assumptions, alongside a few limitations, is available in Table 37.

At this point, it should be mentioned that during the extraction of data from the National Typology, the author of this thesis noticed several discrepancies in data values. For instance, the textual description of the National Typology presented a different slab thickness than the architectural drawings of the same building. On one occasion, an entire floor was added to the building cross-section but missed on the building photos and textual descriptions. For that reason, in the case of any discrepancies, an order of documents that prevailed was established as follows: 1) photos of buildings, 2) textual description, 3) illustrations and 4) architectural drawings.

Two other major limitations may affect the estimation of material stock in Serbia and the amount of CDW in the future. The first one concerns the renovation works on buildings performed before the National Typology database was created. For instance, from 2000 to 2011, SFH buildings and apartments in MFH buildings undertook some renovation works (replacement of windows or facade improvement) to increase their energy efficiency. Judging by the European average renovation rate of 1%, these numbers are not very high (European Commission 2020b), and for southern European countries, Serbian, for example, they are less than average, according to Sandberg et al. (2016) (approx. 0,1%). This is the reason why these works were overlooked and excluded by this thesis, as they were overlooked by the National Typology as well.

The second limitation is related to the installation works. The National Typology had no information for most of the installations in the residential buildings; hence all installation works (sewage, electrical, HVAC) had to be excluded from this thesis. For this reason, no plumbing fixtures and fittings, lavatories, radiators, ventilation shafts and chimneys were considered in this study. Elevators as complex elements may require special treatment at the end-of-life stage; therefore, they were also excluded from this study. A few other data that were left out from the study are mentioned in Table 37.

Table 37 List of assumptions and limitations made during the estimation of the material stock

Construction elements	Assumptions (where data were not available)	Limitations
Foundations	• Dimensions and types of subbase layers and foundation slabs	• No foundations, other than foundation slabs
Floor coverings	• Thermal insulation material and floor coverings in corridors, on stairs, in kitchens, bathrooms, storage rooms and rooms	• No adhesives
Openings	• Door and window frame dimensions and types; glass thickness • Door leaf structure is included in the frame calculation • Internal door material type and dimensions • Height of parapet walls • Quantity and type of the openings and frames in the basement	• No shades • No lintels • No window sills

Walls and slabs	• Quantity and dimensions of tie-columns and tie-beams • Types of internal walls (in the apartments)	• No mortar in clay bricks and blocks walls
Wall and ceiling coverings	• Type of plasters	• No facade decorations • No wall paint
Roof	• Roof structure elements (quantity and dimensions)	
Roof covering And rain sewage	• Dimension of gutters and eaves • Type of thermal insulation material	

Additionally, several assumptions had to be made to compensate for the lack of data in the architectural drawings and technical descriptions from the National Typology. Most of these assumptions were based on available textbooks, rulebooks, standards and finally, the expert knowledge of the author.

Since the National Typology was created with energy efficiency and heated area as the main focus, a considerable amount of data on internal openings, types of floor coverings, pitched roof structure, roof coverings, and rain sewage was missing. For that reason, the structure of the pitched roof for all SFH buildings and half of the MFH buildings had to be entirely reconstructed. Based on the roof description, the top floor perimeter and area and typical slope for gable and gipped roofs in Serbia, as well as the type of wooden elements, were assumed, and their dimensions were calculated.

Similarly, there was very little information on window and door properties, especially internal doors, as well as the quantity and the type of the basement's openings. The National Typology indicated that window frames on all building types were wooden, double framed and with single glazing. However, the dimensions of these elements were missing and had to be acquired from construction textbooks. It was adopted that most of the internal doors on the ground and above ground floors matched the entrance doors that, in most cases, were made of plywood and cardboard. Whereas in the basement, steel and metal sheets were assumed as the materials for windows and doors and their frames. Finally, different parapet wall heights were assumed in bathrooms when the data on parapet walls were missing.

Two other important assumptions relate to the structure, i.e., the foundations and tie-columns and tie-beams. The foundation types (except foundation slab and accompanied sub-layers) were excluded from the estimation as there was not enough information on building foundations that would allow the analysis. To support the exclusion, in the process of demolitions, foundation elements, when crushed, are usually and to a large extent mixed with soil and may be used only for low-grade applications, such as backfilling and disposal. When it comes to tie-columns and tie-beams, a Rulebook on technical standards for construction of buildings in seismic areas adopted in the 70s was consulted on the number and the dimensions of these beams and columns. It was also assumed that buildings built before this period had no tie-beams and tie-columns. Additionally, horizontal tie-beams were included in the dimensions of slabs.

In the end, a few data were missing on wall and ceiling coverings (type of plaster) and thermal insulation material and floor coverings in certain rooms. On these occasions, values that were adopted were either the same as in the buildings from the same period of construction or were adopted from the building standards for that period, such as wooden flooring (parquet) for rooms, terrazzo for corridors and clay tiles for bathrooms and kitchens. A detailed list of assumptions with particulars is given in Table 37.

In the period 1946—1990, the entire residential built environment in Serbia was represented by 20 building types. Even though the data from the National Typology allowed precise identification of material types and calculations of their masses, it would be unreasonable to claim that this may be simply transferred to individual buildings. To the best of the author's knowledge, there is no other way to determine the material composition except by physical examination and surveying of each building, which takes into account the number of residential buildings within the region or a country becomes practically impossible. However, it should be noted that authors of the National Typology surveyed approximately 1% of the entire building stock in Serbia (Jovanović-Popović et al. 2013) before a set of 20 types singled out as the "real representatives". To date, no other attempt to do anything similar has been made, which shaped this typology as the best available building stock representation in Serbia, to date.

Table 38 lists all the assumptions made during the calculation of construction and demolition waste quantity and composition. There were two major assumptions in this stage of the methodology. The first is related to the calculation of the number of buildings to be demolished and renovated (i.e., the demolition and renovation rates). As mentioned in Subchapter 3.4.1, these rates were adopted from the existing dynamic building stock model developed by Sandberg et al. (2016). However, to apply these rates to a particular building type (or cohorts), a rate for a particular cohort had to be calculated. These were calculated following the assumption that the share of cohorts in the entire building stock corresponds to the share in the total demolition or renovation rate.

The second assumption concerns the amount and the composition of the material demolished in the renovation activity. The renovation activity considered in this thesis was limited just to construction measures, i.e., the demolition that was necessary to perform thermal envelope improvement measures. In addition to these measures suggested in the National Typology (Jovanović-Popović et al. 2013), the author of the thesis assumed that the building owners would also replace all the internal doors and floors (except in basements). To simplify calculations, it was adopted that all these renovation measures will happen in one year, and their duration will not exceed this year.

Table 38 List of assumptions and limitations made for the estimation of the CDW quantities and composition

Activity	Assumption and limitations
Demolition	• Annual demolition rate values as in Sandberg et al. (2016) • Segmentation of rates is based on cohorts' share • Rounding of building numbers
Renovation	• 50 years renovation cycle • Annual renovation rate values as in Sandberg et al. (2016) • Segmentation of rates is based on cohorts' share • Improvement measures from the National Typology (Jovanović-Popović et al. 2013) • Additional measures: replacement of internal doors and floors • Renovation occurs within one year and last one year • Rounding of building numbers

Finally, a small amount of uncertainty also lies in the fact that the annual number of buildings to be demolished or renovated had to be rounded to a whole number. The author considered that this is more in line with a real-life situation, where partial demolition of buildings rarely happens. The situation is slightly different for renovation, especially for MFH buildings, where in the past, each apartment owner performed renovation activities at their own pace and time. But the assumption in this thesis is that renovation in the coming years will be partially subsidized by national or local governments, and therefore they will need to be synchronised and scheduled better.

There are also several assumptions made in the third stage of the methodology. A comprehensive list is given in Table 39, and in the following text, only the most important ones will be explained in detail. At first, a few general assumptions were made regarding the time frame of the analysis (set at 26 years) with the year 2021 set as the base year, meaning that all the prices taken from the existing literature had to be adjusted to that base year. This was done with the average inflation rate from Eurostat (Eurostat n.d.) or the NBS (National Bank of Serbia n.d.), where it was applicable. The analysis also used constant discount rates over time, even though some guidelines suggest that a social discount rate should decline over time, especially in projects with time horizons over 30 years (Freeman, Groom, and Spackman 2018).

Two of the most important assumptions consider waste treatment rates and types of waste treatment facilities. In this thesis, it was assumed that the waste treatment rates that were assigned to different alternatives follow a linear distribution. However, this might not be the case in real-life, especially when we take into account that in the future national and local governments may enforce laws that limit the amount of waste disposed of in landfills or even set a recycling threshold for public works. This may also be a reason for varying gate fees and landfill taxes.

When it comes to waste treatment facilities, the characteristics of an energy recovery facility were taken from a previously published analysis made by the author of the thesis (Nikolic, Mikic, and Naunovic 2017). The mobile recycling facility was assumed to be similar to the one used in the analysis made by Hoang et al. (2021) and Di Maria, Eyckmans, and Van Acker (2018). It consisted of an excavator, vibrating feeder, magnetic separator, crusher, horizontal screen, and two conveyors. Consequently, all capital and operational expenditures were based on their inputs. The data for advanced mobile recycling was extracted from a study by Lotfi et al. (2017).

Table 39 List of assumptions and limitations made for the assessment of CDW management alternatives

Indicators	**Assumption and Limitations**
General	• Waste treatment rates follow the linear distribution • The base year is 2021, and a time horizon of 26 years is observed • Discount rates are constant over time • All prices taken from the literature are adjusted to the base year
Economic	• Recycling plant characteristics as in Lotfi et al. (2017), Di Maria, Eyckmans, and Van Acker (2018) and Hoang et al. (2021) • Administration costs as in Di Maria, Eyckmans, and Van Acker (2018) but scaled to the national context • The RC facility set up is within one year, while the project duration for ER facility is taken from Nikolic, Mikic, and Naunovic (2017) • Prices for secondary raw materials are constant over time • The gate fee is the same for all waste streams
Environmental	• Only air pollution (CO_2 emissions) is analysed • GHG emissions from recycling and illegal dumping are constant over time • The unit cost of CO_2-eq per tonne follows the linear distribution
Social	• Change in price assumed 5% (European Commission 2014a) • The affected area set from 1 km to 2 km from the landfills • Landfill land consumption, as in Nikolic, Mikic, and Naunovic (2017)

The environmental impact of different waste management options was concentrated around the emission to air, more particularly CO_2 emissions. This was done for two reasons. The first is because CO_2 pollution can be easily monetised through the widely known and accepted price of CO_2-eq. And the second is in line with the recommendations of the EU commission guidelines that state that other emissions such as NO_x, SO_2 and particulate matter are insignificant in monetary terms (European Commission 2014a). Other emissions to water and soil with an improvement of waste management and the application of best available practices applied are considered to be minimised and therefore also disregarded in this analysis.

Finally, the calculation of the social impact needed the assumption of the location of landfills and their minimum distance from human settlement. The maximum distance where odour and noise from landfills may cause discomfort to humans is set at 2 km, which is in line with the recommendations from the EU commission (European Commission 2014a) as well as with the previously published work on that topic (Iodice et al. 2021). After careful investigation of the real estate market and the prices of similar properties in the same tax area zones, the change in unit price per square meter was assumed to be 5%.

And finally, the majority of these limitations and assumptions were covered with the development of different alternatives. This is especially related to the assumptions on the building typologies and demolition and recovery rates. Most of the assumptions adopted in the sustainability assessment stage were tested in the following subchapter in the sensitivity analysis.

5.4 Verification and Validation of the Results

In an attempt to overcome some of these limitations, the verification and validation of results were performed. To do this, a series of tests were conducted. The following chapters present the results of these tests, while the details of the test procedures are described in Subchapter 3.5.

5.4.1 Verification of the Results

One of the first tests that were conducted at the stage of verification was the structure assessment test. This test was performed in order to establish the validity of the model structure proposed in Chapter 3. By its nature, the test is qualitative and includes the comparison of the proposed model and the real environment that the model represents. Considering the fact that the model was proposed based on current knowledge of the waste management systems available in the literature, its variables and relationships among them, the author consider that the model is a good representation of the CDW management system.

The second test that was performed on the model was the assessment of its boundaries. This test was conducted in order to double-check whether all factors that could affect the CDW management system behaviour are included. Similar to model structures, variables used in this model also originated from existing CDW management studies and as such, they covered the intended purpose of the model. In addition, spatial and temporal boundaries, as well as system boundaries related to CDW management, were defined, taking into account the particulars of the case study. The author believes that each of the variables used in the model is fundamental for the evaluation of sustainability performance.

The final test performed at this stage was a dimension consistency test. It was conducted in order to verify that the dimensions used in this model were consistent throughout the entire model. Most of the dimensions involved in the model were basic or derived units related to the measure of areas or volume (square and cubic metres), weights (kilograms, tonnes), density (kilograms per cubic metres), time (hours, months, years) or currencies (euros), etc. These units were run through all the equations from the model to verify that the left-hand side and the right-hand sides of the equations are equal. On the occasion when this was not the case, both the equation and the units of the variables were checked for error.

5.4.2 Validation of the Results

As mentioned in Subchapter 3.5, the validation of the model included three simulation tests: extreme conditions test, sensitivity analysis and comparison with analytical data. The extreme test was performed to examine the behaviour of the model when the model variables assume extreme values.

For this purpose, several variables were chosen for testing all three stages of the model. These included the number of buildings, the demolition and renovation rate, recovery rates, capital and operational costs, unit prices of recovered materials and energy, treatment revenues and costs of GHG emissions. The first three variables affected the model in all stages, while the other four affected only the sustainability performance stage. The first test used zero values for the number of buildings. This affected the quantity of CDW that resulted in zero, as well as the outputs of the sustainability analysis. The demolition rate assumed two values: 0% and 100%. When demolition and renovation rates were set at zero, there was no waste to process. On the other hand, when the demolition rate assumed the maximum value, the weight of the waste equalled the weight of the entire building stock (714.6 million tonnes).

In addition, the variables from the sustainability assessment analysis were used in a similar manner, and they produced logical results as well. Recovery rates set at zero returned zero values of FNPV and ENPV. Extreme values of capital costs (two times higher than the baseline analysis) mostly returned negative net present values in both analysis and all three alternatives. For instance, the FNPV ranged from -77.4 to -49.9 million euros, and the ENPV ranged from -43.5 to 46.6 million euros. Even though the economic net present value was positive for Alternative 3, the rate of return was close to the adopted social discount rate suggesting that this alternative's net present value is close to zero. Likewise, when operational costs doubled, the alternatives performed even worse. The financial net present values ranged from -121.2 to -60.9 million euros, while the economic net present values ranged from -42.6 to 14.2 million euros.

Additionally, when the unit prices of the recovered materials, energy and treatment were set to zero, the only revenues that remained belonged to the residual values of the treatment facilities, land consumption, public discomfort due to the landfills and the avoidance of the carbon tax payment. And finally, a zero value of the carbon tax in Alternatives 2 and 3 decreased the benefits significantly to -21.8 and 10.32 million euros, respectively. Considering the fact that all variables yielded logical and expected results in the natural environment, the author believes that the model has successfully passed the extreme condition test.

Due to their complexity, the two other validation tests that remained, the sensitivity analysis and comparison with the analytical data, will be explained in separate subchapters.

5.4.2.1 Sensitivity Analysis

Uncertainties related to the model and experiments explained in Subchapters 3.4.5 and 5.3 may be analysed and measured with the sensitivity analysis. This analysis tests key variables of the model and the elasticity of the sustainability performance results when changes in variables occur. For the sustainability assessment, analysis of these variables may be grouped into process data or cost data. Process data includes the variables related to the renovation and demolition rate and, consequently, the quantities of waste generated. The cost data are connected to the capital and operational costs for treatment facilities, treatment revenues, unit prices of recovered material and energy, cost of land, carbon tax, etc. In addition, the financial and social discount rates are tested for sensitivity.

The first step in this test was to search all variables to find the most critical ones. This procedure consists of changing all variables by 1% and separating the ones that change the outputs of financial and economic analysis by 1% or more. These are the critical variables, and they should be tested further in the sensitivity analysis. Table 40 provides an overview of the entire list of variables, details of the critical variables testing and the results obtained during that process.

Table 40 List of variables with changes in output values of the sustainability performance (in percentages)

Variable	**CDW Quantity**			**FNPV**			**ENPV**			**Test results**
	BAU	**EU28**	**CE**	**BAU**	**EU28**	**CE**	**BAU**	**EU28**	**CE**	
Estimation variables										
Demolition rate	0.97	0.97	0.95	-1.61	-3.54	5.63	-1.51	4.93	1.71	Critical
Renovation rate	0.02	0.02	0.04	-0.03	-0.14	0.76	-0.04	0.15	0.14	Non-critical
Sustainability assessment variables										
Financial discount rate				-0.19	0.41	-3.25				Critical
CAPEX (total costs)				1.59	2.57	-3.50	1.21	-2.08	-0.51	Critical
OPEX (unit costs)				1.74	5.92	-6.59	1.16	-3.98	-0.85	Critical
Treatment revenues										
Recycling gate fee						1.73			0.25	Critical
Energy recovery gate fee					-0.20	0.62		0.14	0.08	Non-critical
Disposal gate fee				-2.05	-1.67	1.43	-1.60	1.43	0.23	Critical
Landfill tax					-0.41	0.57		0.28	0.07	Non-critical
Unit prices of recovered materials and energy										
Bricks						3.92			0.50	Critical
CRCA					-1.24	2.48		0.90	0.32	Critical
FRCA					-1.38	1.63		1.56	0.25	Critical
Metal				-1.38	-1.43	1.95	-1.12	1.20	0.28	Critical
Electricity					-0.20	0.58		0.14	0.07	Non-critical
Heat					-0.31	0.90		0.22	0.11	Non-critical
Social discount rate							-0.32	-3.01	-1.93	Critical
Cost of land (land consumption)							-0.02	0.03	0.01	Non-critical
Change in price							0.62	-0.58	-0.08	Non-critical
Cost of CO2								1.80	0.89	Critical

Sixteen out of twenty variables were selected as the critical variables after the testing. The variables that changed the output values the most are the demolition rate, CAPEX and OPEX, disposal gate fees and unit prices of metal and recycled aggregates. The changes in financial and economic output values for these variables ranged from -6.59 to 5.92% and -3.98 and 4.93%.

It is important to note that several variables affected only the financial or only the economic outputs, such as the carbon tax or a change in property price (economic outputs), or they affected only one or two alternatives, such as the unit price of reused bricks (Alternative 3). Similarly, all sustainability assessment variables did not affect the estimation of CDW. For that reason, Table 40 has empty cells under the CDW quantity column.

The next step in the sensitivity analysis included further testing of the financial and economic outputs of the critical variables. A range of ±30% with a change rate of 5% was adopted for each variable, and the change of outputs was recorded in charts shown in Figure 24—Figure 29 that follow.

Figure 24 depicts the distribution of elasticity changes in quantities of CDW with changes in the demolition rates. Considering that the demolition rate remained the same in all alternatives, Alternative 3 was chosen for the illustration of the sensitivity analysis. However, changes in Alternative 1 were also calculated. It was decided to cover these two alternatives as they represent the minimum and maximum alternatives of CDW quantities. In this way, both the minimum and maximum renovation rates were considered as well as waste quantities that may be generated due to different demolition rates.

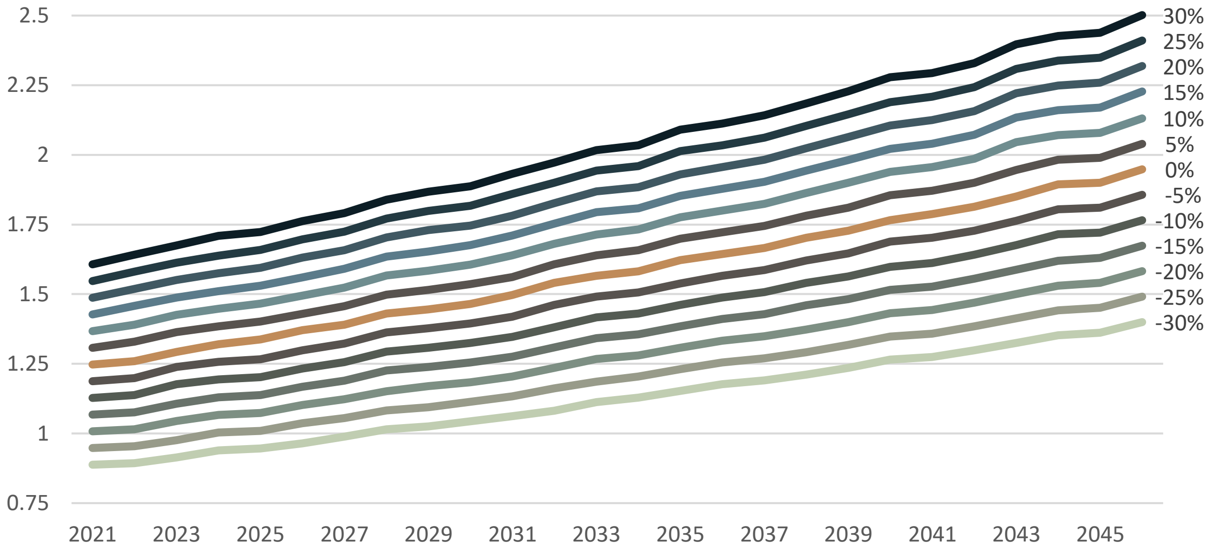


Figure 24 CDW estimation elasticity change as a function of demolition rate in Alternative 3

The figure above shows that changing the demolition rates in the range of 0,41—0,84% of the entire building stock built from 1946 to 1990 may generate waste quantities that range from 0.89 million tonnes in 2021 to 2.5 million tonnes in 2046. When the aggregated quantities are looked at, the CDW quantities are in the range of 29.2—52.9 million tonnes by 2046. These amounts may be less than 0.87 million tonnes in total or 0.33 million tonnes on average per year if Alternative 1 is taken into consideration.

The changes in demolition rates greatly affected the financial and economic outputs of the alternatives as well (Figure 25). In Alternative 1, the increase in the quantity of waste doubled the financial and environmental benefits. Similarly, in Alternative 2, the financial project outputs went above zero with a 30% change in the demolition rate. The highest absolute values of changes were noted in the economic analysis of Alternatives 2 and financial analysis of Alternative 3, where the net present values increased approximately by 150 and 172%. This indicates that the increase in CDW does not necessarily mean an increase in the financial and environmental benefits. For instance, the increase in CDW may lead to greater financial benefits to the waste operator when CDW is managed under Alternative 3, while at the same time, the highest increase in benefits to the environment and the society are achieved under Alternative 2. Similar trends were noted when the amount of waste decreased by 30%.

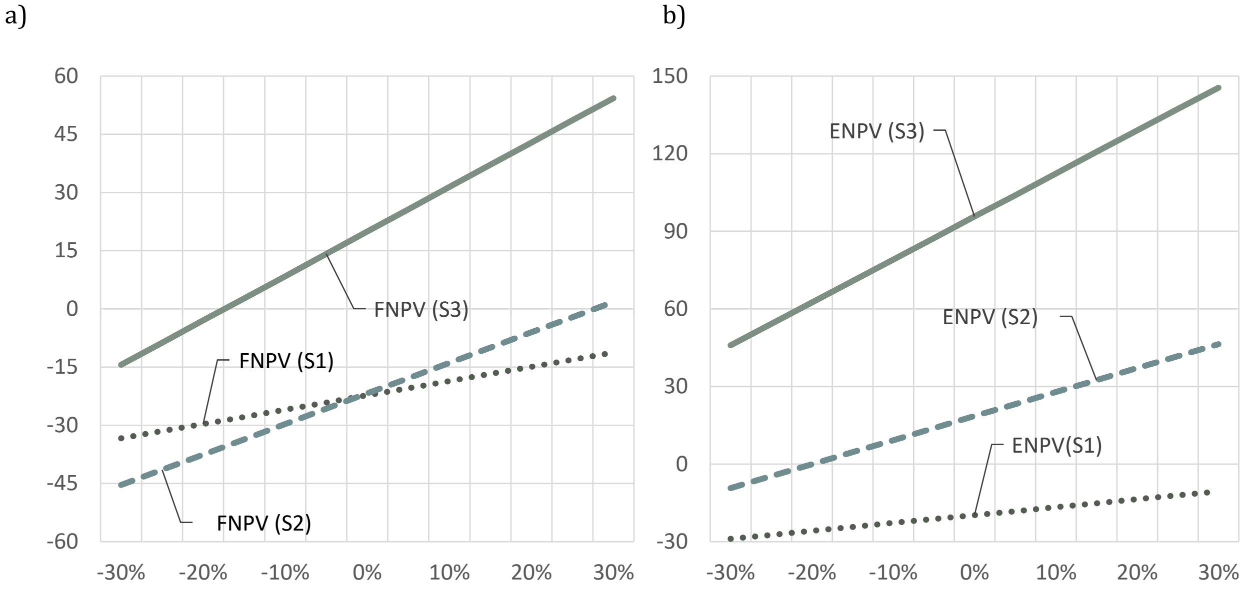


Figure 25 Financial (a) and economic (b) outputs as a function of demolition rate

The next variables that were analysed were the financial and social discount rates. These rates are very important elements of the economic and environmental analyses; they vary over countries worldwide, and they can be very sensitive to market distortions. Figure 26a and 26b illustrate the effects that changes in these rates may have on the corresponding analysis. While the change showed little to no impact on both outputs of Alternative 1 and the financial output of Alternative 2, other outputs proved to be very sensitive to the changes in the financial and social discount rate. A change of rate by 30% resulted in more than double the financial net present value; on the other hand, a decrease of 30% resulted in a decrease of 85% in the net present value of Alternative 3. The environmental outputs of Alternative 2 showed to be very sensitive to the social discount rate changes in addition to Alternative 3. These changes ranged from 47 to 72% when the social discount rates increased by 30% or from 74 to 118% when rates decreased by 30%.

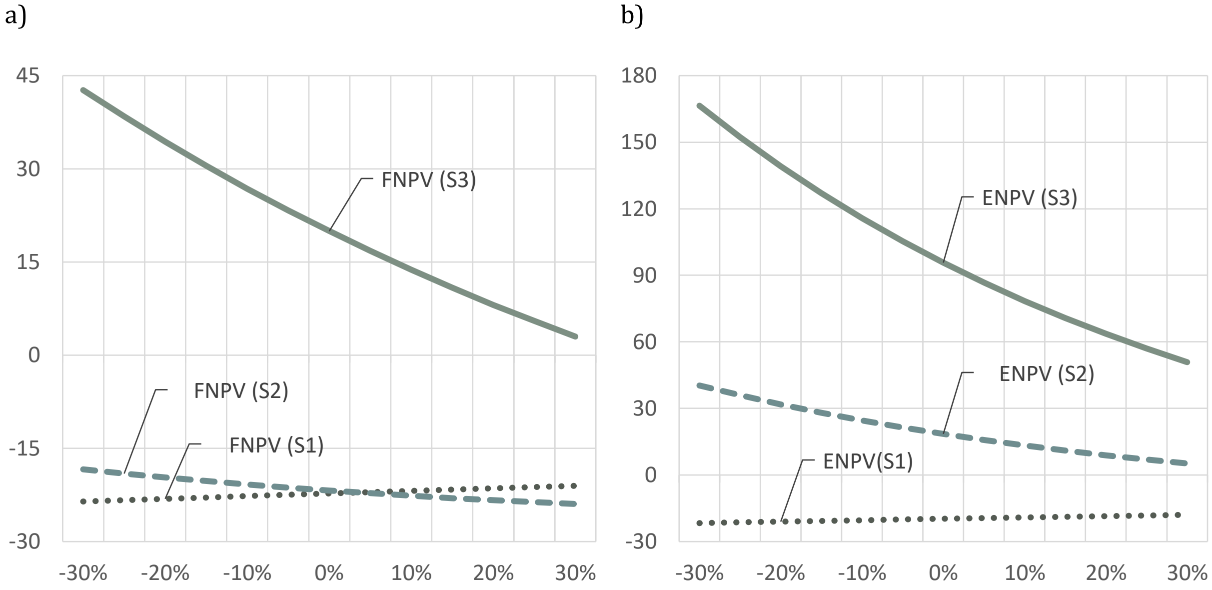


Figure 26 Financial (a) and economic (b) outputs as a function of financial and social discount rates

The following four figures illustrate the elasticity changes of the financial and economic outputs when the capital and operational expenditures increase or decrease. Both the capital and operational costs hide crucial elements in them, such as the labour and energy costs, which often fluctuate in the market; therefore, the sensitivity analysis of these variables is very important. As may be expected, the changes in both CAPEX and OPEX greatly affected the financial and economic outputs of the sustainability analysis. These changes were bigger for the financial outputs in all three alternatives (48—105% for CAPEX and 52—198% for OPEX) as well as the economic outputs of Alternative 2 (62% for CAPEX and 96% for OPEX). This implies that there would be no significant increase in the environmental benefits with more investments in the CDW management practice under Alternatives 1 and 3.

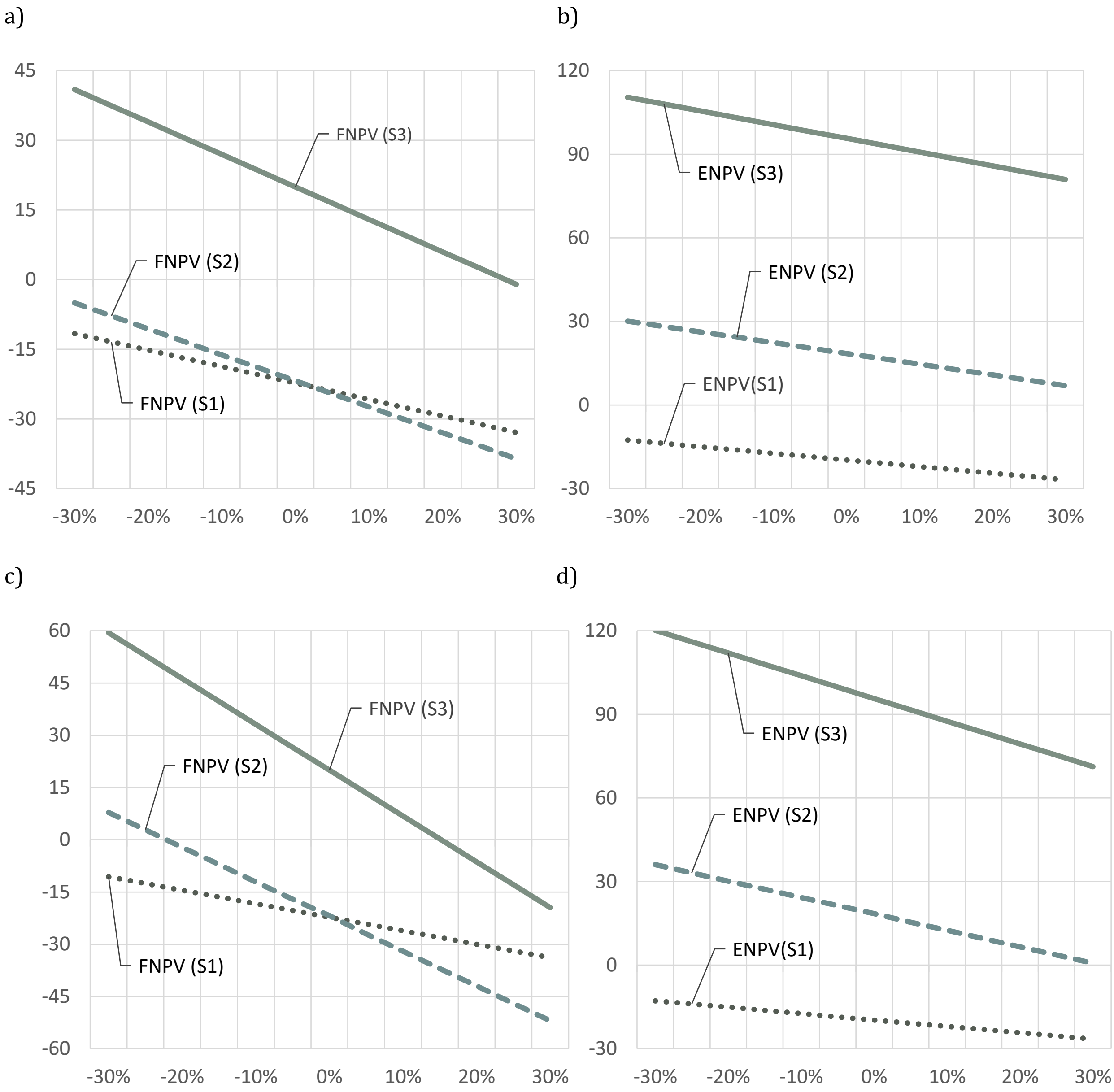


Figure 27 Financial (a, c) and economic (b, d) outputs as a function of capital (a, b) and operational (c, d) expenditures

While the above figures analysed the elasticity changes of cost variables, the following figures will analyse the sensitivity of financial and economic outputs of revenue variables. To begin with the disposal gate fee, the changes in the financial and economic outputs are shown in Figure 28a andFigure 28b, respectively. As expected, as most of the revenues in Alternative 1 rely on the disposal fee, the greatest changes were noted in these outputs (61% for the financial outputs and 48% for the economic outputs); half of these values were grouped around -14.9 and -29.1 million euros. Alternative 2 was the second alternative that was significantly affected by the change in disposal rates, which ranged from 43 to 50%. Half of the financial outputs in these alternatives were grouped around -16.3 and -27.2 million euros, while half of the economic outputs ranged between 14.5 and 22.8 million euros. When it comes to Alternative 3, as the financial output was affected at similar levels as in Alternative 2, the economic outputs were fairly robust to these changes (half of the ENPV ranged between 92.5 and 99.03 million euros), implying that the increase in disposal gate fees in Alternative 3 will not bring significant additional benefits to the environment and the society.

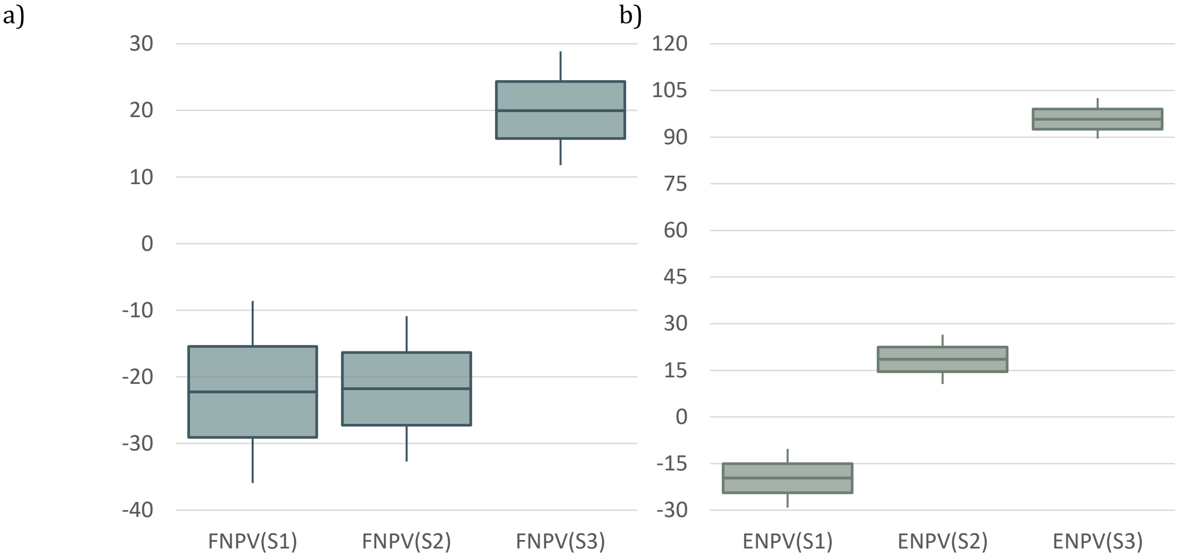


Figure 28 Financial (a) and economic (b) outputs as a function of the disposal gate fee

In addition, the financial and economic outputs of the recycling gate fee changes were also analysed, but they were not shown in separate figures as they affected only Alternative 3. The environmental benefits of Alternative 3 proved to be more resistant to recycling gate fee changes than the financial benefits. Namely, an increase of 30% in the recycling gate fee (2.6 euros per tonne) may bring an increase of 52 and 8% in the financial and economic benefits. At the same time, a decrease of 30% (2.6 euros per tonne) may decrease these benefits up to 52 and 8%, respectively. It can be concluded that, similar to the disposal gate fees, the increase in the recycling gate fees does not bring significant environmental and social benefits.

Similar to the recycling gate fee, the outputs due to changes in the carbon tax were not shown in separate figures as they affected only the environmental benefits of Alternatives 2 and 3. Since both alternatives predicted delayed implementation of the carbon tax (from 2032), changes in the outputs ranged from 54% in Alternative 2 and 27% in Alternative 3 for a 30% change in the carbon tax.

And finally, the last variables that were examined in the sensitivity analysis included revenues from recovered materials, especially recovered metal and aggregates. The elasticity of the financial and economic outputs due to these changes is illustrated in Figure 29a and Figure 29b. Alternative 1 does not predict any recycling of concrete; therefore, there are no changes in the sustainability outputs due to the change in the unit price of recovered aggregate. On the other hand, both price fluctuations have significant effects on the financial net present values. When calculated, these effects ranged between 41 and 59% in the financial benefits or between 8 to 34% in the economic benefits when the unit price of metal went 30% up. The same percentages applied when the unit price of metal went down by 30 %. Moreover, half of the financial net present values in Alternatives 1 and 2 and half of the economic net present values in Alternative 1 changed within the limits of -16.3 and -26.9 million euros with a change in the metal unit price. At the same time, half of the economic outputs of Alternatives 2 and 3 fell between 14.1 and 25.8 and 91.6 and 99.7 million euros, respectively.

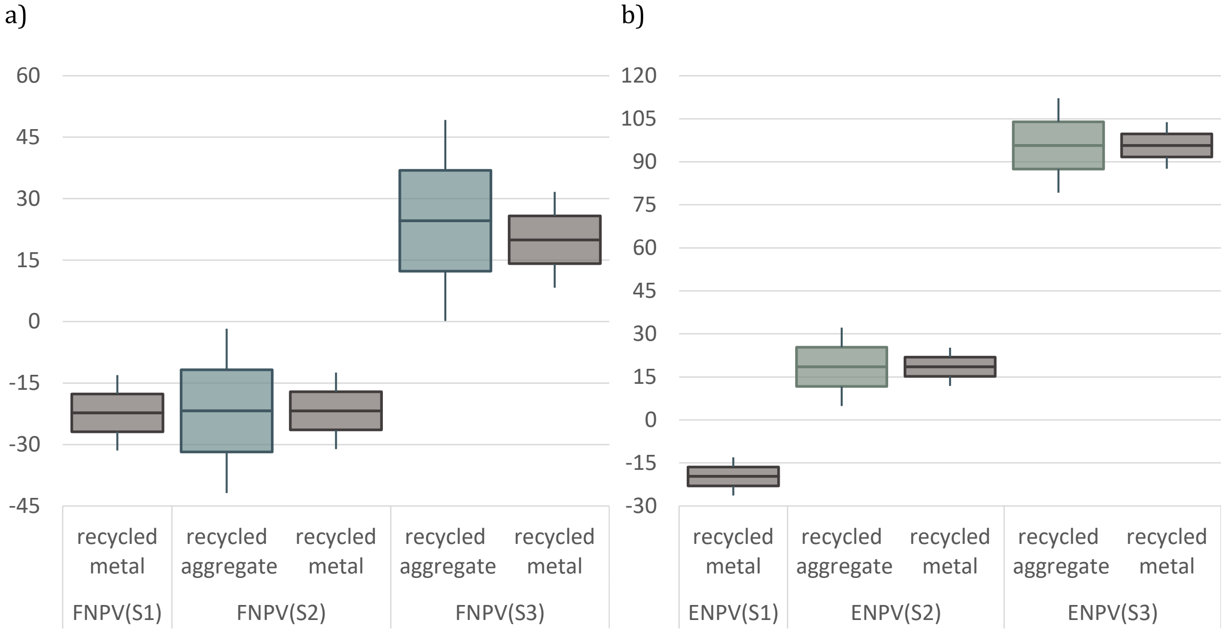


Figure 29 Financial (a) and economic (b) outputs as a function of the unit price of recovered metals and aggregates

The effects of the unit price of the recovered aggregates changes were much bigger. The changes in financial outputs were 92 and 123% in Alternatives 2 and 3, respectively, while the changes in the economic outputs ranged between 17 and 74%. Similarly, half of the financial net present values in these alternatives grouped around -31.8 and -11.8 million euros in Alternative 2 and 7.7 and 32.3 million euros in Alternative 3, whereas the economic net benefits fell in the range 11.7—25.3 in Alternative 2 and 87.5 and 103.9 million euros in Alternative 3.

Based on the above, several conclusions related to the sensitivity of the financial and economic outputs due to a change in critical variables may be drawn. First, the variables that had the biggest influence on the sustainability outputs, i.e. the variables that changed the outputs by more than 70%, were the demolition rate, discount rates, capital and operational costs and the unit price of recovered bricks and aggregates. On the other hand, the variables that had the least influence on these outputs were the unit price of metal and the recycling gate gee. On the other hand, the most robust alternative in terms of financial benefits was Alternative 1, while the most robust alternative in terms of environmental and social benefits was Alternative 3.

It is also important to note that the ranking of alternatives against different decision-making preferences was robust for most of the variable changes and decision-making scenarios. The only exception was the holistic point of view on CDW management, where the optimal alternative shifted from Alternative 3 to Alternative 1 for several variable changes. These variables were the demolition rate, financial and social discount rates, disposal gate fee, unit prices of recovered aggregates and the cost of GHG emissions.

5.4.2.2 Comparison with Other Studies

The best to validate results would be to compare them with actual data on material stock, waste quantities and outputs of CDW management sustainability assessment. While the actual data on CDW quantities may be found in the official statistic records, the two other sets of data cannot be compared with the actual data on material stock and sustainability performance outputs. In the lack of these data, results from the previous studies found in the scientific literature were used.

The first set of results from this thesis to be compared with the results from other studies was the MS data. For this comparison, two specific indicators, material intensity coefficients from similar periods, were derived for each building type, the total quantity of materials embedded, and the quantity of mineral-based materials. These MICs were then compared to MICs from other studies that are either directly reported or derived from their results. Details on this comparison are provided in Table 41.

Values of both MICs for the total quantities of waste calculated in tonnes per square or cubic metres are indicated in the table. The values in the parenthesis are the quantities of mineral-based materials. This comparison is limited by the number of MS studies. Only five MS studies were found for Europe, with only two (Germany and Sweden) that calculated MS on a national scale. Additionally, the study from Germany included only multi-family house buildings.

Table 41 Comparison of material intensity coefficients (MICs); current and recent studies

Study	**Location**	**Period**	**Type of building**	**Material intensity coefficients**	
				tonnes per m^2	**tonnes per m^3**
This thesis	Serbia	1946-1990	SFH	15.90 (13.5)	4.83 (4.11)
			MFH	21.06 (18.21)	7.40 (6.36)
			Total	36.96 (31.71)	12.23 (40.47)
(Ortlepp, Gruhler, and Schiller 2016b)	Germany	1949—1990	MFH	4.31 (3.81)	0.97(0.86)
(Kleemann et al. 2016)	Vienna, Austria	1946—1996	Total	n/a	0.88 (0.86)
(Mastrucci et al. 2017)	Luxembourg Esch-sur-Alzette	1949—1994	SFH	4.00 (3.18)	n/a
			MFH	3.71 (2.94)	
(Gontia et al. 2018)	Sweden	1946—1996	SFH	2.68 (1.72)	0.77 (0.62)
			MFH	13.15 (10.76)	
(Miatto et al. 2019)	Padua, Italy	1954—1996	Total		0.61 (0.57)

SFH – Single-family house buildings; MFH – Multi-family house buildings

When looking at the national scale, both MICs for Serbia are significantly higher than the ones for Germany and Sweden. Namely, the quantities of materials embedded in SFH buildings per gross surface area are six times higher in Serbia than in Sweden, while the MIC of MFH buildings is 1.6 times lower than in Serbia. It may be concluded that Serbia and Sweden share similar practices when the construction of MFH buildings is in question, in contrast to SFH buildings. Namely, structures of SFH buildings in Sweden are mostly made of wood, in contrast to Serbia, where SFH buildings are made of bricks. A closer look into the composition of MS and the share of wood supports this fact. The average amount of wooden-based material per square meter of surface in Sweden is 0.32 tonnes per m^2 in contrast to 0.24 tonnes per m^2 in Serbia.

Another national scale study for Germany also had significantly lower MICs for MFH buildings than in Serbia. However, the German MICs are investigated empirically rather than calculated from buildings inventories as in Sweden and as in this thesis. For that reason, the German results should be considered with caution.

Studies of MICs at the local scale exhibit similar numbers when compared. They range between 0.61 to 0.88 tonnes per m^3 of gross volume of all building types. However, these numbers cannot be directly compared to numbers on the national scale due to architectural differences, construction practices and percentages of build-up area land covers in urban and rural areas. In addition, the materials stock in these studies was calculated through spatial analyses of building geometries in contrast to building inventory analyses done for Sweden and Serbia.

Nevertheless, these numbers may be used to indicate the share of the mineral-based materials in the materials stock. While the amount of materials per surface area varies, the share of mineral-based materials is consistent in most countries. It ranges from 71% for Sweden to 88% for Germany. The share of mineral-based materials in Serbia for both building types fell into this range, indicating that the construction industry across Europe used similar materials for building structures.

In search of the CDW quantities, the easiest way would be to look into the official waste statistic. For instance, the European Commission publishes the amount of waste, by waste category, for the European countries bi-annually (Eurostat 2021a). The latest data for 2018 are shown in Figure 30. The numbers from the figure vary greatly between the European countries. One may rightfully assume that this is due to geographic, economic and cultural differences between the countries. Additionally, the choice of the approach to waste data collection may also affect these figures. The EU regulation on waste statistics foresees that each Member State may choose from four approaches: survey, reporting obligation, statistical estimation or a combination of these three approaches (The European Parliament and the Council of the European Union 2010).

Figure 30 shows that population is more related to CDW quantities than GDP per capita. The countries that reported high values of CDW generation in the range of 137.8—240.2 million tonnes, such as France, Germany and the United Kingdom, have average values of GDP per capita. On the other hand, countries with more than average GDP per capita and similar populations report between 5.6 and 22.7 million tonnes (Norway, Denmark, Sweden, Belgium). Additionally, these are the countries with mature waste statistics and hence a high quality of waste data.

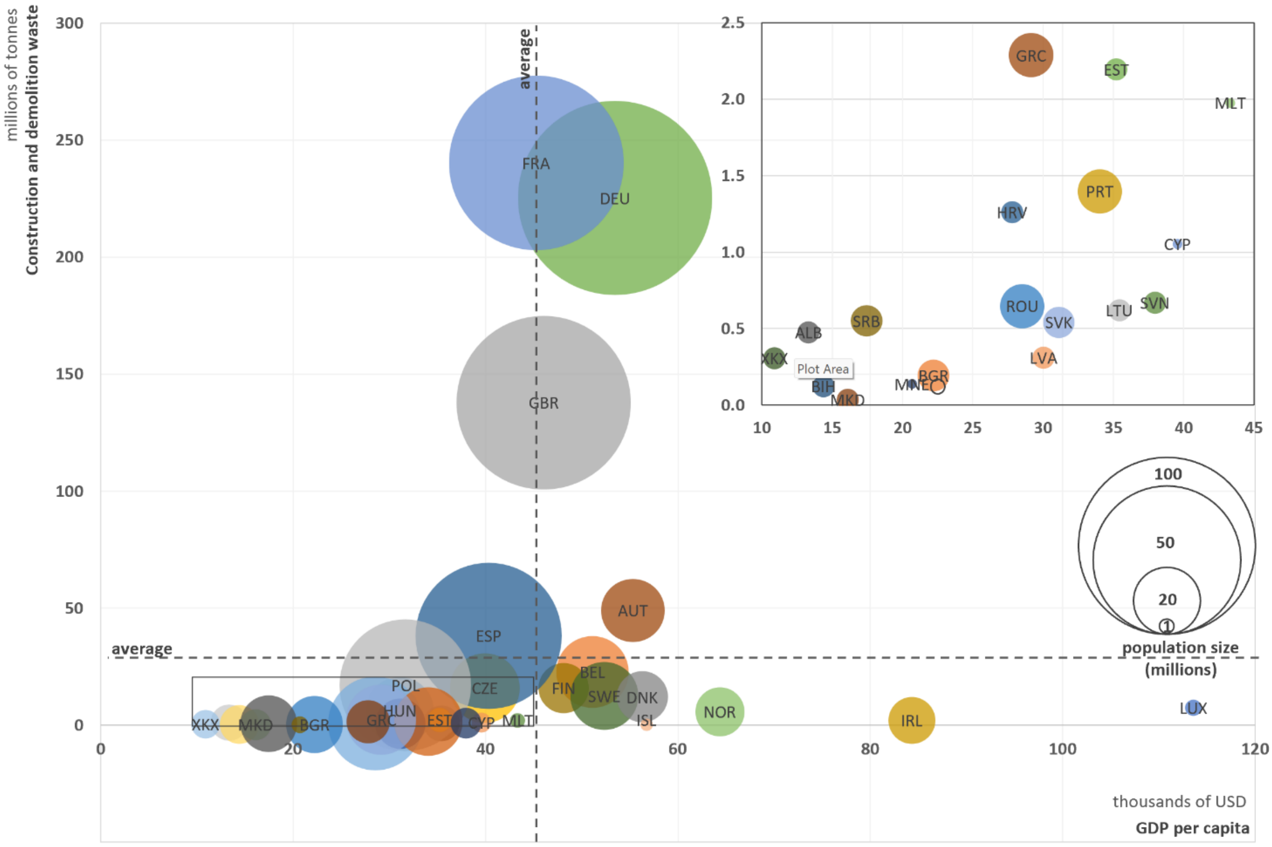


Figure 30 European CDW generation rates (in million tonnes) in relation to GDP per capita and population size (Nadazdi, Naunovic, and Ivanisevic 2022)

According to Figure 30, Serbia generated 0.55 million tonnes of CDW in 2018. However, official statistics of CDW quantities in Serbia are undeveloped. The Serbian statistical office based this data on waste generation reporting from companies, which, although obligatory, is poorly implemented in practice. For that reason, the author believes that official statistical quantities are underestimated. This is further supported by the National Waste Program, which, based on the generation data from the EU, predicts annual amounts of CDW of 3.6 million tonnes.

This thesis estimates 1.25 million tonnes calculated for 2021 or approximately 1.45 million tonnes in 2030, with the average annual value from 2021 to 2046 between 1.55 and 1.58 million tonnes. These results are, according to Figure 30, more aligned with two EU countries, Croatia (1.26 million tonnes) and Portugal (1.40 million tonnes). When it comes to population, Serbia, with 6.9 million inhabitants, is between Croatia's and Portugal's populations of 4.1 and 10.3 million, respectively. On the other hand, Serbia has the lowest GDP per capita, 17.4 thousand dollars, in contrast to 27.8 (Croatia) and 34 thousand dollars (Portugal).

Aside from waste generation statistics, the other approach for the validation of the results on CDW quantities is a comparison with the existing studies. The first approach in the comparison would be to compare the annual or total quantities of waste in a certain period or waste generation rate indicators derived from them, such as WPC or WPA. The second approach would be to compare the compositions of particular waste streams in the total CDW quantities.

Similar to the MS results, aside from the official statistics, very few EU studies at a national scale are available for the comparison of CDW quantities and WGR indicators. The details of the comparison with the available studies are provided in Table 42. The only available study for national scale CDW quantities is for Luxembourg. Although both of the studies predict similar annual CDW quantities, the Luxembourg study estimates up to ten times higher CDW per capita waste quantities than Serbia. The explanation for this may be found in the population of Luxembourg, which is approximately ten times lower the in Serbia.

Other studies estimated CDW at the local scale and the regional scale. While there is a significant difference in the numbers for Padua due to its size and population (210,000 inhabitants), the numbers for Vienna and the region of Lisbon are aligned to a satisfying extent. Namely, waste per capita at these locations varies from 0.04—0.25 tonnes for Lisbon and 0.61 tonnes for Vienna in contrast to 0.18—0.30 tonnes for Serbia. These small differences may be explained with higher rates of build-up areas at the city scale than on the national scale. The high rates of buildings constructed in urban areas consequently generate high rates of waste when these buildings are demolished or renovated.

Table 42 Comparison of annual waste quantities and per capita indicators (in million tonnes); current and recent studies

Study	Location	Type of buildings	Period	CDW quantity	Waste per capita
This thesis	Serbia	RB	1946—1990	1.25—1.95	0.18—0.30
(Bernardo, Gomes, and de Brito 2016)	Lisbon, Portugal Metropolitan Area	B	2012	0.56	0.04—0.25
(Kleemann et al. 2017)	Vienna, Austria	B	2013	1.1	0.61
(Miatto et al. 2019)	Padua, Italy	B	2030	0.40	1.9
(Bogoviku and Waldmann 2021)	Luxembourg	RB	2022—2100	1.38—1.49	2.25—2.42

B – Building; RB – Residential buildings.

The other approach to the comparison of CDW studies would be to analyse the composition of particular CDW fractions in the total quantity of waste. These numbers depend on design preferences and construction techniques in a particular country and period rather than on total CDW quantities. Table 43 summarizes the most important findings on shares of major CDW streams in residential buildings from the recent case studies conducted worldwide. The share of particular waste steam is presented in the range of minimum, and maximum values reported in the studies. The table distinguishes eight categories of waste streams that were reported in the literature.

Table 43 Comparison of CDW composition (in percentages); current and recent studies

Study	Location	Concrete-based	Plaster-based	Clay-based	Metal-based	Wood-based	Bitumen-based	Glass-based	Stone-based
This thesis	Serbia	23—24	16—17	42—43	2	2—3	1—2	0.22—0.35	10.5—10.9
(Iodice et al. 2021)	Campania Italy	4.84 (+stone)			12.6	0.2	10.24	0.41	
(Miatto et al. 2019)	Padua, Italy	32—36	19—20	38—41	3	1			
(Kleemann et al. 2017)	Vienna, Austria	49.7	13	30.5	2	1.85	0.44	0.11	1.43

The numbers from the table show that the content of mineral fractions of CDW is nearly aligned between studies. Concrete-based and plaster-based waste fractions are around 35% on average for concrete-based and 16.3% on average for the plaster-based fraction. The relatively small differences in concrete-based percentages in Serbia, Padua and Vienna may come from the construction practice specifics of a particular country, where due to higher industrialisation levels, buildings in Italy and Austria used more concrete in the structure of buildings than in Serbia. This is further supported by the fact that clay-based fractions in these countries are lower than the ones in Serbia.

The only exception is in the composition of the mineral fractions of waste in the Campania study. This study reports much lower shares of concrete based waste than the three other studies. The explanation for this may be found in the two limitations of the Campania study. First, in contrast to other studies, this study includes mixed CDW fractions of waste at a share of 36.3%. This mixed CDW usually has a high content of concrete and clay based-fractions. And the second is related to the soil-based fraction (34.8%), which is included in the Campania study in contrast to other studies. If this fraction is excluded, all the fractions would increase their shares.

And finally, a comparison of the sustainability performance outputs was conducted. Only four studies that conducted the sustainability performance of CDW management options to some extent could be compared to the results of this thesis. All of the studies used different MCDM analyses. However, they shared similar results. It is important to note that the majority of earlier studies limited their treatment options and waste management alternatives to recycling (backfilling) and landfilling (Kourmpanis et al. 2008; Coronado et al. 2011). An exception is a study by Roussat, Dujet, and Méhu (2009), who included energy recovery.

The studies also had different decision-making preferences. Roussat, Dujet, and Méhu (2009) assigned equal weight to all criteria, while the two others had scenarios where both the economic and the environmental criteria were more important than others (Kourmpanis et al. 2008) or scenarios where the environmental criteria were more or less important than the other (Coronado et al. 2011).

In search of the optimal CDW management alternative, all these studies concluded that selective demolition and primary separation were essential. This is also aligned with the results of this thesis, where Alternative 3, with a higher share of selective demolition, ranked as the optimal CDW management alternative in two decision-making scenarios: environmental and holistic. All of the studies included high rates of recycling in their optimal CDW management alternatives, which is also in line with the results of this thesis. In addition, the optimal alternative in the study by (Roussat, Dujet, and Méhu 2009) included specific treatment of hazardous waste and recovery of wood, which is also included in Alternative 3, which was the highest-ranking alternative under the environmental and holistic preferences.

More interesting information was obtained when the results of this thesis were compared with the more recent study by (Iodice et al. 2021). Although the CDW management alternatives in these two studies have some differences, the results are very similar. Namely, when all the sustainability criteria are considered, the optimal alternative that ranked the first included selective demolition, primary separation and high-quality recycling, which corresponds to the results of this thesis under the holistic decision-making scenario. However, the hypothetical alternative where all the waste was sent to landfills had the lowest rank for almost all criteria, in contrast to this thesis in which this “poor management” had the highest ranks in the economic and social decision-making scenarios. This can be explained by the fact that managing waste under this alternative required minimal capital and operational costs, and at the same time, the social and environmental burdens were not enough to put this alternative at a disadvantage.

5.5 Summary

This chapter summarizes the most important findings and discusses the implication of the results in this thesis. In addition, the limitations of the results as well as suggestions for their improvement were addressed and explained. The robustness of the results was analysed through a verification and validation process. The latter included the extreme condition testing and sensitivity analysis of the critical variables. The chapter concludes with the comparison of the results with relevant studies from the literature.

6 Closing Remarks

6.1 Introduction

This is the final chapter of the thesis. It includes the conclusions drawn from the previous chapters. These conclusions are related to the material stock database, the estimation of CDW quantities and the evaluation of CDW management sustainability performance. Aside from this, the contribution to the body of knowledge will be explained as well as the recommendations to researchers.

6.2 Conclusions

In order to find the optimal construction and demolition waste (CDW) management alternative that would be the least detrimental to the environment and society, the scientific community has devoted a great effort to the assessment of key sustainability aspects. However, the available studies rarely included all three pillars of sustainability: economic, environmental and social. Therefore, this research aimed to propose a decision-support model for sustainability assessment of different construction waste management alternatives while integrating the concept of sustainable development and circular economy.

The research hypothesis was that a CDW management decision-support model might be created through an integration of bottom-up inventory analysis and dynamic building stock modelling for the estimation of the material stock and estimation of CDW quantities and composition, Cost-Benefit Analysis (CBA) for sustainability assessment and Multi-Criteria Decision-Making analysis for ranking of the CDW alternatives and selecting the optimal CDW alternative.

A new model for the sustainability assessment of CDW management and selection of the optimal CDW management alternative has been created. To this extent, the following specific goals were achieved: 1) the setting up of a unique material stock database that includes the types and quantities of materials embedded in buildings; 2) proposing possible CDW management alternatives; 3) proposing a model for estimating future quantities and composition of CDW, 4) proposing a model for assessing the sustainability performance of the proposed alternatives; 4) comparing and ranking the CDW management alternatives; 5) results' analysis and choosing optimal CDW alternative.

The model was tested in the case study for the management of CDW from residential buildings in Serbia. In this case study, the renovation and CDW management alternatives that were evaluated and ranked included the current CDW management (BAU), the alternative that aims to achieve the EU average CDW recovery rates (EU28(2018)) and the alternative that implements circular economy principles in CDW management practices (CE). Each alternative was ranked against four different decision-makers scenarios: economic, environmental, social and holistic.

The implementation of the model in the selected case study yielded three sets of results and, consequently, three groups of conclusions. The first group is related to the material stock database, where the most important findings concern the quantity and composition of the material embedded in SFH and MFH residential buildings built between 1946 and 1990. The total calculated weight of the material embedded in these residential buildings is 714.6 million tonnes, out of which 601.1 million tonnes are embedded in SHF buildings and 113.5 million tonnes of materials are embedded in MFH buildings. The materials with the highest share in the quantities for both building types belong to the mineral fraction: concrete, bricks, tiles, and ceramics. They account for 83.6% in SFH buildings and 84.5% in MFH buildings.

The analysis of the composition of both stocks showed different shares of clay-based and concrete-based construction materials depending on the building type. This analysis indicated waste streams with great circular potential. Clay-based materials contributed within the range of 36 to 62.3% in SFH buildings depending on the period of construction, in contrast to 7.6 to 55% in MHF buildings. The lower share of clay-based materials in MFH buildings waste was traded-off with concrete-based materials, which ranged from 26.7 to 73.7%, depending on the period of construction. These findings imply that there is a great potential for the high-quality recovery of these materials when they become waste at the end of their service life, especially through reuse and recycling.

The second group of conclusions is related to the estimation of the CDW quantity and composition for the period 2021—2046. This estimation was analysed in three alternatives. The alternatives included the same demolition rate and different renovation rates that corresponded to the specifics of each alternative. The results from the case study showed minor differences in the total amount of waste in different alternatives, which confirmed the results of the previous studies that stated that demolition waste contributes significantly more than renovation waste. Depending on the alternative, the total amount of CDW for this period ranged between 40.2 and 41.1 million tonnes, with the average annual contribution between 1.5 and 1.6 million tonnes. These small differences between the alternatives suggested that the majority of CDW consists of demolition waste, rather than renovation waste, i.e., four times increase in the renovation rate may only bring an increase of 0.9 million tonnes of CDW in total. Furthermore, the sensitivity analysis amplified this conclusion. The change in increments of 5% up to 30% may result in a significant decrease/increase of the annual waste quantities; the lower limit would be 0.89 million tonnes, while the highest would go up to 2.5 million tonnes.

As expected, the composition of CDW follows the specifics of the material stock, meaning that the costs and benefits of a certain alternative were mostly determined by the quantity and the composition of the mineral waste stream and, to some extent, the metal waste stream due to the high unit prices metal scraps. However, the share of the mineral waste streams marginally decreased over time in favour of non-minerals that are expected to be generated during renovation activity due to an increase in the renovation rates in the EU28(2018) and CE alternative, the share of the mineral waste streams marginally decreases over time in favour of non-minerals that are generated during renovation activity. The highest share of the waste belonged to clay (43%) and concrete (24%). Although the composition of CDW implies promising waste recovery rates, to grasp the full potential of recovery, a deeper analysis of construction elements, their locations in buildings and, more importantly, the conditions in which they exist in buildings needs to be done.

The third group of conclusions concerns the evaluation of the overall sustainability performance of CDW management alternatives and the selection of optimal CDW management alternatives. The implementation of the model in the case study confirmed that the CBA indicators increase their values as CDW management practices get better. The six CBA indicators served to analyse the potential impacts that a particular alternative might have on waste operators (financial analysis) or the environment and the society (economic analysis). It included net present values, rates of return and B/C ratios. In addition, the sensitivity analysis of CBA outputs revealed that they are highly dependent on several critical variables: demolition rate, discount rates, capital and operational costs and unit prices of recovered bricks and aggregates. These are the variables that should be carefully considered when CDW management strategies are planned. This is particularly related to unit prices of recovered bricks and aggregates that could be subsidised by the government to support secondary material markets.

While the CBA ranked the CDW management alternatives based on two criteria, i.e., the financial and economic net present value, without any preference for each, different decision-making scenarios allowed the ranking of alternatives against various weights of the basic sustainability indicators (criteria).

In total, 16 basic sustainability indicators classified as costs and revenues were calculated and compared in four decision-making scenarios. When economic and social criteria prevailed in decision-making in the selected case study, the current management alternative was the highest-ranked alternative. This is no surprise as decision-makers, especially public entities, often decide on the lowest costs option. On the other hand, when the environmental or the holistic approach is adopted in decision making, the highest-ranked alternative is the CE alternative. The EU28(2018) alternative was ranked considerably lower than the other alternatives except under the environmental and holistic decision-making scenarios. Clearly, the environmental benefits of this alternative would not be enough to compensate for the initial investment costs and the costs of operation. The sensitivity analysis confirmed the ranks of the alternatives in all decision-making scenarios except the CE alternative, in which the CE management alternative shifted to the current CDW management alternative when critical variables changed. This indicates that governmental support should be carefully balanced to enable the viability of the CE alternative.

Finally, the quality of the results from the case study indicates that the proposed model that integrates bottom-up inventory analysis and dynamic building stock modelling and Cost-Benefit and Multi-Criteria Decision-Making analysis may be used for the estimation of quantity and CDW composition, sustainability performance of the CDW management alternatives and the selection of optimal alternative which confirms the initial research hypothesis.

6.3 Contribution to the Knowledge Base

There are several contributions of this thesis to the body of knowledge. First and foremost, the methodology presented in this thesis facilitates the prediction of future quantities and composition of CDW on the bases of material stock modelling. It also integrates all three aspects of sustainability in CDW management assessments and ranking, thus bridging one of the gaps identified in the current sustainability assessment studies. In addition, the CDW management alternatives that were considered and ranked included more CDW treatment options, such as reuse, high-quality recycling and energy recovery.

A more specific contribution is related to the MS database creation for the case study in Serbia that was used for the estimation of CDW quantities and composition in this study. Aside from enabling a more accurate estimation of CDW quantities and composition in this thesis, the MS database may have several other functions. It may serve as an urban mining database for the evaluation of the circularity index of materials embedded in residential buildings, i.e., the percentages of each of the materials that can be cycled back into the economy.

Moreover, the implementation of the methodology in the selected case study provides a benchmark for other studies that investigate innovative and sustainable alternatives for construction and demolition waste management. The MS database may also be used for comparison with other studies that either calculate material stock or estimate the quantities of waste, especially GIS or BIM-based studies where matching building footprints with building typologies may lead to a more precise estimation of MS stock and, consequently CDW quantities. The MS database may be easily updated, expanded or altered when and if more data on residential and non-residential buildings in Serbia becomes available. And finally, due to architectural and construction similarities and in lack of their own MS databases, nearby countries, especially the Western Balkans countries, may use this MS database or MIC coefficients for the estimation of CDW.

6.4 Recommendations for Future Research

The limitations of the proposed methodology and the results obtained point future research in several directions. The first would be the expansion of the MS database to the entire construction stock by including non-residential buildings and civil works and the expansion of the temporary boundary to include the entire stock. To that extent, both BIM and GIS may be used to validate and expand the MS Database. Additionally, when it comes to CDW quantities, although considered insignificant when compared to demolition waste, future studies should include waste from construction activities.

When it comes to the composition of CDW, further studies may include analyses that go deeper into waste stream compositions to evaluate the circularity potential of each construction element or product depending on its state and location within the building. For instance, these studies may help the identification of the share of prefabricated concrete elements that may be reused in new constructions rather than crushed and recycled.

Future research on sustainability assessments may include different CDW management alternatives with more advanced sorting and recovery technologies, other regulatory and economic instruments such as bans on aggregate extraction, subsides to secondary markets or recycling facilities to decrease operational costs, etc. In addition, sustainability performance assessments may be expanded to include more environmental and social indicators such as acidification, eutrophication, toxicity, water use, creation of new jobs, occupational health, etc.

In the end, future studies should also consider changing the spatial boundary to allow for the estimation of CDW and sustainability performance at regional or local levels, as CDW is usually managed at this scale. To that extent, the findings of this thesis may be used for studies related to optimal locations of mobile recycling plants as a decision on the location of the plant in a specific geographic area depends on the balance between the quantity of waste that will be treated in that area and the demand for the secondary raw material.

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Appendix A

Single-family House Buildings Material Stock Database

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
A	B	D	E	F	G	H	I	J	K	L=IxJ	M=JxK	N=f(G)	O=MxN	P=HxO	Q=f(G)
SFH	1946-60	C1	Gf	base slab - gravel	gravel	1	8.95	8.95	0.1	80.10	8.01	1850	14,818.96	14,818.96	stone-based
SFH	1946-60	C1	Gf	base slab	concrete	1	8.95	8.95	0.1	80.10	8.01	2400	19,224.60	19,224.60	concrete-based
SFH	1946-60	C1	Gf	floor covering - water-proofing	bitumen	1	8.95	8.95	0.01	80.10	0.80	1500	1,201.54	1,201.54	bitumen-based
SFH	1946-60	C1	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	63.86	3.19	2100	6,705.30	6,705.30	plaster-based
SFH	1946-60	C1	Gf	floor covering - asphalt	asphalt	1	n/a	n/a	0.006	63.86	0.38	2100	804.64	804.64	bitumen-based
SFH	1946-60	C1	Gf	floor covering - tiles	clay tiles	1	1.5	2	0.01	3.00	0.03	1800	54.00	54.00	clay-based
SFH	1946-60	C1	Gf	floor covering - parquet	wood	1	8.25	8.25	0.016	60.86	0.97	455	443.06	443.06	wood-based
SFH	1946-60	C1	Gf	openings - window	glass	1	0.38	1.22	0.008	0.46	0.004	2580	9.49	9.49	glass-based
SFH	1946-60	C1	Gf	openings - window	glass	1	1.28	1.07	0.008	1.37	0.01	2580	28.27	28.27	glass-based
SFH	1946-60	C1	Gf	openings - window	glass	3	1.38	1.22	0.008	1.68	0.01	2580	34.75	104.25	glass-based
SFH	1946-60	C1	Gf	openings - window frame	wood	1	0.1	0.18	23.495	0.02	0.42	455	192.42	192.42	wood-based
SFH	1946-60	C1	Gf	openings - door	glass	1	0.93	1.895	0.008	1.75	0.01	2580	36.18	36.18	glass-based
SFH	1946-60	C1	Gf	openings - door	wood	3	0.81	1.985	0.04	1.61	0.06	455	29.26	87.79	wood-based
SFH	1946-60	C1	Gf	openings - door	wood	1	0.71	1.985	0.04	1.41	0.06	455	25.65	25.65	wood-based
SFH	1946-60	C1	Gf	openings - door frame	wood	1	0.09	0.31	23.735	0.03	0.66	455	301.30	301.30	wood-based
SFH	1946-60	C1	Gf	walls	clay bricks	1	36.2	4.2	0.38	143.41	54.49	1800	98,090.24	98,090.24	clay-based
SFH	1946-60	C1	Gf	walls	clay bricks	1	12.24	3	0.25	33.50	8.38	1800	15,076.94	15,076.94	clay-based
SFH	1946-60	C1	Gf	walls	clay bricks	1	7.08	3	0.12	18.42	2.21	1800	3,979.00	3,979.00	clay-based
SFH	1946-60	C1	Gf	wall covering - plaster	lime-sand plaster	1	130.2	3	0.03	390.66	11.72	1800	21,095.90	21,095.90	plaster-based
SFH	1946-60	C1	Gf	wall covering	stone tiles	1	31.8	1.2	0.04	38.16	1.53	2690	4,106.02	4,106.02	stone-based
SFH	1946-60	C1	Gf	stairs	reinf. concrete	5	0.28	0.17	1.1	0.02	0.03	2500	65.45	327.25	concrete-based
SFH	1946-60	C1	Gf	ceiling covering - reed	reed	1	n/a	n/a	0.01	63.86	0.64	150	95.79	95.79	organic - misc.
SFH	1946-60	C1	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.04	63.86	2.55	1800	4,597.92	4,597.92	plaster-based
SFH	1946-60	C1	Gf	ceiling covering - battens	wood	30	0.03	0.04	8.95	0.001	0.01	455	4.89	145.79	wood-based
SFH	1946-60	C1	Gf	ceiling covering - beams	wood	32	0.1	0.12	3.5	0.01	0.04	455	19.11	611.52	wood-based
SFH	1946-60	C1	Gf	ceiling covering - rammed earth	earth	1	n/a	n/a	0.1	63.86	6.39	400	2,554.40	2,554.40	soil-based
SFH	1946-60	C1	Roof	roof - beams	wood	38	0.12	0.14	4	0.02	0.07	455	30.58	1,161.89	wood-based
SFH	1946-60	C1	Roof	roof - battens	wood	27	0.048	0.033	8	0.002	0.01	455	5.77	153.75	wood-based
SFH	1946-60	C1	Roof	roof covering - tiles	clay roof-tiles	1825	0.4	0.2	0.02	0.08	0.002	1644	2.63	4,799.99	clay-based
SFH	1946-60	C1	Roof	gutters	sheet metal	1	52.58	0.2	0.00065	10.52	0.01	7860	53.73	53.73	metal-based
SFH	1946-60	C2	Gf	base slab - gravel	gravel	1	n/a	n/a	0.1	282.57	28.26	1850	52,275.45	52,275.45	stone-based
SFH	1946-60	C2	Gf	base slab	concrete	1	n/a	n/a	0.1	282.57	28.26	2400	67,816.80	67,816.80	concrete-based
SFH	1946-60	C2	Gf	floor covering - water-proofing	bitumen	1	n/a	n/a	0.01	282.57	2.83	1500	4,238.55	4,238.55	bitumen-based
SFH	1946-60	C2	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	282.57	14.13	2100	29,669.85	29,669.85	plaster-based
SFH	1946-60	C2	Gf	floor covering - asphalt	asphalt	1	n/a	n/a	0.006	126.21	0.76	2100	1,590.25	1,590.25	bitumen-based
SFH	1946-60	C2	Gf	floor covering - tiles	clay tiles	1	1.77	2.88	0.1	5.098	0.51	1800	917.57	917.57	clay-based
SFH	1946-60	C2	Gf	floor covering - parquet	wood	1	n/a	n/a	0.016	121.11	1.94	455	881.70	881.70	wood-based
SFH	1946-60	C2	Gf	openings - window	glass	2	1.78	1.59	0.008	2.83	0.02	2580	58.41	116.83	glass-based
SFH	1946-60	C2	Gf	openings - window	glass	3	1.24	1.06	0.008	1.31	0.01	2580	27.13	81.40	glass-based
SFH	1946-60	C2	Gf	openings - window	glass	1	1.02	0.82	0.008	0.84	0.01	2580	17.27	17.27	glass-based
SFH	1946-60	C2	Gf	openings - window	glass	1	0.28	0.22	0.008	0.06	0.0005	2580	1.27	1.27	glass-based
SFH	1946-60	C2	Gf	openings - window frame	wood	1	0.1	0.18	31.953	0.018	0.58	455	261.70	261.70	wood-based
SFH	1946-60	C2	Gf	openings - door	wood	2	2.73	2.495	0.04	4.533	0.18	455	82.49	164.99	wood-based
SFH	1946-60	C2	Gf	openings - door	glass	2	2.73	2.495	0.008	2.266	0.02	2580	46.78	93.55	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1946-60	C2	Gf	openings - door	glass	3	1.03	2.095	0.008	2.15	0.02	2580	44.32	132.97	glass-based
SFH	1946-60	C2	Gf	openings - door	glass	3	0.65	1.955	0.008	1.26	0.01	2580	26.03	78.08	glass-based
SFH	1946-60	C2	Gf	openings - door	wood	6	0.83	2.045	0.04	1.70	0.07	455	30.89	185.35	wood-based
SFH	1946-60	C2	Gf	openings - door frame	wood	1	0.09	0.31	58.83	0.03	1.64	455	746.82	746.82	wood-based
SFH	1946-60	C2	Gf	walls	clay bricks	1	109.51	3.6	0.38	357.31	135.78	1800	244,399.34	244,399.34	clay-based
SFH	1946-60	C2	Gf	walls	clay bricks	1	44.63	2.9	0.25	121.738	30.43	1800	54,781.90	54,781.90	clay-based
SFH	1946-60	C2	Gf	wall coverings - plaster	lime-sand plaster	1	n/a	n/a	0.02	852.45	17.05	1800	30,688.22	30,688.22	plaster-based
SFH	1946-60	C2	Gf	ceiling covering - reed	reed	1	n/a	n/a	0.01	283.58	2.84	150	425.37	425.37	organic - misc.
SFH	1946-60	C2	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.04	283.58	11.34	1800	20,417.76	20,417.76	plaster-based
SFH	1946-60	C2	Gf	ceiling covering - beams	wood	13	0.16	0.2	12.5	0.03	0.40	455	182.00	2,366.00	wood-based
SFH	1946-60	C2	Gf	ceiling covering - beams	wood	23	0.16	0.2	8.2	0.03	0.26	455	119.39	2,785.81	wood-based
SFH	1946-60	C2	Gf	ceiling covering - boards	wood	1	n/a	n/a	0.05	283.580	14.18	455	6,451.45	6,451.45	wood-based
SFH	1946-60	C2	Gf	roof - beams	wood	58	0.1	0.15	2	0.02	0.03	455	13.65	791.70	wood-based
SFH	1946-60	C2	Gf	roof - beams	wood	28	0.1	0.14	4.5	0.01	0.06	455	28.67	796.25	wood-based
SFH	1946-60	C2	Gf	roof - battens	wood	13	0.1	0.14	25.15	0.01	0.35	455	160.21	2,136.07	wood-based
SFH	1946-60	C2	Gf	roof - battens	wood	30	0.048	0.033	12.5	0.002	0.02	455	9.01	270.27	wood-based
SFH	1946-60	C2	Gf	roof covering - tiles	clay roof-tiles	5227	0.4	0.2	0.02	0.08	0.002	1644	2.63	13,748.96	clay-based
SFH	1946-60	C2	Gf	gutters	sheet metal	1	70.2	0.2	0.00065	14.04	0.01	7860	71.73	71.73	metal-based
SFH	1961-70	D1	B-Gf	base slab - gravel	gravel	1	9.9	8.3	0.1	82.17	8.22	1850	15,201.45	15,201.45	stone-based
SFH	1961-70	D1	B-Gf	base slab	concrete	1	9.9	8.3	0.1	82.17	8.22	2400	19,720.80	19,720.80	concrete-based
SFH	1961-70	D1	B-Gf	floor covering - water-proofing	bitumen	1	9.9	8.3	0.01	82.17	0.82	1500	1,232.55	1,232.55	bitumen-based
SFH	1961-70	D1	B	floor covering - screed	cement-sand plaster	1	9	4	0.05	36.00	1.80	2100	3,780.00	3,780.00	plaster-based
SFH	1961-70	D1	B	floor covering - asphalt	asphalt	1	6	4	0.006	24.00	0.14	2100	302.40	302.40	bitumen-based
SFH	1961-70	D1	B	floor covering - parquet	wood	1	6	4	0.016	24.00	0.38	455	174.72	174.72	wood-based
SFH	1961-70	D1	B	floor covering - tiles	clay tiles	1	2.5	4	0.01	10.00	0.10	1800	180.00	180.00	clay-based
SFH	1961-70	D1	B	openings - window	glass	1	0.905	0.93	0.008	0.84	0.01	2580	17.37	17.37	glass-based
SFH	1961-70	D1	B	openings - window	glass	1	0.625	0.93	0.008	0.58	0.005	2580	12.00	12.00	glass-based
SFH	1961-70	D1	B	openings - window	glass	1	0.525	0.68	0.008	0.36	0.003	2580	7.37	7.37	glass-based
SFH	1961-70	D1	B	openings - window frame	wood	1	0.11	0.14	9.19	0.02	0.14	455	64.39	64.39	wood-based
SFH	1961-70	D1	B	openings - door	plywood	2	0.61	1.985	0.012	1.21	0.01	427	6.20	12.41	wood-based
SFH	1961-70	D1	B	openings - door	plywood	1	0.81	1.985	0.012	1.61	0.02	427	8.24	8.24	wood-based
SFH	1961-70	D1	B	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	4.03	0.12	5.8	0.70	0.70	organic - misc.
SFH	1961-70	D1	B	openings - door frame	wood	1	0.09	0.31	13.94	0.03	0.39	455	176.96	176.96	wood-based
SFH	1961-70	D1	B	walls	stone	1	44.9	2.45	0.5	106.62	53.31	2670	142,334.03	142,334.03	stone-based
SFH	1961-70	D1	B	walls	clay bricks	1	4	2.45	0.38	7.38	2.80	1800	5,046.76	5,046.76	clay-based
SFH	1961-70	D1	B	wall covering - plaster	lime-sand plaster	1	49.5	2.45	0.03	121.37	3.64	1800	6,554.19	6,554.19	plaster-based
SFH	1961-70	D1	B	stairs	reinf. concrete	9	0.28	0.22	1.00	0.03	0.03	2500	77.00	693.00	concrete-based
SFH	1961-70	D1	B	stairs	reinf. concrete	11	0.18	0.33	1.10	0.03	0.03	2500	81.68	898.43	concrete-based
SFH	1961-70	D1	B	ceiling covering - plaster	lime-sand plaster	1	8.8	4	0.03	35.20	1.06	1800	1,900.80	1,900.80	plaster-based
SFH	1961-70	D1	B	slab	reinf. concrete	1	9.5	5	0.16	47.50	7.60	2500	19,000.00	19,000.00	concrete-based
SFH	1961-70	D1	Gf	balcony	gravel	1	4	2.5	0.1	10.00	1.00	1850	1,850.00	1,850.00	stone-based
SFH	1961-70	D1	Gf	balcony	concrete	1	4	2.5	0.1	10.00	1.00	2400	2,400.00	2,400.00	concrete-based
SFH	1961-70	D1	Gf	balcony	gravel	1	4.9	1.15	0.1	5.64	0.56	1850	1,042.48	1,042.48	stone-based
SFH	1961-70	D1	Gf	balcony	concrete	1	4.9	1.15	0.1	5.64	0.56	2400	1,352.40	1,352.40	concrete-based
SFH	1961-70	D1	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	68.35	3.42	2100	7,176.75	7,176.75	plaster-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1961-70	D1	Gf	floor covering - water-proofing	bitumen	1	3	3.5	0.01	10.50	0.11	1500	157.50	157.50	bitumen-based
SFH	1961-70	D1	Gf	floor covering - tiles	clay tiles	1	3	3.5	0.01	10.50	0.11	1800	189.00	189.00	clay-based
SFH	1961-70	D1	Gf	floor covering - asphalt	asphalt	1	7.5	4.5	0.006	33.75	0.20	2100	425.25	425.25	bitumen-based
SFH	1961-70	D1	Gf	floor covering - parquet	wood	1	n/a	n/a	0.022	57.85	1.27	455	579.08	579.08	wood-based
SFH	1961-70	D1	Gf	openings - window	glass	2	1.775	1.23	0.008	2.18	0.02	2580	45.06	90.12	glass-based
SFH	1961-70	D1	Gf	openings - window	glass	2	0.825	1.23	0.008	1.01	0.01	2580	20.94	41.89	glass-based
SFH	1961-70	D1	Gf	openings - window	glass	2	0.375	0.93	0.008	0.35	0.003	2580	7.20	14.40	glass-based
SFH	1961-70	D1	Gf	openings - window frame	wood	1	0.11	0.14	25.46	0.02	0.39	455	178.40	178.40	wood-based
SFH	1961-70	D1	Gf	openings - door	glass	1	1.025	1.995	0.008	2.04	0.02	2580	42.21	42.21	glass-based
SFH	1961-70	D1	Gf	openings - door	glass	1	0.725	1.995	0.008	1.45	0.01	2580	29.85	29.85	glass-based
SFH	1961-70	D1	Gf	openings - door	plywood	2	0.725	1.885	0.012	1.37	0.02	427	7.00	14.01	wood-based
SFH	1961-70	D1	Gf	openings - door	plywood	2	0.81	1.885	0.012	1.53	0.02	427	7.82	15.65	wood-based
SFH	1961-70	D1	Gf	openings - door	plywood	2	0.71	1.885	0.012	1.34	0.02	427	6.86	13.72	wood-based
SFH	1961-70	D1	Gf	openings - door	plywood	1	0.61	1.885	0.012	1.15	0.01	427	5.89	5.89	wood-based
SFH	1961-70	D1	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	9.61	0.29	5.8	1.67	1.67	organic - misc.
SFH	1961-70	D1	Gf	openings - door frame	wood	1	0.09	0.31	41.22	0.03	1.15	455	523.27	523.27	wood-based
SFH	1961-70	D1	Gf	walls	clay bricks	1	40.8	2.7	0.38	98.05	37.26	1800	67,065.11	67,065.11	clay-based
SFH	1961-70	D1	Gf	walls	clay bricks	1	7.5	2.7	0.25	17.52	4.38	1800	7,882.54	7,882.54	clay-based
SFH	1961-70	D1	Gf	walls	clay bricks	1	10	2.7	0.12	24.51	2.94	1800	5,294.55	5,294.55	clay-based
SFH	1961-70	D1	Gf	walls	clay bricks	1	6.5	2.7	0.065	14.87	0.97	1800	1,740.18	1,740.18	clay-based
SFH	1961-70	D1	Gf	wall covering	lime-sand plaster	1	114.8	2.7	0.02	309.90	6.20	1800	11,156.42	11,156.42	plaster-based
SFH	1961-70	D1	Gf	stairs	reinf. concrete	9	0.28	0.22	1.1	0.03	0.03	2500	84.70	762.30	concrete-based
SFH	1961-70	D1	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.03	68.35	2.05	1800	3,690.90	3,690.90	plaster-based
SFH	1961-70	D1	Gf	slab	prefab. concrete	36	0.055	0.25	5	0.01	0.07	2500	171.88	6,144.53	concrete-based
SFH	1961-70	D1	Gf	slab	concrete	1	8.3	10	0.05	83.00	4.15	2400	9,960.00	9,960.00	concrete-based
SFH	1961-70	D1	1st	balcony	reinf. concrete	1	1	1.7	0.1	1.70	0.17	2500	425.00	425.00	concrete-based
SFH	1961-70	D1	1st	balcony	reinf. concrete	1	0.9	3	0.1	2.70	0.27	2500	675.00	675.00	concrete-based
SFH	1961-70	D1	1st	balcony - railings	steel	2	8.5	0.016	0.016	0.14	0.002	7860	17.10	34.21	metal-based
SFH	1961-70	D1	1st	balcony - railings	steel	85	0.02	0.016	0.84	0.0003	0.0003	7860	2.11	179.59	metal-based
SFH	1961-70	D1	1st	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	68.35	3.42	2100	7,176.75	7,176.75	plaster-based
SFH	1961-70	D1	1st	floor covering - water-proofing	bitumen	1	3	3.5	0.01	10.50	0.11	1500	157.50	157.50	bitumen-based
SFH	1961-70	D1	1st	floor covering - tiles	clay tiles	1	3	3.5	0.01	10.50	0.11	1800	189.00	189.00	clay-based
SFH	1961-70	D1	1st	floor covering - parquet	wood	1	n/a	n/a	0.022	57.85	1.27	455	579.08	579.08	wood-based
SFH	1961-70	D1	1st	openings - window	glass	2	0.375	0.93	0.008	0.35	0.003	2580	7.20	14.40	glass-based
SFH	1961-70	D1	1st	openings - window	glass	2	0.825	1.23	0.008	1.01	0.01	2580	20.94	41.89	glass-based
SFH	1961-70	D1	1st	openings - window	glass	2	1.025	1.23	0.008	1.26	0.01	2580	26.02	52.04	glass-based
SFH	1961-70	D1	1st	openings - window frame	wood	1	0.14	0.09	22.46	0.01	0.28	455	128.76	128.76	wood-based
SFH	1961-70	D1	1st	openings - door	glass	1	0.725	1.995	0.008	1.45	0.01	2580	29.85	29.85	glass-based
SFH	1961-70	D1	1st	openings - door	glass	2	0.425	1.995	0.008	0.85	0.01	2580	17.50	35.00	glass-based
SFH	1961-70	D1	1st	openings - door	plywood	2	0.81	1.795	0.012	1.45	0.02	427	7.45	14.90	wood-based
SFH	1961-70	D1	1st	openings - door	plywood	2	0.81	1.885	0.012	1.53	0.02	427	7.82	15.65	wood-based
SFH	1961-70	D1	1st	openings - door	plywood	2	0.71	1.885	0.012	1.34	0.02	427	6.86	13.72	wood-based
SFH	1961-70	D1	1st	openings - door	plywood	1	0.61	1.885	0.012	1.15	0.01	427	5.89	5.89	wood-based
SFH	1961-70	D1	1st	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	9.79	0.29	5.8	1.70	1.70	organic - misc.
SFH	1961-70	D1	1st	openings - door frame	wood	1	0.09	0.31	44.845	0.03	1.25	455	569.28	569.28	wood-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1961-70	D1	1st	walls	clay bricks	1	48.6	2.8	0.25	123.25	30.81	1800	55,464.58	55,464.58	clay-based
SFH	1961-70	D1	1st	walls	clay bricks	1	10	2.8	0.12	25.32	3.04	1800	5,469.83	5,469.83	clay-based
SFH	1961-70	D1	1st	walls	clay bricks	1	6.5	2.8	0.065	15.52	1.01	1800	1,816.23	1,816.23	clay-based
SFH	1961-70	D1	1st	wall covering - plaster	lime-sand plaster	1	117.2	2.8	0.02	328.20	6.56	1800	11,815.29	11,815.29	plaster-based
SFH	1961-70	D1	1st	stairs	reinf. concrete	9	0.28	0.22	1.1	0.03	0.03	2500	84.70	762.30	concrete-based
SFH	1946-60	D1	1st	ceiling covering - reed	reed	1	n/a	n/a	0.01	73.20	0.73	150	109.80	109.80	organic - misc.
SFH	1961-70	D1	1st	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.03	73.20	2.20	1800	3,952.80	3,952.80	plaster-based
SFH	1961-70	D1	1st	ceiling covering - battens	wood	21	0.04	0.06	9.9	0.002	0.02	455	10.81	224.32	wood-based
SFH	1961-70	D1	1st	ceiling covering - beams	wood	42	0.14	0.2	4.6	0.03	0.13	455	58.60	2,461.37	wood-based
SFH	1961-70	D1	1st	ceiling covering - boards	wood	1	n/a	n/a	0.02	73.20	1.46	455	666.12	666.12	wood-based
SFH	1961-70	D1	1st	ceiling covering - rammed earth	earth	1	n/a	n/a	0.1	73.20	7.32	400	2,928.00	2,928.00	soil-based
SFH	1961-70	D1	Roof	roof - beams	wood	46	0.1	0.14	6.3	0.01	0.09	455	40.13	1,846.03	wood-based
SFH	1961-70	D1	Roof	roof - battens	wood	42	0.048	0.033	8.7	0.002	0.01	455	6.27	263.35	wood-based
SFH	1961-70	D1	Roof	roof covering - tiles	clay roof-tiles	1622	0.4	0.2	0.02	0.08	0.002	1644	2.63	4,266.30	clay-based
SFH	1961-70	D1	Roof	gutters	sheet metal	1	63.4	0.2	0.00065	12.68	0.01	7860	64.78	64.78	metal-based
SFH	1961-70	D2	B-Gf	base slab - gravel	gravel	1	n/a	n/a	0.1	106.89	10.69	1850	19,774.65	19,774.65	stone-based
SFH	1961-70	D2	B-Gf	base slab	concrete	1	n/a	n/a	0.1	106.89	10.69	2400	25,653.60	25,653.60	concrete-based
SFH	1961-70	D2	B-Gf	floor covering - water-proofing	bitumen	1	n/a	n/a	0.01	106.89	1.07	1500	1,603.35	1,603.35	bitumen-based
SFH	1961-70	D2	B-Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.025	106.89	2.67	2100	5,611.73	5,611.73	plaster-based
SFH	1961-70	D2	B-Gf	floor covering - bitumen	bitumen	1	n/a	n/a	0.06	75.21	4.51	1500	6,768.90	6,768.90	bitumen-based
SFH	1961-70	D2	B-Gf	floor covering - tiles	clay tiles	1	n/a	n/a	0.01	9.54	0.10	1800	171.72	171.72	clay-based
SFH	1961-70	D2	B-Gf	floor covering - parquet	wood	1	n/a	n/a	0.016	83.30	1.33	455	606.42	606.42	wood-based
SFH	1961-70	D2	B	openings - window	glass	1	0.59	0.60	0.008	0.35	0.003	2580	7.30	7.30	glass-based
SFH	1961-70	D2	B	openings - window frame	wood	1	0.1	0.18	2.379	0.02	0.04	455	19.48	19.48	wood-based
SFH	1961-70	D2	B	openings - door	glass	1	0.69	1.825	0.04	1.25	0.05	2580	129.01	129.01	glass-based
SFH	1961-70	D2	B	openings - door frame	wood	1	0.09	0.31	4.335	0.03	0.12	455	55.03	55.03	wood-based
SFH	1961-70	D2	B	walls	clay bricks	1	17.8	2.9	0.25	50.02	12.50	1800	22,507.30	22,507.30	clay-based
SFH	1961-70	D2	B	wall covering - plaster	lime-sand plaster	1	34.494	2.9	0.02	100.03	2.00	1800	3,601.17	3,601.17	plaster-based
SFH	1961-70	D2	B	stairs	reinf. concrete	4	0.25	0.2	1	0.03	0.03	2500	62.50	250.00	concrete-based
SFH	1961-70	D2	B	stairs	reinf. concrete	12	0.17	0.3	1.15	0.03	0.03	2500	73.31	879.75	concrete-based
SFH	1961-70	D2	B	slab	clay blocks	338	0.25	0.25	0.16	0.03	0.005	1000	5.00	1,692.00	clay-based
SFH	1961-70	D2	B	slab	concrete	1	n/a	n/a	0.04	20.92	0.84	2400	2,008.32	2,008.32	concrete-based
SFH	1961-70	D2	Gf	openings - window	glass	3	1.59	1.30	0.008	2.07	0.02	2580	42.67	128.02	glass-based
SFH	1961-70	D2	Gf	openings - window	glass	2	0.79	1.30	0.008	1.02	0.01	2580	21.14	42.28	glass-based
SFH	1961-70	D2	Gf	openings - window	glass	1	0.59	0.60	0.008	0.35	0.003	2580	7.30	7.30	glass-based
SFH	1961-70	D2	Gf	openings - window frame	wood	1	0.1	0.18	28.074	0.02	0.51	455	229.93	229.93	wood-based
SFH	1961-70	D2	Gf	openings - door	glass	3	0.54	2.115	0.04	1.13	0.05	2580	116.77	350.32	glass-based
SFH	1961-70	D2	Gf	openings - door	wood	3	0.53	1.775	0.04	0.93	0.04	455	16.96	50.88	wood-based
SFH	1961-70	D2	Gf	openings - door	wood	1	0.33	1.775	0.04	0.58	0.02	455	10.50	10.50	wood-based
SFH	1961-70	D2	Gf	openings - door frame	wood	1	0.09	0.31	30.395	0.03	0.85	455	385.85	385.85	wood-based
SFH	1961-70	D2	Gf	walls	clay bricks	1	61.21	2.9	0.25	165.51	41.38	1800	74,479.38	74,479.38	clay-based
SFH	1961-70	D2	Gf	walls	clay bricks	1	2.5	2.9	0.12	7.25	0.87	1800	1,566.00	1,566.00	clay-based
SFH	1961-70	D2	Gf	walls	clay bricks	1	13.73	2.9	0.07	36.44	2.55	1800	4,592.01	4,592.01	clay-based
SFH	1961-70	D2	Gf	wall covering - plaster	lime-sand plaster	1	119.62	2.9	0.02	346.89	6.94	1800	12,488.20	12,488.20	plaster-based
SFH	1961-70	D2	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	87.08	1.74	1800	3,134.88	3,134.88	plaster-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1961-70	D2	Gf	slab	clay blocks	1376	0.25	0.25	0.16	0.03	0.01	1000	5.00	6,880.80	clay-based
SFH	1961-70	D2	Gf	slab	concrete	1	n/a	n/a	0.04	87.08	3.48	2400	8,359.68	8,359.68	concrete-based
SFH	1961-70	D2	Roof	floor covering - mud and husk	mud and husk	1	n/a	n/a	0.06	87.08	5.22	400	2,089.92	2,089.92	organic - misc.
SFH	1961-70	D2	Roof	roof - beams	wood	1	0.14	0.16	36.75	0.01	0.41	455	187.28	187.28	wood-based
SFH	1961-70	D2	Roof	roof - beams	wood	19	0.1	0.14	5	0.01	0.04	455	15.93	300.58	wood-based
SFH	1961-70	D2	Roof	roof - beams	wood	6	0.1	0.14	6.2	0.01	0.04	455	19.75	116.01	wood-based
SFH	1961-70	D2	Roof	roof - beams	wood	6	0.1	0.14	7.4	0.01	0.05	455	23.57	138.47	wood-based
SFH	1961-70	D2	Roof	roof - battens	wood	50	0.048	0.033	12.25	0.001	0.01	455	4.41	218.95	wood-based
SFH	1961-70	D2	Roof	roof - battens	wood	12	0.048	0.033	4.7	0.001	0.004	455	1.69	20.15	wood-based
SFH	1961-70	D2	Roof	roof covering - tiles	clay roof-tiles	1393	0.4	0.2	0.02	0.040	0.001	1644	1.32	1,832.44	clay-based
SFH	1961-70	D2	Roof	gutters	sheet metal	1	41.9	0.2	0.00065	4.190	0.003	7860	21.41	21.41	metal-based
SFH	1971-80	E1	B	base slab - gravel	gravel	1	9.3	8.2	0.1	76.26	7.63	1850	14,108.10	14,108.10	stone-based
SFH	1971-80	E1	B	base slab	concrete	1	9.3	8.2	0.1	76.26	7.63	2400	18,302.40	18,302.40	concrete-based
SFH	1971-80	E1	B	floor covering - water-proofing	bitumen	1	9.3	8.2	0.01	76.26	0.76	1500	1,143.90	1,143.90	bitumen-based
SFH	1971-80	E1	B	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	57.94	2.90	2100	6,083.70	6,083.70	plaster-based
SFH	1971-80	E1	B	openings - window	glass	1	1.775	0.53	0.008	0.94	0.01	2580	19.42	19.42	glass-based
SFH	1971-80	E1	B	openings - window	glass	5	0.705	0.53	0.008	0.37	0.003	2580	7.71	38.56	glass-based
SFH	1971-80	E1	B	openings - window frame	wood	1	0.14	0.09	16.96	0.01	0.21	455	97.23	97.23	wood-based
SFH	1971-80	E1	B	openings - door	glass	1	0.425	1.895	0.008	0.81	0.01	2580	16.62	16.62	glass-based
SFH	1971-80	E1	B	openings - door	plywood	1	0.91	1.885	0.012	1.72	0.02	427	8.79	8.79	wood-based
SFH	1971-80	E1	B	openings - door	plywood	1	0.8	1.885	0.012	1.51	0.02	427	7.73	7.73	wood-based
SFH	1971-80	E1	B	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	3.24	0.10	5.8	0.56	0.56	organic - misc.
SFH	1971-80	E1	B	openings - door frame	wood	1	0.09	0.31	13.465	0.03	0.38	455	170.93	170.93	wood-based
SFH	1971-80	E1	B	walls - tie columns	reinf. concrete	5	0.5	0.5	2.41	0.25	0.60	2500	1,506.25	7,531.25	concrete-based
SFH	1971-80	E1	B	walls	clay bricks	1	30	2.11	0.5	59.69	29.84	1800	53,717.06	53,717.06	clay-based
SFH	1971-80	E1	B	walls	clay bricks	1	10.9	2.11	0.12	19.78	2.37	1800	4,271.54	4,271.54	clay-based
SFH	1971-80	E1	B	wall covering - plaster	lime-sand plaster	1	75.3	2.11	0.02	158.92	3.18	1800	5,721.21	5,721.21	plaster-based
SFH	1971-80	E1	B	stairs	reinf. concrete	11	0.25	0.22	0.95	0.03	0.03	2500	65.31	718.44	concrete-based
SFH	1971-80	E1	B	stairs	reinf. concrete	15	0.3	0.15	1.7	0.02	0.04	2500	95.63	1,434.38	concrete-based
SFH	1971-80	E1	B	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	57.94	1.16	1800	2,085.84	2,085.84	plaster-based
SFH	1971-80	E1	B	slab	clay blocks	824	0.25	0.25	0.2	0.06	0.01	1000	12.50	10,305.41	clay-based
SFH	1971-80	E1	B	slab	prefab. concrete	824	0.12	0.25	0.16	0.03	0.005	2500	12.00	9,893.19	concrete-based
SFH	1971-80	E1	B	slab	concrete	1	9.3	8.2	0.04	76.26	3.05	2400	7,320.96	7,320.96	concrete-based
SFH	1971-80	E1	Gf	balcony	reinf. concrete	1	8.2	0.9	0.1	7.38	0.74	2500	1,845.00	1,845.00	concrete-based
SFH	1971-80	E1	Gf	balcony - floor covering	clay tiles	1	8.2	0.9	0.01	7.38	0.07	1800	132.84	132.84	clay-based
SFH	1971-80	E1	Gf	balcony	reinf. concrete	1	4.6	1.3	0.1	5.98	0.60	2500	1,495.00	1,495.00	concrete-based
SFH	1971-80	E1	Gf	balcony - floor covering	clay tiles	1	4.6	1.3	0.01	5.98	0.06	1800	107.64	107.64	clay-based
SFH	1971-80	E1	Gf	balcony - railings	steel	16	0.02	0.016	0.84	0.0003	0.0003	7860	2.11	33.80	metal-based
SFH	1971-80	E1	Gf	balcony - railings	wood	4	19.9	0.02	0.12	0.3980	0.0478	455	21.73	86.92	wood-based
SFH	1971-80	E1	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.3	57.94	17.38	2100	36,502.20	36,502.20	plaster-based
SFH	1971-80	E1	Gf	floor covering - tiles	clay tiles	1	n/a	n/a	0.01	11.47	0.11	1800	206.37	206.37	clay-based
SFH	1971-80	E1	Gf	floor covering - parquet	wood	1	n/a	n/a	0.022	46.48	1.02	455	465.21	465.21	wood-based
SFH	1971-80	E1	Gf	openings - window	glass	1	0.495	0.43	0.008	0.21	0.002	2580	4.39	4.39	glass-based
SFH	1971-80	E1	Gf	openings - window	glass blocks	1	0.98	1.25	0.08	1.23	0.10	950	93.10	93.10	glass-based
SFH	1971-80	E1	Gf	openings - window	glass	1	0.9	1.23	0.008	1.138	0.01	2580	23.48	23.48	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1971-80	E1	Gf	openings - window	glass	2	1.78	1.23	0.008	2.18	0.02	2580	45.06	90.12	glass-based
SFH	1971-80	E1	Gf	openings - window frame	wood	1	0.14	0.09	18.18	0.01	0.23	455	104.23	104.23	wood-based
SFH	1971-80	E1	Gf	openings - door	glass	2	0.425	1.895	0.008	0.81	0.01	2580	16.62	33.25	glass-based
SFH	1971-80	E1	Gf	openings - door	glass	1	0.925	1.895	0.008	1.75	0.01	2580	36.18	36.18	glass-based
SFH	1971-80	E1	Gf	openings - door	glass	2	0.725	1.895	0.008	1.374	0.01	2580	28.36	56.71	glass-based
SFH	1971-80	E1	Gf	openings - door	plywood	2	0.71	1.985	0.012	1.41	0.02	427	7.22	14.44	wood-based
SFH	1971-80	E1	Gf	openings - door	plywood	1	0.61	1.985	0.012	1.21	0.01	427	6.20	6.20	wood-based
SFH	1971-80	E1	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	4.03	0.12	5.8	0.70	0.70	organic - misc.
SFH	1971-80	E1	Gf	openings - door frame	wood	1	0.09	0.31	36.115	0.03	1.01	455	458.46	458.46	wood-based
SFH	1971-80	E1	Gf	walls - tie columns	reinf. concrete	5	0.5	0.5	2.85	0.25	0.71	2500	1,781.25	8,906.25	concrete-based
SFH	1971-80	E1	Gf	walls	clay bricks	1	30	2.85	0.5	75.57	37.79	1800	68,015.95	68,015.95	clay-based
SFH	1971-80	E1	Gf	walls	clay bricks	1	15.5	2.85	0.12	38.43	4.61	1800	8,300.46	8,300.46	clay-based
SFH	1971-80	E1	Gf	wall covering - plaster	lime-sand plaster	1	80.0	2.85	0.02	228.00	4.56	1800	8,208.10	8,208.10	plaster-based
SFH	1971-80	E1	Gf	stairs	reinf. concrete	17	0.26	0.17	0.95	0.02	0.02	2500	52.49	892.29	concrete-based
SFH	1971-80	E1	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	57.94	1.16	1800	2,085.84	2,085.84	plaster-based
SFH	1971-80	E1	Gf	slab	clay blocks	824	0.25	0.25	0.2	0.06	0.01	1000	12.50	10,305.41	clay-based
SFH	1971-80	E1	Gf	slab	prefab. concrete	824	0.12	0.25	0.16	0.03	0.005	2500	12.00	9,893.19	concrete-based
SFH	1971-80	E1	Gf	slab	concrete	1	9.3	8.2	0.04	76.26	3.05	2400	7,320.96	7,320.96	concrete-based
SFH	1971-80	E1	Gf	balcony	reinf. concrete	1	4.3	0.9	0.1	3.87	0.39	2500	967.50	967.50	concrete-based
SFH	1971-80	E1	Gf	balcony - floor covering	clay tiles	1	4.3	0.9	0.01	3.87	0.04	1800	69.66	69.66	clay-based
SFH	1971-80	E1	Gf	balcony	reinf. concrete	1	4.6	1.3	0.1	5.98	0.60	2500	1,495.00	1,495.00	concrete-based
SFH	1971-80	E1	Gf	balcony - floor covering	clay tiles	1	4.6	1.3	0.01	5.98	0.06	1800	107.64	107.64	clay-based
SFH	1971-80	E1	Gf	balcony - railings	steel	12	0.02	0.016	0.84	0.0003	0.0003	7860	2.11	25.35	metal-based
SFH	1971-80	E1	1st	balcony - railings	wood	4	13.3	0.02	0.12	0.27	0.03	455	14.52	58.09	wood-based
SFH	1971-80	E1	1st	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.3	57.94	17.38	2100	36,502.20	36,502.20	plaster-based
SFH	1971-80	E1	1st	floor covering - tiles	clay tiles	1	1.64	3.1	0.01	5.08	0.05	1800	91.51	91.51	clay-based
SFH	1971-80	E1	1st	floor covering - parquet	wood	1	n/a	n/a	0.022	52.86	1.16	455	529.09	529.09	wood-based
SFH	1971-80	E1	1st	openings - window	glass	1	0.495	0.43	0.008	0.21	0.002	2580	4.39	4.39	glass-based
SFH	1971-80	E1	1st	openings - window	glass blocks	1	0.98	2.45	0.08	2.40	0.19	950	182.48	182.48	glass-based
SFH	1971-80	E1	1st	openings - window	glass	1	0.8	1.23	0.008	1.015	0.01	2580	20.94	20.94	glass-based
SFH	1971-80	E1	1st	openings - window	glass	2	1.78	1.23	0.008	2.18	0.02	2580	45.06	90.12	glass-based
SFH	1971-80	E1	1st	openings - window frame	wood	1	0.14	0.09	17.98	0.01	0.23	455	103.08	103.08	wood-based
SFH	1971-80	E1	1st	openings - door	glass	2	0.425	1.895	0.008	0.81	0.01	2580	16.62	33.25	glass-based
SFH	1971-80	E1	1st	openings - door	plywood	3	0.71	1.985	0.012	1.41	0.02	427	7.22	21.66	wood-based
SFH	1971-80	E1	1st	openings - door	plywood	1	0.61	1.985	0.012	1.21	0.01	427	6.20	6.20	wood-based
SFH	1971-80	E1	1st	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	5.44	0.16	5.8	0.95	0.95	organic - misc.
SFH	1971-80	E1	1st	openings - door frame	wood	1	0.09	0.31	27.05	0.03	0.75	455	343.39	343.39	wood-based
SFH	1971-80	E1	1st	walls - tie columns	reinf. concrete	5	0.5	0.5	2.7	0.25	0.68	2500	1,687.50	8,437.50	concrete-based
SFH	1971-80	E1	1st	walls	clay bricks	1	30	2.85	0.5	75.89	37.95	1800	68,304.74	68,304.74	clay-based
SFH	1971-80	E1	1st	walls	clay bricks	1	17.9	2.85	0.12	45.58	5.47	1800	9,844.44	9,844.44	clay-based
SFH	1971-80	E1	1st	wall covering - plaster	lime-sand plaster	1	85.2	2.85	0.02	242.94	4.86	1800	8,745.86	8,745.86	plaster-based
SFH	1971-80	E1	1st	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	57.94	1.16	1800	2,085.84	2,085.84	plaster-based
SFH	1971-80	E1	1st	slab	clay blocks	824	0.25	0.25	0.2	0.06	0.01	1000	12.50	10,305.41	clay-based
SFH	1971-80	E1	1st	slab	prefab. concrete	824	0.12	0.25	0.16	0.03	0.005	2500	12.00	9,893.19	concrete-based
SFH	1971-80	E1	1st	slab	concrete	1	0.12	8.2	0.04	0.98	0.04	2400	94.46	94.46	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1971-80	E1	Roof	walls	clay bricks	2	8.2	2.45	0.25	10.05	2.51	1800	4,520.25	9,040.50	clay-based
SFH	1971-80	E1	Roof	wall covering - plaster	lime-sand plaster	1	8.2	2.45	0.02	40.18	0.80	1800	1,446.48	1,446.48	plaster-based
SFH	1971-80	E1	Roof	roof - beams	wood	2	0.12	0.14	9.3	0.02	0.16	455	71.09	142.18	wood-based
SFH	1971-80	E1	Roof	roof - beams	wood	24	0.1	0.14	5.4	0.01	0.08	455	34.40	825.55	wood-based
SFH	1971-80	E1	Roof	roof - battens	wood	36	0.048	0.033	9.3	0.002	0.01	455	6.70	241.30	wood-based
SFH	1971-80	E1	Roof	roof covering - tiles	clay roof-tiles	1401	0.4	0.2	0.02	0.08	0.002	1644	2.63	3,684.24	clay-based
SFH	1971-80	E1	Roof	gutters	sheet metal	1	45.8	0.2	0.00065	9.16	0.006	7860	46.80	46.80	metal-based
SFH	1971-80	E2	Gf	base slab - gravel	gravel	1	15.62	11.98	0.1	187.13	18.71	1850	34,618.61	34,618.61	stone-based
SFH	1971-80	E2	Gf	base slab	reinf. concrete	1	15.62	11.98	0.06	187.13	11.23	2500	28,069.14	28,069.14	concrete-based
SFH	1971-80	E2	Gf	floor covering - water-proofing	bitumen	1	10.02	11.98	0.01	120.04	1.20	1500	1,800.59	1,800.59	bitumen-based
SFH	1971-80	E2	Gf	floor covering - concrete	concrete	1	10.02	11.98	0.06	120.04	7.20	2400	17,285.70	17,285.70	concrete-based
SFH	1971-80	E2	Gf	floor covering - rock wool	rock wool	1	10.02	11.98	0.04	120.04	4.80	160	768.25	768.25	stone-based
SFH	1971-80	E2	Gf	floor covering - florbit	florbit	1	10.02	11.98	0.038	120.04	4.56	770	3,512.36	3,512.36	bitumen-based
SFH	1971-80	E2	Gf	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.002	24.54	0.05	1800	88.34	88.34	clay-based
SFH	1971-80	E2	Gf	floor covering - terazzo	terazzo	1	n/a	n/a	0.002	26.85	0.05	2500	134.25	134.25	concrete-based
SFH	1971-80	E2	Gf	floor covering - textil	textil	1	10.0	11.98	0.002	68.65	0.14	146.15	20.07	20.07	textil-based
SFH	1971-80	E2	Gf	openings - window	glass	3	1.325	1.27	0.008	1.68	0.01	2580	34.73	104.20	glass-based
SFH	1971-80	E2	Gf	openings - window	glass	3	1.125	1.27	0.008	1.43	0.01	2580	29.49	88.47	glass-based
SFH	1971-80	E2	Gf	openings - window	glass	3	0.525	1.27	0.008	0.67	0.01	2580	13.76	41.29	glass-based
SFH	1971-80	E2	Gf	openings - window frame	wood	1	0.14	0.09	40.71	0.01	0.51	455	233.39	233.39	wood-based
SFH	1971-80	E2	Gf	openings - door	glass	3	0.765	2.235	0.008	1.71	0.01	2580	35.29	105.87	glass-based
SFH	1971-80	E2	Gf	openings - door	glass	3	2.475	2.235	0.008	5.53	0.04	2580	114.17	342.52	glass-based
SFH	1971-80	E2	Gf	openings - door	wood	6	0.735	2.295	0.04	1.69	0.07	455	30.70	184.20	wood-based
SFH	1971-80	E2	Gf	openings - door	wood	9	0.525	2.295	0.04	1.20	0.05	455	21.93	197.36	wood-based
SFH	1971-80	E2	Gf	openings - door frame	wood	1	0.09	0.31	68.49	0.03	1.91	455	869.45	869.45	wood-based
SFH	1971-80	E2	Gf	walls - tie columns	reinf. concrete	8	0.25	0.25	2.85	0.06	0.18	2500	445.31	3,562.50	concrete-based
SFH	1971-80	E2	Gf	walls	clay bricks - facing	1	42.64	2.85	0.25	83.40	20.85	1300	27,106.49	27,106.49	clay-based
SFH	1971-80	E2	Gf	walls	clay bricks	1	31.24	2.85	0.12	89.03	10.68	1800	19,231.34	19,231.34	clay-based
SFH	1971-80	E2	Gf	walls	clay bricks	1	35.79	2.85	0.065	86.10	5.60	1800	10,073.37	10,073.37	clay-based
SFH	1971-80	E2	Gf	wall coverings - gypsum boards	gypsum board	1	69.7	2.85	0.0125	198.59	2.48	732	1,817.08	1,817.08	gypsum-based
SFH	1971-80	E2	Gf	wall coverings - thermal plaster	termon plaster	1	22.8	2.85	0.03	64.98	1.95	280	545.83	545.83	plaster-based
SFH	1971-80	E2	Gf	wall coverings - plaster	lime-sand plaster	1	22.8	2.85	0.03	350.26	10.51	1800	18,914.16	18,914.16	plaster-based
SFH	1971-80	E2	Gf	stairs	reinf. concrete	42	0.25	0.2	0.9	0.03	0.02	2500	56.25	2,362.50	concrete-based
SFH	1971-80	E2	Gf	stairs	reinf. concrete	12	0.3	0.15	1.2	0.02	0.03	2500	67.50	810.00	concrete-based
SFH	1971-80	E2	Gf	slab	hollow core slab	29	4	1.2	0.25	4.80	1.20	1360	1,632.00	47,817.60	concrete-based
SFH	1971-80	E2	1st	floor covering - concrete	concrete	1	n/a	n/a	0.03	23.40	0.70	2400	1,684.80	1,684.80	concrete-based
SFH	1971-80	E2	1st	floor covering - thermal insulation	rock wool	1	n/a	n/a	0.04	23.40	0.94	160	149.76	149.76	stone-based
SFH	1971-80	E2	1st	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	23.40	1.17	2500	2,925.00	2,925.00	concrete-based
SFH	1971-80	E2	1st	floor covering - sound insulation	cork panels	1	11.4	9.44	0.01	107.62	1.08	150	161.42	161.42	wood-based
SFH	1971-80	E2	1st	floor covering - florbit	florbit	1	11.4	9.44	0.038	107.62	4.09	770	3,148.84	3,148.84	bitumen-based
SFH	1971-80	E2	1st	floor covering - terazzo	terazzo	1	n/a	n/a	0.002	26.85	0.05	2500	134.25	134.25	concrete-based
SFH	1971-80	E2	1st	floor covering - textil	textil	1	n/a	n/a	0.002	99.34	0.20	146.15	29.04	29.04	textil-based
SFH	1971-80	E2	1st	openings - window	glass	3	1.325	1.27	0.008	1.68	0.01	2580	34.73	104.20	glass-based
SFH	1971-80	E2	1st	openings - window	glass	3	0.925	1.27	0.008	1.17	0.01	2580	24.25	72.74	glass-based
SFH	1971-80	E2	1st	openings - window frame	wood	1	0.14	0.09	28.74	0.01	0.36	455	164.77	164.77	wood-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1971-80	E2	1st	openings - door	glass	3	0.765	2.235	0.008	1.71	0.01	2580	35.29	105.87	glass-based
SFH	1971-80	E2	1st	openings - door	wood	9	0.525	2.295	0.04	1.20	0.05	455	21.93	197.36	wood-based
SFH	1971-80	E2	1st	openings - door frame	wood	1	0.09	0.31	15.705	0.03	0.44	455	199.37	199.37	wood-based
SFH	1971-80	E2	1st	walls - tie columns	reinf. concrete	8	0.25	0.25	2.8	0.06	0.18	2500	437.50	3,500.00	concrete-based
SFH	1971-80	E2	1st	walls	clay bricks - facing	1	42.64	2.8	0.25	105.69	26.42	1300	34,349.31	34,349.31	clay-based
SFH	1971-80	E2	1st	walls	clay bricks	1	31.24	2.8	0.12	87.47	10.50	1800	18,893.95	18,893.95	clay-based
SFH	1971-80	E2	1st	walls	clay bricks	1	33.3	2.8	0.065	82.40	5.36	1800	9,640.35	9,640.35	clay-based
SFH	1971-80	E2	1st	wall coverings - gypsum boards	gypsum board	1	65.8	2.8	0.0125	184.18	2.30	732	1,685.28	1,685.28	gypsum-based
SFH	1971-80	E2	1st	wall coverings - thermal plaster	termon plaster	1	22.8	2.8	0.03	63.84	1.92	280	536.26	536.26	plaster-based
SFH	1971-80	E2	1st	wall coverings - plaster	lime-sand plaster	1	121.334	2.8	0.03	339.74	10.19	1800	18,345.76	18,345.76	plaster-based
SFH	1971-80	E2	1st	slab	hollow core slab	29	4	1.2	0.25	4.80	1.20	1360	1,632.00	47,817.60	concrete-based
SFH	1971-80	E2	Roof	floor covering - thermal insulation	glass wool	1	10	12	0.05	120.00	6.00	130	780.00	780.00	glass-based
SFH	1971-80	E2	Roof	roof - beams	wood	30	0.12	0.14	6.5	0.02	0.11	455	49.69	1,490.58	wood-based
SFH	1971-80	E2	Roof	roof - battens	wood	43	0.048	0.033	12	0.002	0.02	455	8.65	374.77	wood-based
SFH	1971-80	E2	Roof	roof covering - tiles	clay roof-tiles	2212	0.4	0.2	0.02	0.080	0.002	1644	2.63	5,818.02	clay-based
SFH	1971-80	E2	Roof	gutters	sheet metal	1	34.5	0.2	0.00065	6.90	0.004	7860	35.25	35.25	metal-based
SFH	1981-90	F1	Gf	base slab - gravel	gravel	1	9.8	8.4	0.1	82.32	8.23	1850	15,229.20	15,229.20	stone-based
SFH	1981-90	F1	Gf	base slab	concrete	1	9.8	8.4	0.1	82.32	8.23	2400	19,756.80	19,756.80	concrete-based
SFH	1981-90	E1	Gf	balcony	reinf. concrete	1	7.4	1.1	0.1	8.14	0.81	2500	2,035.00	2,035.00	concrete-based
SFH	1981-90	F1	Gf	floor covering - water-proofing	bitumen	1	9.8	8.4	0.01	82.32	0.82	1500	1,234.80	1,234.80	bitumen-based
SFH	1981-90	F1	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	69.23	3.46	2100	7,269.15	7,269.15	plaster-based
SFH	1981-90	F1	Gf	floor covering - tiles	clay tiles	1	n/a	n/a	0.01	4.87	0.05	1800	87.66	87.66	clay-based
SFH	1981-90	F1	Gf	floor covering - tiles	clay tiles	1	2.5	2	0.01	5.00	0.05	1800	90.00	90.00	clay-based
SFH	1981-90	F1	Gf	floor covering - parquet	wood	1	n/a	n/a	0.022	42.06	0.93	455	421.02	421.02	wood-based
SFH	1981-90	F1	Gf	openings - window	glass	1	1.75	1.26	0.008	2.21	0.02	2580	45.51	45.51	glass-based
SFH	1981-90	F1	Gf	openings - window	glass	1	1.65	1.26	0.008	2.08	0.02	2580	42.91	42.91	glass-based
SFH	1981-90	F1	Gf	openings - window	glass	1	0.65	0.66	0.008	0.43	0.003	2580	8.85	8.85	glass-based
SFH	1981-90	F1	Gf	openings - window	glass	1	0.25	0.46	0.008	0.12	0.001	2580	2.37	2.37	glass-based
SFH	1981-90	F1	Gf	openings - window frame	wood	1	0.08	0.07	15.88	0.01	0.09	455	40.46	40.46	wood-based
SFH	1981-90	F1	Gf	openings - door	glass	1	0.55	1.85	0.008	1.02	0.01	2580	21.00	21.00	glass-based
SFH	1981-90	F1	Gf	openings - door	sheet metal	1	2.1	2.1	0.003	4.41	0.01	7860	103.99	103.99	metal-based
SFH	1981-90	F1	Gf	openings - door	wood	1	0.81	1.985	0.04	1.61	0.06	455	29.26	29.26	wood-based
SFH	1981-90	F1	Gf	openings - door	plywood	3	0.61	1.985	0.012	1.21	0.01	427	6.20	18.61	wood-based
SFH	1981-90	F1	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	3.63	0.11	5.8	0.63	0.63	organic - misc.
SFH	1981-90	F1	Gf	openings - door frame	wood	1	0.09	0.31	22.77	0.03	0.64	455	289.05	289.05	wood-based
SFH	1981-90	F1	Gf	walls - tie columns	reinf. concrete	10	0.38	0.38	2.7	0.14	0.39	2500	974.70	9,747.00	concrete-based
SFH	1981-90	F1	Gf	walls	clay bricks	1	33.4	2.7	0.38	79.17	30.09	1800	54,155.46	54,155.46	clay-based
SFH	1981-90	F1	Gf	walls	clay bricks	1	17.3	2.7	0.25	43.08	10.77	1800	19,384.85	19,384.85	clay-based
SFH	1981-90	F1	Gf	walls	clay bricks	1	4.55	2.7	0.12	12.29	1.47	1800	2,653.56	2,653.56	clay-based
SFH	1981-90	F1	Gf	wall covering - plaster	lime-sand plaster	1	99.7	2.7	0.02	269.07	5.38	1800	9,686.67	9,686.67	plaster-based
SFH	1981-90	F1	Gf	stairs	reinf. concrete	17	0.26	0.16	0.95	0.02	0.02	2500	49.40	839.80	concrete-based
SFH	1981-90	F1	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	69.23	1.38	1800	2,492.28	2,492.28	plaster-based
SFH	1981-90	F1	Gf	slab	clay blocks	1317	0.25	0.25	0.16	0.06	0.01	1000	10.00	13,171.20	clay-based
SFH	1981-90	F1	Gf	slab	concrete	1	9.8	8.4	0.04	82.32	3.29	2400	7,902.72	7,902.72	concrete-based
SFH	1981-90	F1	1st	balcony	reinf. concrete	1	7.4	1.1	0.1	8.14	0.81	2500	2,035.00	2,035.00	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1981-90	F1	1st	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	69.23	3.46	2100	7,269.15	7,269.15	plaster-based
SFH	1981-90	F1	1st	floor covering - tiles	clay tiles	1	1.5	1.95	0.01	2.93	0.03	1800	52.65	52.65	clay-based
SFH	1981-90	F1	1st	floor covering - parquet	wood	1	n/a	n/a	0.022	66.31	1.46	455	663.71	663.71	wood-based
SFH	1981-90	F1	1st	openings - window	glass	1	1.75	1.26	0.008	2.21	0.02	2580	45.51	45.51	glass-based
SFH	1981-90	F1	1st	openings - window	glass	2	1.25	1.26	0.008	1.58	0.01	2580	32.51	65.02	glass-based
SFH	1981-90	F1	1st	openings - window	glass	1	0.95	1.26	0.008	1.20	0.01	2580	24.71	24.71	glass-based
SFH	1981-90	F1	1st	openings - window	glass blocks	1	1.15	2	0.08	2.30	0.18	950	174.80	174.80	glass-based
SFH	1981-90	F1	1st	openings - window frame	wood	1	0.08	0.07	20.48	0.006	0.11	455	52.18	52.18	wood-based
SFH	1981-90	F1	1st	openings - door	glass	2	0.55	1.96	0.008	1.08	0.01	2580	22.25	44.50	glass-based
SFH	1981-90	F1	1st	openings - door	plywood	4	0.61	1.985	0.012	1.21	0.01	427	6.20	24.82	wood-based
SFH	1981-90	F1	1st	openings - door	plywood	1	0.51	1.985	0.012	1.01	0.01	427	5.19	5.19	wood-based
SFH	1981-90	F1	1st	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.03	5.86	0.18	5.8	1.02	1.02	organic - misc.
SFH	1981-90	F1	1st	openings - door frame	wood	1	0.09	0.31	31.74	0.03	0.89	455	402.92	402.92	wood-based
SFH	1981-90	F1	1st	walls - tie columns	reinf. concrete	10	0.38	0.38	2.7	0.14	0.39	2500	974.70	9,747.00	concrete-based
SFH	1981-90	F1	1st	walls	clay bricks	1	33.4	2.7	0.38	79.172	30.09	1800	54,153.65	54,153.65	clay-based
SFH	1981-90	F1	1st	walls	clay bricks	1	21.8	2.7	0.25	54.02	13.50	1800	24,307.47	24,307.47	clay-based
SFH	1981-90	F1	1st	walls	clay bricks	1	1.95	2.7	0.1	4.25	0.43	1800	765.48	765.48	clay-based
SFH	1981-90	F1	1st	wall covering - plaster	lime-sand plaster	1	101.81	2.7	0.02	274.88	5.50	1800	9,895.77	9,895.77	plaster-based
SFH	1981-90	F1	1st	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	69.23	1.38	1800	2,492.28	2,492.28	plaster-based
SFH	1981-90	F1	1st	slab	clay blocks	1317	0.25	0.25	0.16	0.06	0.01	1000	10.00	13,171.20	clay-based
SFH	1981-90	F1	1st	slab	concrete	1	9.8	8.4	0.04	82.32	3.29	2400	7,902.72	7,902.72	concrete-based
SFH	1981-90	F1	1st	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.03	69.23	2.08	2100	4,361.49	4,361.49	plaster-based
SFH	1981-90	F1	1st	openings - window	glass blocks	1	1.15	1	0.08	1.15	0.09	950	87.40	87.40	glass-based
SFH	1981-90	F1	Roof	walls	clay bricks	2	9.05	2.45	0.25	9.94	2.48	1800	4,471.31	8,942.63	clay-based
SFH	1981-90	F1	Roof	wall covering - plaster	lime-sand plaster	1	9.05	2.45	0.02	44.35	0.89	1800	1,596.42	1,596.42	plaster-based
SFH	1981-90	F1	Roof	roof - beams	wood	2	0.12	0.14	8.4	0.02	0.14	455	64.21	128.42	wood-based
SFH	1981-90	F1	Roof	roof - beams	wood	22	0.1	0.14	6.3	0.01	0.09	455	40.13	869.94	wood-based
SFH	1981-90	F1	Roof	roof - battens	wood	42	0.048	0.033	8.4	0.002	0.01	455	6.05	254.27	wood-based
SFH	1981-90	F1	Roof	roof covering - tiles	clay roof-tiles	1521	0.4	0.2	0.02	0.08	0.002	1644	2.63	3,999.89	clay-based
SFH	1981-90	F1	Roof	gutters	sheet metal	1	38.4	0.2	0.00065	7.68	0.005	7860	39.24	39.24	metal-based
SFH	1981-90	F2	B	base slab - gravel	gravel	1	7	11.1	0.1	77.70	7.77	1850	14,374.50	14,374.50	stone-based
SFH	1981-90	F2	B	base slab	concrete	1	7	11.1	0.1	77.70	7.77	2400	18,648.00	18,648.00	concrete-based
SFH	1981-90	F2	B	balcony	reinf. concrete	1	7	11.1	0.1	77.70	7.77	2500	19,425.00	19,425.00	concrete-based
SFH	1981-90	F2	B	floor covering - water-proofing	bitumen	1	7	11.1	0.01	77.70	0.78	1500	1,165.50	1,165.50	bitumen-based
SFH	1981-90	F2	B	floor covering - screed	cement-sand plaster	1	7	11.1	0.05	77.70	3.89	2100	8,158.50	8,158.50	plaster-based
SFH	1981-90	F2	B	openings - window	glass	3	0.55	0.56	0.008	0.31	0.002	2580	6.36	19.07	glass-based
SFH	1981-90	F2	B	openings - window frame	wood	1	0.08	0.07	6.66	0.01	0.04	455	16.97	16.97	wood-based
SFH	1981-90	F2	B	openings - door	wood	1	2.25	2.06	0.040	4.64	0.19	455	84.36	84.36	wood-based
SFH	1981-90	F2	B	openings - door	wood	1	1.05	2.06	0.040	2.16	0.09	455	39.37	39.37	wood-based
SFH	1981-90	F2	B	openings - door frame	wood	1	0.09	0.31	11.54	0.03	0.322	455	146.49	146.49	wood-based
SFH	1981-90	F2	B	walls - tie columns	reinf. concrete	6	0.38	0.38	2.5	0.14	0.361	2500	902.50	5,415.00	concrete-based
SFH	1981-90	F2	B	walls	clay bricks	1	12.48	2.5	0.38	25.64	9.74	1800	17,538.44	17,538.44	clay-based
SFH	1981-90	F2	B	walls	clay bricks	1	30.44	2.5	0.25	72.99	18.25	1800	32,845.50	32,845.50	clay-based
SFH	1981-90	F2	B	wall covering - plaster	lime-sand plaster	1	56.70	2.5	0.02	141.76	2.84	1800	5,103.43	5,103.43	plaster-based
SFH	1981-90	F2	B	stairs	reinf. concrete	16	0.16	0.25	1.2	0.02	0.02	2500	60.00	960.00	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1981-90	F2	B	ceiling covering - plaster	lime-sand plaster	1	11.1	7	0.02	77.70	1.55	1800	2,797.20	2,797.20	plaster-based
SFH	1981-90	F2	B	slab	clay blocks	1243	0.25	0.25	0.16	0.06	0.01	1000	10.00	12,432.00	clay-based
SFH	1981-90	F2	B	slab	concrete	1	11.1	7	0.04	77.70	3.11	2400	7,459.20	7,459.20	concrete-based
SFH	1981-90	F2	Gf	floor covering - perlite concrete	perlite concrete	1	11.1	7	0.05	77.70	3.89	500	1,942.50	1,942.50	concrete-based
SFH	1981-90	F2	Gf	floor covering - parquet	wood	1	11.1	7	0.022	69.92	1.54	455	699.92	699.92	wood-based
SFH	1981-90	F2	Gf	floor covering - clay tiles	clay tiles	1	3.05	2.55	0.1	7.78	0.78	1800	1,399.95	1,399.95	clay-based
SFH	1981-90	F2	Gf	openings - window	glass	1	1.25	1.26	0.008	1.58	0.01	2580	32.51	32.51	glass-based
SFH	1981-90	F2	Gf	openings - window	glass	2	0.95	1.26	0.008	1.20	0.01	2580	24.71	49.41	glass-based
SFH	1981-90	F2	Gf	openings - window	glass	2	0.7	0.46	0.008	0.32	0.003	2580	6.65	13.29	glass-based
SFH	1981-90	F2	Gf	openings - window frame	wood	1	0.08	0.07	18.5	0.01	0.10	455	47.14	47.14	wood-based
SFH	1981-90	F2	Gf	openings - door	glass	1	1.05	2.06	0.008	2.16	0.02	2580	44.64	44.64	glass-based
SFH	1981-90	F2	Gf	openings - door	glass	2	0.65	2.06	0.008	1.34	0.01	2580	27.64	55.27	glass-based
SFH	1981-90	F2	Gf	openings - door	wood	1	0.75	2.06	0.040	1.55	0.06	455	28.12	28.12	wood-based
SFH	1981-90	F2	Gf	openings - door	wood	1	0.65	2.06	0.040	1.34	0.05	455	24.37	24.37	wood-based
SFH	1981-90	F2	Gf	openings - door	wood	1	0.55	2.06	0.040	1.13	0.05	455	20.62	20.62	wood-based
SFH	1981-90	F2	Gf	openings - door	wood	2	0.45	2.06	0.040	0.93	0.04	455	16.87	33.74	wood-based
SFH	1981-90	F2	Gf	openings - door frame	wood	1	0.09	0.31	38.16	0.03	1.06	455	484.42	484.42	wood-based
SFH	1981-90	F2	Gf	walls - tie columns	reinf. concrete	6	0.38	0.38	2.9	0.14	0.42	2500	1,046.90	6,281.40	concrete-based
SFH	1981-90	F2	Gf	walls	clay bricks	1	12.48	2.9	0.38	27.36	10.40	1800	18,711.50	18,711.50	clay-based
SFH	1981-90	F2	Gf	walls	clay bricks	1	27.32	2.9	0.25	77.07	19.27	1800	34,679.25	34,679.25	clay-based
SFH	1981-90	F2	Gf	walls	clay bricks	1	7.91	2.9	0.065	18.61	1.21	1800	2,177.72	2,177.72	clay-based
SFH	1981-90	F2	Gf	wall covering - plaster	lime-sand plaster	1	76.23	2.5	0.02	190.57	3.81	1800	6,860.45	6,860.45	plaster-based
SFH	1981-90	F2	Gf	stairs	reinf. concrete	16	0.16	0.25	1.2	0.02	0.02	2500	60.00	960.00	concrete-based
SFH	1981-90	F2	Gf	slab	clay blocks	1243	0.25	0.25	0.16	0.06	0.01	1000	10.00	12,432.00	clay-based
SFH	1981-90	F2	Gf	slab	concrete	1	11.1	7	0.04	77.70	3.11	2400	7,459.20	7,459.20	concrete-based
SFH	1981-90	F2	1st	floor covering - screed	cement-sand plaster	1	11.1	7	0.05	77.70	3.89	2100	8,158.50	8,158.50	plaster-based
SFH	1981-90	F2	1st	floor covering - parquet	wood	1	11.1	7	0.022	74.13	1.63	455	742.04	742.04	wood-based
SFH	1981-90	F2	1st	floor covering - clay tiles	clay tiles	1	1.4	2.55	0.1	3.57	0.36	1800	642.60	642.60	clay-based
SFH	1981-90	F2	1st	openings - window	glass	3	0.95	1.26	0.008	1.20	0.01	2580	24.71	74.12	glass-based
SFH	1981-90	F2	1st	openings - window	glass	2	0.7	0.46	0.008	0.32	0.003	2580	6.65	13.29	glass-based
SFH	1981-90	F2	1st	openings - window frame	wood	1	0.08	0.07	17.9	0.01	0.10	455	45.61	45.61	wood-based
SFH	1981-90	F2	1st	openings - door	glass	1	1.05	2.06	0.008	2.16	0.02	2580	44.64	44.64	glass-based
SFH	1981-90	F2	1st	openings - door	glass	3	0.65	2.06	0.008	1.34	0.01	2580	27.64	82.91	glass-based
SFH	1981-90	F2	1st	openings - door	wood	3	0.65	2.06	0.040	1.34	0.05	455	24.37	73.11	wood-based
SFH	1981-90	F2	1st	openings - door frame	wood	1	0.09	0.31	33.79	0.03	0.94	455	428.95	428.95	wood-based
SFH	1981-90	F2	1st	walls - tie columns	reinf. concrete	6	0.38	0.38	2.9	0.14	0.42	2500	1,046.90	6,281.40	concrete-based
SFH	1981-90	F2	1st	walls	clay bricks	1	12.48	2.9	0.38	27.94	10.62	1800	19,110.96	19,110.96	clay-based
SFH	1981-90	F2	1st	walls	clay bricks	1	27.32	2.9	0.25	75.73	18.93	1800	34,076.70	34,076.70	clay-based
SFH	1981-90	F2	1st	walls	clay bricks	1	11.55	2.9	0.065	30.82	2.00	1800	3,605.59	3,605.59	clay-based
SFH	1981-90	F2	1st	wall covering - plaster	lime-sand plaster	1	85.39	2.5	0.02	213.47	4.27	1800	7,684.78	7,684.78	plaster-based
SFH	1981-90	F2	1st	ceiling covering - plaster	lime-sand plaster	1	11.1	7	0.02	77.70	1.55	1800	2,797.20	2,797.20	plaster-based
SFH	1981-90	F2	1st	slab	clay blocks	1243	0.25	0.25	0.16	0.06	0.01	1000	10.00	12,432.00	clay-based
SFH	1981-90	F2	1st	slab	concrete	1	11.1	7	0.04	77.70	3.11	2400	7,459.20	7,459.20	concrete-based
SFH	1981-90	F2	Roof	floor covering - thermal insulation	rock wool	1	11.1	7	0.1	77.70	7.77	160	1,243.20	1,243.20	stone-based
SFH	1981-90	F2	Roof	roof - beams	wood	18	0.12	0.14	6.15	0.02	0.10	455	47.01	822.69	wood-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
SFH	1981-90	F2	Roof	roof - battens	wood	41	0.048	0.033	7	0.002	0.01	455	5.05	206.85	wood-based
SFH	1981-90	F2	Roof	roof covering - tiles	clay roof-tiles	1359	0.4	0.2	0.02	0.08	0.002	1644	2.63	3,574.23	clay-based
SFH	1981-90	F2	Roof	gutters	sheet metal	1	26	0.2	0.00065	5.20	0.003	7860	26.57	26.57	metal-based

Appendix B

Multi-family House Buildings Material Stock Database

Multi-family House Buidlings Material Stock Database

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
A	B	D	E	F	G	H	I	J	K	L=IxJ	M=JxK	N=f(G)	O=MxN	P=HxO	Q=f(G)
MFH	1946-60	C3	B	base slab - gravel	gravel	1	12.74	10.58	0.10	134.79	13.48	1850	24,936.00	24,936.00	stone-based
MFH	1946-60	C3	B	base slab	concrete	1	12.74	10.58	0.10	134.79	13.48	2400	32,349.41	32,349.41	concrete-based
MFH	1946-60	C3	B	floor covering - water-proofing	bitumen	1	12.74	10.58	0.01	134.79	1.35	1500	2,021.84	2,021.84	bitumen-based
MFH	1946-60	C3	B	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	117.64	5.88	2100	12,352.20	12,352.20	plaster-based
MFH	1946-60	C3	B	openings - window	glass	8	1.50	0.79	0.004	1.19	0.005	2580	12.23	97.83	glass-based
MFH	1946-60	C3	B	openings - window frame	steel	1	0.10	0.005	36.64	0.001	0.02	7860	144.00	144.00	metal-based
MFH	1946-60	C3	B	walls	clay bricks	1	65.78	2.7	0.38	168.13	63.89	1800	114,998.18	114,998.18	clay-based
MFH	1946-60	C3	B	walls	clay bricks	1	8.60	2.7	0.20	23.22	4.64	1800	8,359.20	8,359.20	clay-based
MFH	1946-60	C3	B	wall covering - plaster	lime-sand plaster	1	141.74	2.7	0.02	382.69	7.65	1800	13,776.91	13,776.91	plaster-based
MFH	1946-60	C3	B	wall covering - tiles	concrete	1	46.28	1.6	0.03	74.05	2.22	2400	5,331.46	5,331.46	concrete-based
MFH	1946-60	C3	B	stairs	reinf. concrete	16	0.29	0.17	1.15	0.02	0.03	2500	70.87	1,133.90	concrete-based
MFH	1946-60	C3	B	stairs - railings	steel	2	6.6	0.016	0.016	0.11	0.002	7860	13.28	26.56	metal-based
MFH	1946-60	C3	B	stairs - railings	steel	66	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	111.55	metal-based
MFH	1946-60	C3	B	slab	reinf. concrete	39	0.07	10.58	0.25	0.74	0.19	2500	462.88	17,869.78	concrete-based
MFH	1946-60	C3	B	slab	reinf. concrete	1	12.74	10.58	0.05	134.79	6.74	2500	16,848.65	16,848.65	concrete-based
MFH	1946-60	C3	Gf	floor covering - battens	wood	21	10.58	0.08	0.05	0.85	0.04	455	19.26	408.86	wood-based
MFH	1946-60	C3	Gf	floor covering - sand	sand	1	9.80	9.6	0.05	76.11	3.81	1300	4,947.03	4,947.03	plaster-based
MFH	1946-60	C3	Gf	floor covering - boards	wood	1	9.80	9.6	0.02	94.08	2.26	455	1,027.35	1,027.35	wood-based
MFH	1946-60	C3	Gf	floor covering - parquet	wood	1	9.80	12	0.02	90.96	2.00	455	910.51	910.51	wood-based
MFH	1946-60	C3	Gf	floor covering - terazzo	terazzo	2	3.30	1.7	0.05	5.61	0.28	2500	701.25	1,402.50	concrete-based
MFH	1946-60	C3	Gf	floor covering - terazzo	terazzo	1	4.40	1.8	0.05	7.92	0.40	2500	990.00	990.00	concrete-based
MFH	1946-60	C3	Gf	floor covering - terazzo	terazzo	1	5.70	2.3	0.05	13.11	0.66	2500	1,638.75	1,638.75	concrete-based
MFH	1946-60	C3	Gf	openings - window	glass	2	2.08	1.22	0.008	2.54	0.02	2580	52.39	104.78	glass-based
MFH	1946-60	C3	Gf	openings - window	glass	2	1.63	1.22	0.008	1.99	0.02	2580	41.02	82.04	glass-based
MFH	1946-60	C3	Gf	openings - window	glass	4	1.03	1.22	0.008	1.25	0.01	2580	25.87	103.50	glass-based
MFH	1946-60	C3	Gf	openings - window	glass	2	0.18	0.42	0.008	0.07	0.001	2580	1.53	3.06	glass-based
MFH	1946-60	C3	Gf	openings - window	glass	1	1.73	1.42	0.004	2.45	0.01	2580	25.33	25.33	glass-based
MFH	1946-60	C3	Gf	openings - window frame	wood	1	0.14	0.09	51.26	0.01	0.65	455	293.86	293.86	wood-based
MFH	1946-60	C3	Gf	openings - door	glass	1	1.73	2.00	0.008	3.44	0.03	2580	71.03	71.03	glass-based
MFH	1946-60	C3	Gf	openings - door	glass	2	1.23	2.00	0.008	2.444	0.02	2580	50.44	100.88	glass-based
MFH	1946-60	C3	Gf	openings - door	wood	2	0.86	2.09	0.04	1.793	0.07	455	32.63	65.27	wood-based
MFH	1946-60	C3	Gf	openings - door	wood	2	0.76	2.09	0.04	1.58	0.06	455	28.84	57.68	wood-based
MFH	1946-60	C3	Gf	openings - door	wood	6	0.61	2.09	0.04	1.27	0.05	455	23.15	138.89	wood-based
MFH	1946-60	C3	Gf	openings - door frame	wood	1	0.05	0.115	64.75	0.01	0.37	455	169.39	169.39	wood-based
MFH	1946-60	C3	Gf	walls	clay bricks	1	67.78	3.2	0.38	185.14	70.35	1800	126,637.83	126,637.83	clay-based
MFH	1946-60	C3	Gf	walls	clay bricks	1	8.60	3.2	0.25	27.52	6.88	1800	12,384.00	12,384.00	clay-based
MFH	1946-60	C3	Gf	walls	clay bricks	1	15.40	3.2	0.07	41.65	2.92	1800	5,247.76	5,247.76	clay-based
MFH	1946-60	C3	Gf	wall covering - plaster	lime-sand plaster	1	158.94	3.2	0.05	508.62	25.431	1800	45,776.15	45,776.15	plaster-based
MFH	1946-60	C3	Gf	stairs	reinf. concrete	7	0.17	0.29	1.90	0.02	0.047	2500	117.09	819.61	concrete-based
MFH	1946-60	C3	Gf	stairs - railings	steel	2	6.6	0.016	0.016	0.11	0.002	7860	13.28	26.56	metal-based
MFH	1946-60	C3	Gf	stairs - railings	steel	66	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	111.55	metal-based
MFH	1946-60	C3	Gf	stairs	reinf. concrete	20	0.16	0.29	1.15	0.02	0.03	2500	66.70	1,334.00	concrete-based
MFH	1946-60	C3	Gf	ceiling covering - reed	reed	1	n/a	n/a	0.01	106.14	1.06	150	159.21	159.21	organic - misc.
MFH	1946-60	C3	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.04	106.14	4.25	1800	7,642.08	7,642.08	plaster-based
MFH	1946-60	C3	Gf	ceiling covering - battens	wood	16	0.03	0.04	12.74	0.001	0.02	455	6.96	107.82	wood-based
MFH	1946-60	C3	Gf	ceiling covering - battens	wood	19	0.03	0.04	9.80	0.001	0.01	455	5.35	98.99	wood-based
MFH	1946-60	C3	Gf	slab	reinf. concrete	33	0.07	5.55	0.25	0.39	0.10	2500	242.81	8,093.75	concrete-based
MFH	1946-60	C3	Gf	slab	reinf. concrete	39	0.07	4.65	0.25	0.33	0.08	2500	203.44	7,853.92	concrete-based
MFH	1946-60	C3	Gf	slab	reinf. concrete	1	12.74	10.58	0.05	134.79	6.74	2500	16,848.65	16,848.65	concrete-based
MFH	1946-60	C3	1st - 3rd	balcony	reinf. concrete	3	5.50	1	0.10	5.50	0.55	2500	1,375.00	4,125.00	concrete-based
MFH	1946-60	C3	1st - 3rd	floor covering - terazzo	terazzo	3	5.50	1	0.05	5.50	0.28	2500	687.50	2,062.50	concrete-based
MFH	1946-60	C3	1st - 3rd	balcony	reinf. concrete	6	2.50	1.2	0.10	3.00	0.30	2500	750.00	4,500.00	concrete-based
MFH	1946-60	C3	1st - 3rd	floor covering - terazzo	terazzo	6	2.50	1.2	0.05	3.00	0.15	2500	375.00	2,250.00	concrete-based
MFH	1946-60	C3	1st - 3rd	balcony - railings	steel	624	0.020	0.016	0.84	0.0003	0.0003	7860	2.11	1,318.37	metal-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C3	1st - 3rd	balcony - railings	steel	3	20.80	0.016	0.02	0.3328	0.01	7860	41.85	125.56	metal-based
MFH	1946-60	C3	1st - 3rd	floor covering - screed	cement-sand plaster	3	12.00	9.8	0.05	111.39	5.57	2100	11,695.95	35,087.85	plaster-based
MFH	1946-60	C3	1st - 3rd	floor covering - terazzo	terazzo	3	3.30	3.2	0.05	10.56	0.53	2500	1,320.00	3,960.00	concrete-based
MFH	1946-60	C3	1st - 3rd	floor covering - terazzo	terazzo	3	4.40	1.8	0.05	7.92	0.40	2500	990.00	2,970.00	concrete-based
MFH	1946-60	C3	1st - 3rd	floor covering - parquet	wood	3	n/a	n/a	0.02	92.91	2.04	455	930.03	2,790.09	wood-based
MFH	1946-60	C3	1st - 3rd	openings - window	glass	3	2.08	1.22	0.008	2.54	0.02	2580	52.39	157.17	glass-based
MFH	1946-60	C3	1st - 3rd	openings - window	glass	6	1.53	1.22	0.008	1.87	0.01	2580	38.50	230.97	glass-based
MFH	1946-60	C3	1st - 3rd	openings - window	glass	12	1.03	1.22	0.008	1.25	0.01	2580	25.87	310.49	glass-based
MFH	1946-60	C3	1st - 3rd	openings - window	glass	6	0.93	1.22	0.008	1.13	0.01	2580	23.35	140.10	glass-based
MFH	1946-60	C3	1st - 3rd	openings - window	glass	6	0.18	0.42	0.008	0.07	0.001	2580	1.53	9.17	glass-based
MFH	1946-60	C3	1st - 3rd	openings - window	glass	3	1.73	1.42	0.004	2.45	0.01	2580	25.33	76.00	glass-based
MFH	1946-60	C3	1st - 3rd	openings - window frame	wood	3	0.14	0.09	452.08	0.01	5.70	455	2,591.77	7,775.31	wood-based
MFH	1946-60	C3	1st - 3rd	openings - door	glass	12	0.43	2.00	0.008	0.85	0.01	2580	17.50	210.00	glass-based
MFH	1946-60	C3	1st - 3rd	openings - door	wood	6	0.86	2.09	0.04	1.79	0.07	455	32.63	195.81	wood-based
MFH	1946-60	C3	1st - 3rd	openings - door	wood	9	0.76	2.09	0.04	1.58	0.06	455	28.84	259.56	wood-based
MFH	1946-60	C3	1st - 3rd	openings - door	wood	18	0.61	2.09	0.04	1.27	0.05	455	23.15	416.66	wood-based
MFH	1946-60	C3	1st - 3rd	openings - door frame	wood	3	0.05	0.115	213.57	0.01	1.23	455	558.75	1,676.26	wood-based
MFH	1946-60	C3	1st - 3rd	walls	clay bricks	3	69.98	3.2	0.38	198.51	75.434	1800	135,781.60	407,344.80	clay-based
MFH	1946-60	C3	1st - 3rd	walls	clay bricks	3	4.30	3.2	0.25	13.76	3.44	1800	6,192.00	18,576.00	clay-based
MFH	1946-60	C3	1st - 3rd	walls	clay bricks	3	25.30	3.2	0.07	73.33	5.13	1800	9,239.44	27,718.32	clay-based
MFH	1946-60	C3	1st - 3rd	wall covering - plaster	lime-sand plaster	3	178.50	3.2	0.02	571.20	11.42	1800	20,563.20	61,689.60	plaster-based
MFH	1946-60	C3	1st - 3rd	stairs	reinf. concrete	60	0.16	0.29	1.15	0.02	0.03	2500	66.70	4,002.00	concrete-based
MFH	1946-60	C3	1st - 3rd	stairs - railings	steel	6	6.6	0.016	0.016	0.11	0.002	7860	13.28	79.68	metal-based
MFH	1946-60	C3	1st - 3rd	stairs - railings	steel	198	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	334.66	metal-based
MFH	1946-60	C3	1st - 3rd	ceiling covering - reed	reed	3	n/a	n/a	0.01	106.14	1.06	150	159.21	477.63	organic - misc.
MFH	1946-60	C3	1st - 3rd	ceiling covering - plaster	lime-sand plaster	3	n/a	n/a	0.04	106.14	4.25	1800	7,642.08	22,926.24	plaster-based
MFH	1946-60	C3	1st - 3rd	ceiling covering - battens	wood	47	0.03	0.04	12.74	0.001	0.02	455	6.96	323.46	wood-based
MFH	1946-60	C3	1st - 3rd	ceiling covering - battens	wood	56	0.03	0.04	9.80	0.001	0.01	455	5.35	296.97	wood-based
MFH	1946-60	C3	1st - 3rd	slab	reinf. concrete	100	0.07	5.55	0.25	0.39	0.10	2500	242.81	24,281.25	concrete-based
MFH	1946-60	C3	1st - 3rd	slab	reinf. concrete	116	0.07	4.65	0.25	0.33	0.08	2500	203.44	23,561.76	concrete-based
MFH	1946-60	C3	1st - 3rd	slab	reinf. concrete	3	12.74	10.58	0.05	134.79	6.74	2500	16,848.65	50,545.95	concrete-based
MFH	1946-60	C3	Roof	floor covering - mud and husk	mud and husk	1	n/a	n/a	0.05	117.64	5.88	400	2,352.80	2,352.80	organic - misc.
MFH	1946-60	C3	Roof	slab	reinf. concrete	1	6.00	2.3	0.10	13.80	1.38	2500	3,450.00	3,450.00	concrete-based
MFH	1946-60	C3	Roof	walls	clay bricks	2	12.74	3.5	0.25	22.30	5.57	1800	10,032.75	20,065.50	clay-based
MFH	1946-60	C3	Roof	wall covering - plaster	lime-sand plaster	1	12.74	3.5	0.02	44.59	0.89	1800	1,605.24	1,605.24	plaster-based
MFH	1946-60	C3	Roof	roof - beams	wood	42	0.12	0.14	6.80	0.02	0.11	455	51.98	2,183.13	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	8	0.14	0.14	2.30	0.02	0.05	455	20.51	164.09	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	16	0.10	0.12	1.10	0.01	0.01	455	6.01	96.10	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	2	0.14	0.14	3.00	0.02	0.06	455	26.75	53.51	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	4	0.10	0.12	0.60	0.01	0.01	455	3.28	13.10	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	4	0.14	0.16	3.00	0.02	0.07	455	30.58	111.30	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	16	0.12	0.14	4.00	0.02	0.07	455	30.58	489.22	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	2	0.14	0.14	10.44	0.02	0.20	455	93.10	186.21	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	2	0.14	0.14	12.80	0.02	0.25	455	114.15	228.30	wood-based
MFH	1946-60	C3	Roof	roof - beams	wood	3	0.14	0.14	2.40	0.02	0.05	455	21.40	64.21	wood-based
MFH	1946-60	C3	Roof	roof - battens	wood	45	0.05	0.033	12.80	0.002	0.02	455	9.23	418.21	wood-based
MFH	1946-60	C3	Roof	roof covering - tiles	clay roof-tiles	2428	0.40	0.2	0.02	0.08	0.002	1644	2.63	6,386.19	clay-based
MFH	1946-60	C3	Roof	gutters	sheet metal	1	104.80	0.2	0.00065	20.96	0.01	7860	107.08	107.08	metal-based
MFH	1946-60	C4	B	base slab - gravel	gravel	1	17.50	11	0.10	192.50	19.25	1850	35,612.50	35,612.50	stone-based
MFH	1946-60	C4	B	base slab	concrete	1	17.50	11	0.10	192.50	19.25	2400	46,200.00	46,200.00	concrete-based
MFH	1946-60	C4	B	floor covering - water-proofing	bitumen	1	17.50	11	0.01	192.50	1.93	1500	2,887.50	2,887.50	bitumen-based
MFH	1946-60	C4	B	floor covering - screed	cement-sand plaster	1	17.50	11	0.05	192.50	9.63	2100	20,212.50	20,212.50	plaster-based
MFH	1946-60	C4	B	openings - window	glass	12	0.50	0.40	0.004	0.20	0.001	2580	2.06	24.77	glass-based
MFH	1946-60	C4	B	openings - window frame	steel	1	0.10	0.005	21.60	0.001	0.01	7860	84.89	84.89	metal-based
MFH	1946-60	C4	B	openings - door	glass	1	0.90	2.00	0.004	1.80	0.01	2580	18.53	18.53	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C4	B	openings - door frame	steel	1	0.10	0.005	4.89	0.001	0.002	7860	19.22	19.22	metal-based
MFH	1946-60	C4	B	walls	clay bricks	1	45.00	2.2	0.38	94.80	36.03	1800	64,846.28	64,846.28	clay-based
MFH	1946-60	C4	B	walls	clay bricks	1	28.48	2.2	0.25	62.66	15.66	1800	28,195.20	28,195.20	clay-based
MFH	1946-60	C4	B	wall covering - plaster	lime-sand plaster	1	143.15	2.2	0.02	314.92	6.30	1800	11,337.16	11,337.16	plaster-based
MFH	1946-60	C4	B	wall covering - plaster	concrete	1	35.00	1.2	0.03	42.00	1.26	2400	3,024.00	3,024.00	concrete-based
MFH	1946-60	C4	B	stairs	prefab. concrete	16	0.05	0.3	1.20	0.02	0.02	2500	45.00	720.00	concrete-based
MFH	1946-60	C4	B	stairs - railings	steel	2	6.8	0.016	0.016	0.11	0.002	7860	13.68	27.37	metal-based
MFH	1946-60	C4	B	stairs - railings	steel	68	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	114.93	metal-based
MFH	1946-60	C4	B	slab	prefab. concrete	44	0.06	4.2	0.25	0.23	0.06	2500	144.38	6,316.41	concrete-based
MFH	1946-60	C4	B	slab	prefab. concrete	38	0.06	6	0.25	0.33	0.08	2500	206.25	7,734.38	concrete-based
MFH	1946-60	C4	B	slab	concrete	1	17.50	11	0.05	192.50	9.63	2400	23,100.00	23,100.00	concrete-based
MFH	1946-60	C4	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.03	164.46	4.93	2100	10,360.98	10,360.98	plaster-based
MFH	1946-60	C4	Gf	floor covering - terazzo	terazzo	1	2.50	2.06	0.05	5.15	0.26	2500	643.75	643.75	concrete-based
MFH	1946-60	C4	Gf	floor covering - terazzo	terazzo	1	2.60	2.6	0.05	6.76	0.34	2500	845.00	845.00	concrete-based
MFH	1946-60	C4	Gf	floor covering - terazzo	terazzo	2	6.10	3.2	0.05	19.52	0.98	2500	2,440.00	4,880.00	concrete-based
MFH	1946-60	C4	Gf	floor covering - parquet	wood	1	n/a	n/a	0.03	111.08	3.33	455	1,516.24	1,516.24	wood-based
MFH	1946-60	C4	Gf	openings - window	glass	8	1.53	1.22	0.008	1.87	0.01	2580	38.50	307.96	glass-based
MFH	1946-60	C4	Gf	openings - window	glass	1	0.53	1.22	0.008	0.64	0.01	2580	13.25	13.25	glass-based
MFH	1946-60	C4	Gf	openings - window	glass	4	0.33	0.42	0.008	0.14	0.001	2580	2.84	11.35	glass-based
MFH	1946-60	C4	Gf	openings - window frame	wood	1	0.14	0.09	53.45	0.01	0.67	455	306.42	306.42	wood-based
MFH	1946-60	C4	Gf	openings - door	glass	1	1.88	2.15	0.008	4.02	0.03	2580	83.03	83.03	glass-based
MFH	1946-60	C4	Gf	openings - door	glass	2	1.38	1.85	0.008	2.54	0.02	2580	52.38	104.76	glass-based
MFH	1946-60	C4	Gf	openings - door	plywood	7	0.81	1.94	0.012	1.57	0.02	427	8.03	56.22	wood-based
MFH	1946-60	C4	Gf	openings - door	plywood	2	0.71	1.94	0.012	1.37	0.02	427	7.04	14.08	wood-based
MFH	1946-60	C4	Gf	openings - door	plywood	3	0.61	1.94	0.012	1.18	0.01	427	6.05	18.14	wood-based
MFH	1946-60	C4	Gf	openings - door	plywood	1	0.51	1.94	0.012	0.99	0.01	427	5.06	5.06	wood-based
MFH	1946-60	C4	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	18.25	0.55	5.8	3.17	3.17	organic - misc.
MFH	1946-60	C4	Gf	openings - door frame	wood	1	0.09	0.31	76.04	0.03	2.12	455	965.25	965.25	wood-based
MFH	1946-60	C4	Gf	walls	clay bricks	1	45.00	2.9	0.38	109.07	41.45	1800	74,605.30	74,605.30	clay-based
MFH	1946-60	C4	Gf	walls	clay bricks	1	40.28	2.9	0.25	113.40	28.35	1800	51,031.06	51,031.06	clay-based
MFH	1946-60	C4	Gf	walls	clay bricks	1	31.40	2.9	0.12	72.44	8.69	1800	15,646.91	15,646.91	clay-based
MFH	1946-60	C4	Gf	walls	clay bricks	1	12.66	2.9	0.08	35.53	2.84	1800	5,116.85	5,116.85	clay-based
MFH	1946-60	C4	Gf	wall covering - tiles	lime-sand plaster	1	227.89	2.9	0.02	660.89	13.22	1800	23,792.22	23,792.22	plaster-based
MFH	1946-60	C4	Gf	stairs	prefab. concrete	20	0.05	0.3	1.20	0.02	0.02	2500	45.00	900.00	concrete-based
MFH	1946-60	C4	Gf	stairs - railings	steel	2	6.8	0.016	0.016	0.11	0.002	7860	13.68	27.37	metal-based
MFH	1946-60	C4	Gf	stairs - railings	steel	68	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	114.93	metal-based
MFH	1946-60	C4	Gf	ceiling covering - reed	reed	1	16.98	10.24	0.01	158.25	1.58	150	237.38	237.38	organic - misc.
MFH	1946-60	C4	Gf	ceiling covering - plaster	lime-sand plaster	1	16.98	10.24	0.04	158.25	6.33	1800	11,394.01	11,394.01	plaster-based
MFH	1946-60	C4	Gf	ceiling covering - battens	wood	11	0.03	0.04	17.00	0.001	0.02	455	9.28	104.42	wood-based
MFH	1946-60	C4	Gf	ceiling covering - battens	wood	16	0.03	0.04	14.50	0.001	0.02	455	7.92	128.65	wood-based
MFH	1946-60	C4	Gf	slab	prefab. concrete	44	0.06	4.5	0.25	0.25	0.06	2500	154.69	6,767.58	concrete-based
MFH	1946-60	C4	Gf	slab	prefab. concrete	38	0.06	6.5	0.25	0.36	0.09	2500	223.44	8,378.91	concrete-based
MFH	1946-60	C4	Gf	slab	concrete	1	17.50	11	0.05	192.50	9.63	2400	23,100.00	23,100.00	concrete-based
MFH	1946-60	C4	1st - 3rd	balcony	concrete	3	3.40	0.9	0.10	3.06	0.31	2400	734.40	2,203.20	concrete-based
MFH	1946-60	C4	1st - 3rd	floor covering - terazzo	terazzo	3	3.40	0.9	0.05	3.06	0.15	2500	382.50	1,147.50	concrete-based
MFH	1946-60	C4	1st - 3rd	balcony	concrete	6	2.20	0.8	0.10	1.76	0.18	2400	422.40	2,534.40	concrete-based
MFH	1946-60	C4	1st - 3rd	floor covering - terazzo	terazzo	6	2.20	0.8	0.05	1.76	0.09	2500	220.00	1,320.00	concrete-based
MFH	1946-60	C4	1st - 3rd	balcony - railings	concrete	3	7.80	0.1	0.84	0.78	0.66	2400	1,572.48	4,717.44	concrete-based
MFH	1946-60	C4	1st - 3rd	balcony - railings	steel	144	0.02	0.016	0.84	0.0003	0.0002	7860	1.69	243.39	metal-based
MFH	1946-60	C4	1st - 3rd	floor covering - screed	cement-sand plaster	3	16.98	10.24	0.03	173.88	5.22	2100	10,954.14	32,862.41	plaster-based
MFH	1946-60	C4	1st - 3rd	floor covering - terazzo	terazzo	3	2.60	2.6	0.05	6.76	0.34	2500	845.00	2,535.00	concrete-based
MFH	1946-60	C4	1st - 3rd	floor covering - terazzo	terazzo	6	6.10	3.2	0.05	19.52	0.98	2500	2,440.00	14,640.00	concrete-based
MFH	1946-60	C4	1st - 3rd	floor covering - terazzo	terazzo	6	2.06	2.5	0.05	5.15	0.26	2500	643.75	3,862.50	concrete-based
MFH	1946-60	C4	1st - 3rd	floor covering - parquet	wood	3	n/a	n/a	0.02	111.08	2.44	455	1,111.91	3,335.73	wood-based
MFH	1946-60	C4	1st - 3rd	openings - window	glass	18	1.53	1.22	0.008	1.87	0.01	2580	38.50	692.91	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C4	1st - 3rd	openings - window	glass	6	0.73	1.22	0.008	0.89	0.01	2580	18.30	109.81	glass-based
MFH	1946-60	C4	1st - 3rd	openings - window	glass	12	0.33	0.42	0.008	0.14	0.001	2580	2.84	34.05	glass-based
MFH	1946-60	C4	1st - 3rd	openings - window	glass	3	2.36	2.17	0.004	5.12	0.02	2580	52.85	158.55	glass-based
MFH	1946-60	C4	1st - 3rd	openings - window frame	wood	3	0.14	0.09	167.44	0.01	2.11	455	959.91	2,879.73	wood-based
MFH	1946-60	C4	1st - 3rd	openings - door	glass	9	0.53	2.15	0.008	1.13	0.01	2580	23.24	209.19	glass-based
MFH	1946-60	C4	1st - 3rd	openings - door	glass	2	1.38	1.85	0.008	2.54	0.02	2580	52.38	104.76	glass-based
MFH	1946-60	C4	1st - 3rd	openings - door	plywood	21	0.81	1.94	0.012	1.57	0.02	427	8.03	168.65	wood-based
MFH	1946-60	C4	1st - 3rd	openings - door	plywood	12	0.71	1.94	0.012	1.37	0.02	427	7.04	84.48	wood-based
MFH	1946-60	C4	1st - 3rd	openings - door	plywood	9	0.61	1.94	0.012	1.18	0.01	427	6.05	54.43	wood-based
MFH	1946-60	C4	1st - 3rd	openings - door	plywood	3	0.51	1.94	0.012	0.99	0.01	427	5.06	15.17	wood-based
MFH	1946-60	C4	1st - 3rd	openings - door	cardboard (honeycomb)	3	n/a	n/a	0.030	20.99	0.63	5.8	3.65	10.96	organic - misc.
MFH	1946-60	C4	1st - 3rd	openings - door frame	wood	3	0.09	0.31	260.17	0.03	7.26	455	3,302.68	9,908.03	wood-based
MFH	1946-60	C4	1st - 3rd	walls	clay bricks	3	45.00	2.9	0.38	107.19	40.73	1800	73,320.92	219,962.75	clay-based
MFH	1946-60	C4	1st - 3rd	walls	clay bricks	3	40.28	2.9	0.25	113.40	28.35	1800	51,031.06	153,093.17	clay-based
MFH	1946-60	C4	1st - 3rd	walls	clay bricks	3	31.40	2.9	0.12	73.81	8.86	1800	15,943.66	47,830.99	clay-based
MFH	1946-60	C4	1st - 3rd	walls	clay bricks	3	12.66	2.9	0.08	34.35	2.75	1800	4,946.88	14,840.63	clay-based
MFH	1946-60	C4	1st - 3rd	wall covering - plaster	lime-sand plaster	3	226.73	2.9	0.02	657.53	13.15	1800	23,670.95	71,012.86	plaster-based
MFH	1946-60	C4	1st - 3rd	stairs	reinf. concrete	60	0.05	0.3	1.20	0.02	0.02	2500	45.00	2,700.00	concrete-based
MFH	1946-60	C4	1st - 3rd	stairs - railings	steel	6	6.8	0.016	0.016	0.11	0.002	7860	13.68	82.10	metal-based
MFH	1946-60	C4	1st - 3rd	stairs - railings	steel	204	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	344.80	metal-based
MFH	1946-60	C4	1st - 3rd	ceiling covering - reed	reed	3	16.98	10.24	0.01	159.38	1.59	150	239.06	717.19	organic - misc.
MFH	1946-60	C4	1st - 3rd	ceiling covering - plaster	lime-sand plaster	3	16.98	10.24	0.04	159.38	6.38	1800	11,475.01	34,425.04	plaster-based
MFH	1946-60	C4	1st - 3rd	ceiling covering - battens	wood	83	0.03	0.04	17.00	0.001	0.02	455	9.28	765.77	wood-based
MFH	1946-60	C4	1st - 3rd	slab	prefab. concrete	131	0.06	4.5	0.25	0.25	0.06	2500	154.69	20,302.73	concrete-based
MFH	1946-60	C4	1st - 3rd	slab	prefab. concrete	113	0.06	6.5	0.25	0.36	0.09	2500	223.44	25,136.72	concrete-based
MFH	1946-60	C4	3rd	slab	prefab. concrete	6	0.06	6.5	0.25	0.36	0.09	2500	223.44	1,396.48	concrete-based
MFH	1946-60	C4	1st - 3rd	slab	concrete	3	17.50	11	0.05	192.50	9.63	2400	23,100.00	69,300.00	concrete-based
MFH	1946-60	C4	Roof	floor covering - mud and husk	mud and husk	1	16.98	10.24	0.05	173.875	8.69	400	3,477.50	3,477.50	organic - misc.
MFH	1946-60	C4	Roof	floor covering - sand	sand	1	16.98	10.24	0.02	173.88	3.48	1300	4,520.76	4,520.76	plaster-based
MFH	1946-60	C4	Roof	walls	clay bricks	2	10.24	2.2	0.25	11.26	2.82	1800	5,068.80	10,137.60	clay-based
MFH	1946-60	C4	Roof	wall covering - plaster	lime-sand plaster	2	10.24	2.2	0.02	11.26	0.23	1800	405.50	811.01	plaster-based
MFH	1946-60	C4	Roof	roof - beams	wood	2	0.12	0.14	17.50	0.017	0.29	455	133.77	267.54	wood-based
MFH	1946-60	C4	Roof	roof - beams	wood	2	0.18	0.2	17.50	0.036	0.63	455	286.65	573.30	wood-based
MFH	1946-60	C4	Roof	roof - beams	wood	50	0.12	0.14	5.80	0.017	0.10	455	44.34	2,216.76	wood-based
MFH	1946-60	C4	Roof	roof - battens	wood	23	0.08	0.048	17.50	0.004	0.06	455	29.05	673.90	wood-based
MFH	1946-60	C4	Roof	roof covering - corr. cement sheets	asbestos-cement sheets	185	1.25	1.05	0.006	1.31	0.01	1675	13.19	2,434.04	asbestos-cement-based
MFH	1946-60	C4	Roof	gutters	sheet metal	1	89.40	0.2	0.00065	17.88	0.01	7860	91.35	91.35	metal-based
MFH	1946-60	C5	B	base slab - gravel	gravel	1	17.40	11.4	0.10	198.36	19.84	1850	36,696.60	36,696.60	stone-based
MFH	1946-60	C5	B	base slab	concrete	1	17.40	11.4	0.10	198.36	19.84	2400	47,606.40	47,606.40	concrete-based
MFH	1946-60	C5	B	floor covering - water-proofing	bitumen	1	17.40	11.4	0.01	198.36	1.98	1500	2,975.40	2,975.40	bitumen-based
MFH	1946-60	C5	B	floor covering - screed	cement-sand plaster	1	16.90	10.77	0.05	182.01	9.10	2100	19,111.37	19,111.37	plaster-based
MFH	1946-60	C5	B	walls	clay bricks	1	60.80	2.85	0.38	173.28	65.85	1800	118,523.52	118,523.52	clay-based
MFH	1946-60	C5	B	walls	reinf. concrete	1	11.40	2.85	0.25	32.49	8.12	2500	20,306.25	20,306.25	concrete-based
MFH	1946-60	C5	B	walls	clay bricks	1	24.26	2.85	0.25	69.14	17.29	1800	31,113.45	31,113.45	clay-based
MFH	1946-60	C5	B	wall covering - plaster	lime-sand plaster	1	192.92	2.85	0.02	549.82	11.00	1800	19,793.59	19,793.59	plaster-based
MFH	1946-60	C5	B	stairs	reinf. concrete	10	0.30	0.21	1.30	0.032	0.04	2500	102.38	1,023.75	concrete-based
MFH	1946-60	C5	Gf	stairs - railings	steel	2	6.8	0.016	0.016	0.11	0.002	7860	13.68	27.37	metal-based
MFH	1946-60	C5	Gf	stairs - railings	steel	68	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	114.93	metal-based
MFH	1946-60	C5	B	stairs	reinf. concrete	6	0.30	0.15	1.60	0.023	0.04	2500	90.00	540.00	concrete-based
MFH	1946-60	C5	B	slab	prefab. concrete	33	0.06	5.6	0.25	0.31	0.08	2500	192.50	6,400.63	concrete-based
MFH	1946-60	C5	B	slab	prefab. concrete	37	0.06	5.8	0.25	0.32	0.08	2500	199.38	7,376.88	concrete-based
MFH	1946-60	C5	B	slab	concrete	1	17.40	11.4	0.05	198.36	9.92	2400	23,803.20	23,803.20	concrete-based
MFH	1946-60	C5	Gf	floor covering - magnesite screed	magnesite screed	1	16.90	10.77	0.03	171.19	5.14	1100	5,649.37	5,649.37	concrete-based
MFH	1946-60	C5	Gf	floor covering - terazzo	terazzo	1	1.70	10.2	0.05	17.34	0.87	2500	2,167.50	2,167.50	concrete-based
MFH	1946-60	C5	Gf	floor covering - terazzo	terazzo	1	2.30	2.5	0.05	5.75	0.29	2500	718.75	718.75	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C5	Gf	floor covering - terazzo	terazzo	2	3.80	3	0.05	11.40	0.57	2500	1,425.00	2,850.00	concrete-based
MFH	1946-60	C5	Gf	floor covering - terazzo	terazzo	1	2.00	2.3	0.05	4.60	0.23	2500	575.00	575.00	concrete-based
MFH	1946-60	C5	Gf	floor covering - terazzo	terazzo	1	1.50	4.3	0.05	6.45	0.32	2500	806.25	806.25	concrete-based
MFH	1946-60	C5	Gf	floor covering - terazzo	terazzo	1	3.10	3.2	0.05	9.92	0.50	2500	1,240.00	1,240.00	concrete-based
MFH	1946-60	C5	Gf	floor covering - parquet	wood	1	n/a	n/a	0.02	104.33	2.30	455	1,044.37	1,044.37	wood-based
MFH	1946-60	C5	Gf	openings - window	glass	2	2.08	1.32	0.008	2.75	0.02	2580	56.68	113.35	glass-based
MFH	1946-60	C5	Gf	openings - window	glass	2	1.33	1.32	0.008	1.75	0.01	2580	36.18	72.36	glass-based
MFH	1946-60	C5	Gf	openings - window	glass	2	0.93	1.32	0.008	1.22	0.01	2580	25.26	50.52	glass-based
MFH	1946-60	C5	Gf	openings - window	glass	2	0.58	1.32	0.008	0.76	0.01	2580	15.70	31.40	glass-based
MFH	1946-60	C5	Gf	openings - window	glass	2	0.43	0.62	0.008	0.26	0.002	2580	5.46	10.93	glass-based
MFH	1946-60	C5	Gf	openings - window	glass	1	3.00	3.25	0.004	9.75	0.04	2580	100.62	100.62	glass-based
MFH	1946-60	C5	Gf	openings - window frame	steel	1	0.10	0.005	12.50	0.001	0.01	7860	49.13	49.13	metal-based
MFH	1946-60	C5	Gf	openings - window frame	wood	1	0.14	0.09	44.96	0.01	0.57	455	257.77	257.77	wood-based
MFH	1946-60	C5	Gf	openings - door	glass	1	1.13	2.10	0.008	2.36	0.02	2580	48.65	48.65	glass-based
MFH	1946-60	C5	Gf	openings - door	glass	2	0.53	2.15	0.008	1.13	0.01	2580	23.24	46.49	glass-based
MFH	1946-60	C5	Gf	openings - door	wood	8	0.86	1.94	0.04	1.66	0.067	455	30.29	242.29	wood-based
MFH	1946-60	C5	Gf	openings - door	wood	4	0.61	1.94	0.04	1.18	0.05	455	21.48	85.93	wood-based
MFH	1946-60	C5	Gf	openings - door	glass	1	2.00	2.89	0.004	5.78	0.02	2580	59.65	59.65	glass-based
MFH	1946-60	C5	Gf	openings - door frame	steel	1	0.10	0.005	7.78	0.001	0.004	7860	30.58	30.58	metal-based
MFH	1946-60	C5	Gf	openings - door frame	wood	1	0.05	0.115	70.71	0.01	0.41	455	184.98	184.98	wood-based
MFH	1946-60	C5	Gf	walls	clay bricks	1	48.50	3.07	0.38	119.90	45.56	1800	82,014.46	82,014.46	clay-based
MFH	1946-60	C5	Gf	walls	clay bricks	1	37.70	3.07	0.25	101.05	25.26	1800	45,472.56	45,472.56	clay-based
MFH	1946-60	C5	Gf	walls	reinf. concrete	1	11.40	3.07	0.25	35.00	8.75	2500	21,873.75	21,873.75	concrete-based
MFH	1946-60	C5	Gf	walls	clay bricks	1	17.20	3.07	0.07	43.09	3.02	1800	5,429.38	5,429.38	clay-based
MFH	1946-60	C5	Gf	wall covering - plaster	lime-sand plaster	1	194.82	3.07	0.02	598.09	11.96	1800	21,531.07	21,531.07	plaster-based
MFH	1946-60	C5	Gf	wall covering - aggregate plaster	cement-sand plaster	1	34.80	1	0.03	34.80	1.04	2100	2,192.40	2,192.40	plaster-based
MFH	1946-60	C5	Gf	stairs	reinf. concrete	20	0.16	0.3	1.30	0.02	0.03	2500	78.00	1,560.00	concrete-based
MFH	1946-60	C5	Gf	stairs - railings	steel	2	6.8	0.016	0.016	0.11	0.002	7860	13.68	27.37	metal-based
MFH	1946-60	C5	Gf	stairs - railings	steel	68	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	114.93	metal-based
MFH	1946-60	C5	Gf	ceiling covering - plaster	lime-sand plaster	1	16.90	10.77	0.04	171.19	6.85	1800	12,325.90	12,325.90	plaster-based
MFH	1946-60	C5	Gf	slab	prefab. concrete	44	0.06	5.6	0.25	0.31	0.08	2500	192.50	8,373.75	concrete-based
MFH	1946-60	C5	Gf	slab	prefab. concrete	37	0.06	5.8	0.25	0.32	0.08	2500	199.38	7,376.88	concrete-based
MFH	1946-60	C5	Gf	slab	concrete	1	17.40	11.4	0.05	198.36	9.92	2400	23,803.20	23,803.20	concrete-based
MFH	1946-60	C5	1st - 4th	balcony	reinf. concrete	8	4.80	0.6	0.10	2.88	0.29	2500	720.00	5,760.00	concrete-based
MFH	1946-60	C5	1st - 4th	balcony - railings	steel	8	13.80	0.016	0.016	0.22	0.004	7860	27.77	222.14	metal-based
MFH	1946-60	C5	1st - 4th	balcony - railings	glass	8	4.80	0.84	0.007	4.03	0.03	2580	72.82	582.54	glass-based
MFH	1946-60	C5	1st - 4th	floor covering - magnesite screed	magnesite screed	4	16.90	10.77	0.03	171.19	5.14	1100	5,649.37	22,597.48	concrete-based
MFH	1946-60	C5	1st - 4th	floor covering - terazzo	terazzo	4	5.40	2	0.05	10.80	0.54	2500	1,350.00	5,400.00	concrete-based
MFH	1946-60	C5	1st - 4th	floor covering - terazzo	terazzo	4	2.30	2.5	0.05	5.75	0.29	2500	718.75	2,875.00	concrete-based
MFH	1946-60	C5	1st - 4th	floor covering - terazzo	terazzo	8	3.80	3.2	0.05	12.16	0.61	2500	1,520.00	12,160.00	concrete-based
MFH	1946-60	C5	1st - 4th	floor covering - terazzo	terazzo	4	1.50	4.3	0.05	6.45	0.32	2500	806.25	3,225.00	concrete-based
MFH	1946-60	C5	1st - 4th	floor covering - parquet	wood	4	17.40	11.4	0.02	123.87	2.73	455	1,239.97	4,959.87	wood-based
MFH	1946-60	C5	1st - 4th	openings - window	glass	4	1.45	2.46	0.004	3.57	0.01	2580	36.81	147.25	glass-based
MFH	1946-60	C5	1st - 4th	openings - window	glass	20	1.33	1.32	0.008	1.75	0.01	2580	36.18	723.63	glass-based
MFH	1946-60	C5	1st - 4th	openings - window	glass	8	0.93	1.32	0.008	1.22	0.01	2580	25.26	202.07	glass-based
MFH	1946-60	C5	1st - 4th	openings - window	glass	8	0.58	1.32	0.008	0.76	0.01	2580	15.70	125.61	glass-based
MFH	1946-60	C5	1st - 4th	openings - window	glass	8	0.43	0.62	0.008	0.26	0.002	2580	5.46	43.72	glass-based
MFH	1946-60	C5	1st - 4th	openings - window frame	wood	4	0.14	0.09	220.30	0.01	2.78	455	1,263.00	5,052.01	wood-based
MFH	1946-60	C5	1st - 4th	openings - door	glass	16	0.53	2.15	0.008	1.13	0.01	2580	23.24	371.89	glass-based
MFH	1946-60	C5	1st - 4th	openings - door	wood	40	0.81	1.94	0.04	1.57	0.06	455	28.53	1,141.03	wood-based
MFH	1946-60	C5	1st - 4th	openings - door	wood	12	0.61	1.94	0.04	1.18	0.05	455	21.48	257.79	wood-based
MFH	1946-60	C5	1st - 4th	openings - door frame	wood	4	0.05	0.115	318.00	0.01	1.83	455	831.97	3,327.87	wood-based
MFH	1946-60	C5	1st - 4th	walls	clay bricks	4	48.50	2.85	0.38	119.90	45.56	1800	82,011.82	328,047.29	clay-based
MFH	1946-60	C5	1st - 4th	walls	clay bricks	4	30.50	2.85	0.25	74.51	18.63	1800	33,529.79	134,119.17	clay-based
MFH	1946-60	C5	1st - 4th	walls	reinf. concrete	4	11.40	2.85	0.25	32.49	8.12	2500	20,306.25	81,225.00	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C5	1st - 4th	walls	clay bricks	4	17.20	2.85	0.07	36.46	2.55	1800	4,594.19	18,376.77	clay-based
MFH	1946-60	C5	1st - 4th	wall covering - plaster	lime-sand plaster	4	184.82	2.85	0.02	526.73	10.53	1800	18,962.12	75,848.49	plaster-based
MFH	1946-60	C5	1st - 4th	stairs	reinf. concrete	80	0.16	0.3	1.30	0.02	0.03	2500	78.00	6,240.00	concrete-based
MFH	1946-60	C5	1st - 4th	stairs - railings	steel	8	6.8	0.016	0.016	0.11	0.002	7860	13.68	109.46	metal-based
MFH	1946-60	C5	1st - 4th	stairs - railings	steel	272	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	459.74	metal-based
MFH	1946-60	C5	1st - 4th	ceiling covering - reed	reed	4	16.90	10.77	0.01	171.19	1.71	150	256.79	1,027.16	organic - misc.
MFH	1946-60	C5	1st - 4th	ceiling covering - plaster	lime-sand plaster	4	16.90	10.77	0.04	171.19	6.85	1800	12,325.90	49,303.58	plaster-based
MFH	1946-60	C5	1st - 4th	ceiling covering - battens	wood	108	0.03	0.04	16.90	0.001	0.02	455	9.23	993.79	wood-based
MFH	1946-60	C5	1st - 4th	slab	prefab. concrete	174	0.06	5.6	0.25	0.31	0.08	2500	192.50	33,495.00	concrete-based
MFH	1946-60	C5	1st - 4th	slab	prefab. concrete	148	0.06	5.8	0.25	0.32	0.08	2500	199.38	29,507.50	concrete-based
MFH	1946-60	C5	1st - 4th	slab	concrete	4	17.40	11.4	0.05	198.36	9.92	2400	23,803.20	95,212.80	concrete-based
MFH	1946-60	C5	Roof	floor covering - mud and husk	mud and husk	1	16.90	10.77	0.05	158.36	7.92	400	3,167.26	3,167.26	organic - misc.
MFH	1946-60	C5	Roof	slab	reinf. concrete	1	4.30	5.5	0.10	23.65	2.37	2500	5,912.50	5,912.50	concrete-based
MFH	1946-60	C5	Roof	walls	clay bricks	1	11.40	3.6	0.25	20.52	5.13	1800	9,234.00	9,234.00	clay-based
MFH	1946-60	C5	Roof	walls	reinf. concrete	1	11.40	3.6	0.25	20.52	5.13	2500	12,825.00	12,825.00	concrete-based
MFH	1946-60	C5	Roof	wall covering - plaster	lime-sand plaster	1	11.40	3.6	0.02	82.08	1.64	1800	2,954.88	2,954.88	plaster-based
MFH	1946-60	C5	Roof	roof - beams	wood	5	0.16	0.16	17.40	0.03	0.45	455	202.68	1,013.38	wood-based
MFH	1946-60	C5	Roof	roof - beams	wood	1	0.14	0.16	3.50	0.02	0.08	455	35.67	35.67	wood-based
MFH	1946-60	C5	Roof	roof - beams	wood	8	0.16	0.16	2.54	0.03	0.07	455	29.59	236.69	wood-based
MFH	1946-60	C5	Roof	roof - beams	wood	4	0.16	0.16	3.20	0.03	0.08	455	37.27	149.09	wood-based
MFH	1946-60	C5	Roof	roof - beams	wood	8	0.08	0.16	4.40	0.01	0.06	455	25.63	205.00	wood-based
MFH	1946-60	C5	Roof	roof - beams	wood	8	0.14	0.16	3.90	0.02	0.09	455	39.75	317.99	wood-based
MFH	1946-60	C5	Roof	roof - beams	wood	50	0.14	0.16	6.30	0.02	0.14	455	64.21	3,210.48	wood-based
MFH	1946-60	C5	Roof	roof - battens	wood	25	0.08	0.048	17.40	0.004	0.06	455	28.88	727.81	wood-based
MFH	1946-60	C5	Roof	roof covering - corr. cement sheets	asbestos-cement sheets	200	1.25	1.05	0.006	1.31	0.01	1675	13.19	2,631.58	asbestos-cement-based
MFH	1946-60	C5	Roof	gutters	sheet metal	1	106.80	0.2	0.00065	21.36	0.01	7860	109.13	109.13	metal-based
MFH	1946-60	C6	B1-B2	base slab - gravel	gravel	1	17.50	18.2	0.10	318.50	31.85	1850	58,922.50	58,922.50	stone-based
MFH	1946-60	C6	B1-B2	base slab	concrete	1	17.50	18.2	0.80	318.50	254.80	2400	611,520.00	611,520.00	concrete-based
MFH	1946-60	C6	B1-B2	floor covering - water-proofing	bitumen	1	17.50	18.2	0.01	318.50	3.19	1500	4,777.50	4,777.50	bitumen-based
MFH	1946-60	C6	B1-B2	floor covering - screed	cement-sand plaster	1	16.90	10.77	0.05	182.01	9.10	2100	19,111.37	19,111.37	plaster-based
MFH	1946-60	C6	B2	openings - door	sheet metal	1	1.10	2.09	0.003	2.30	0.01	7860	54.21	54.21	metal-based
MFH	1946-60	C6	B2	openings - door	sheet metal	5	0.80	2.09	0.003	1.67	0.01	7860	39.43	197.13	metal-based
MFH	1946-60	C6	B2	openings - door	sheet metal	1	0.55	2.09	0.003	1.15	0.003	7860	27.11	27.11	metal-based
MFH	1946-60	C6	B2	openings - door frame	steel	1	0.10	0.005	34.91	0.001	0.02	7860	137.20	137.20	metal-based
MFH	1946-60	C6	B2	walls - tie columns	reinf. concrete	8	0.60	2.6	0.60	1.56	0.94	2500	2,340.00	18,720.00	concrete-based
MFH	1946-60	C6	B2	walls	durisol blocks 60	1	32.20	2.3	0.60	74.06	44.44	830	36,881.88	36,881.88	concrete-based
MFH	1946-60	C6	B2	walls	concrete	1	32.20	2.3	0.30	74.06	22.00	2400	52,789.97	52,789.97	concrete-based
MFH	1946-60	C6	B2	walls - tie columns	reinf. concrete	10	0.30	2.6	0.30	0.78	0.23	2500	585.00	5,850.00	concrete-based
MFH	1946-60	C6	B2	walls	durisol blocks 30	1	38.80	2.3	0.30	78.58	23.57	530	12,494.38	12,494.38	concrete-based
MFH	1946-60	C6	B2	walls	concrete	1	34.17	2.3	0.14	78.58	11.00	2400	26,403.22	26,403.22	concrete-based
MFH	1946-60	C6	B2	walls	slag-cement blocks	1	12.80	2.3	0.07	28.29	1.98	790	1,564.46	1,564.46	slag-cement-based
MFH	1946-60	C6	B2	wall covering - plaster	lime-sand plaster	1	157.33	2.3	0.02	361.86	7.24	1800	13,027.07	13,027.07	plaster-based
MFH	1946-60	C6	B2	stairs	reinf. concrete	10	0.18	0.2	1.20	0.02	0.02	2500	54.00	540.00	concrete-based
MFH	1946-60	C6	B2	slab	reinf. concrete	1	1.20	2.34	0.10	2.81	0.28	2500	702.00	702.00	concrete-based
MFH	1946-60	C6	B2	slab	reinf. concrete	1	10.10	15.98	0.20	159.36	31.87	2500	79,679.00	79,679.00	concrete-based
MFH	1946-60	C6	B1	openings - door	sheet metal	1	1.50	2.09	0.003	3.14	0.01	7860	73.92	73.92	metal-based
MFH	1946-60	C6	B1	openings - door	sheet metal	10	0.80	2.09	0.003	1.672	0.01	7860	39.43	394.26	metal-based
MFH	1946-60	C6	B1	openings - door	sheet metal	2	0.70	2.09	0.003	1.463	0.004	7860	34.50	69.00	metal-based
MFH	1946-60	C6	B1	openings - door	sheet metal	2	0.55	2.09	0.003	1.15	0.003	7860	27.11	54.21	metal-based
MFH	1946-60	C6	B1	openings - door frame	steel	1	0.10	0.005	74.70	0.001	0.04	7860	293.57	293.57	metal-based
MFH	1946-60	C6	B1	walls - tie columns	reinf. concrete	6	0.60	2.75	0.60	1.65	0.99	2500	2,475.00	14,850.00	concrete-based
MFH	1946-60	C6	B1	walls	durisol blocks 60	1	26.60	2.45	0.60	63.50	38.10	830	31,622.00	31,622.00	concrete-based
MFH	1946-60	C6	B1	walls	concrete	1	25.92	2.45	0.30	63.50	18.86	2400	45,261.37	45,261.37	concrete-based
MFH	1946-60	C6	B1	walls - tie columns	reinf. concrete	15	0.30	2.75	0.30	0.83	0.25	2500	618.75	9,281.25	concrete-based
MFH	1946-60	C6	B1	walls	durisol blocks 30	1	98.35	2.45	0.30	218.18	65.45	530	34,690.06	34,690.06	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C6	B1	walls	concrete	1	89.05	2.45	0.14	218.18	30.54	2400	73,307.30	73,307.30	concrete-based
MFH	1946-60	C6	B1	walls	slag-cement blocks	1	23.60	2.45	0.07	55.52	3.89	790	3,070.31	3,070.31	slag-cement-based
MFH	1946-60	C6	B1	wall covering - plaster	lime-sand plaster	1	275.26	2.45	0.02	674.39	13.49	1800	24,278.08	24,278.08	plaster-based
MFH	1946-60	C6	B1	stairs	reinf. concrete	15	0.26	0.175	1.20	0.02	0.03	2500	68.25	1,023.75	concrete-based
MFH	1946-60	C6	B1	slab	reinf. concrete	1	n/a	n/a	0.20	293.69	58.74	2500	146,845.00	146,845.00	concrete-based
MFH	1946-60	C6	Gf	balcony	terazzo	2	1.10	2.3	0.05	2.53	0.13	2500	316.25	632.50	concrete-based
MFH	1946-60	C6	Gf	floor covering - magnesite screed	magnesite screed	1	n/a	n/a	0.04	225.08	9.00	1100	9,903.30	9,903.30	concrete-based
MFH	1946-60	C6	Gf	floor covering - terazzo	terazzo	2	5.00	3.8	0.05	19.00	0.95	2500	2,375.00	4,750.00	concrete-based
MFH	1946-60	C6	Gf	floor covering - terazzo	terazzo	2	4.00	3.6	0.05	14.40	0.72	2500	1,800.00	3,600.00	concrete-based
MFH	1946-60	C6	Gf	floor covering - terazzo	terazzo	1	2.65	8.7	0.05	23.06	1.15	2500	2,881.88	2,881.88	concrete-based
MFH	1946-60	C6	Gf	floor covering - asphalt	asphalt	1	n/a	n/a	0.01	225.08	1.35	2100	2,835.95	2,835.95	bitumen-based
MFH	1946-60	C6	Gf	floor covering - parquet	wood	1	n/a	n/a	0.02	191.68	3.07	455	1,395.39	1,395.39	wood-based
MFH	1946-60	C6	Gf	openings - window	glass	4	1.73	0.92	0.008	1.59	0.01	2580	32.86	131.45	glass-based
MFH	1946-60	C6	Gf	openings - window	glass	1	1.33	0.92	0.008	1.22	0.01	2580	25.24	25.24	glass-based
MFH	1946-60	C6	Gf	openings - window	glass	2	1.03	0.92	0.008	0.95	0.01	2580	19.53	39.05	glass-based
MFH	1946-60	C6	Gf	openings - window	glass	5	0.98	0.92	0.008	0.90	0.01	2580	18.57	92.87	glass-based
MFH	1946-60	C6	Gf	openings - window	glass	2	0.58	0.92	0.008	0.53	0.004	2580	10.95	21.91	glass-based
MFH	1946-60	C6	Gf	openings - window	glass	4	0.48	0.62	0.008	0.30	0.002	2580	6.11	24.43	glass-based
MFH	1946-60	C6	Gf	openings - window frame	wood	1	0.14	0.09	67.23	0.01	0.85	455	385.42	385.42	wood-based
MFH	1946-60	C6	Gf	openings - door	glass	2	1.45	2.31	0.004	3.35	0.01	2580	34.57	69.13	glass-based
MFH	1946-60	C6	Gf	openings - door	glass	2	0.73	2.25	0.008	1.63	0.01	2580	33.59	67.19	glass-based
MFH	1946-60	C6	Gf	openings - door	glass	6	0.43	2.25	0.008	0.95	0.01	2580	19.69	118.16	glass-based
MFH	1946-60	C6	Gf	openings - door	plywood	21	0.81	1.985	0.012	1.61	0.02	427	8.24	173.01	wood-based
MFH	1946-60	C6	Gf	openings - door	plywood	10	0.71	1.985	0.012	1.41	0.02	427	7.22	72.22	wood-based
MFH	1946-60	C6	Gf	openings - door	plywood	2	0.56	1.985	0.012	1.11	0.01	427	5.70	11.39	wood-based
MFH	1946-60	C6	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	50.08	1.50	5.8	8.71	8.71	organic - misc.
MFH	1946-60	C6	Gf	openings - door	wood	1	0.09	0.31	215.20	0.03	6.00	455	2,731.86	2,731.86	wood-based
MFH	1946-60	C6	Gf	walls - tie columns	reinf. concrete	30	0.30	3.08	0.30	0.92	0.28	2500	693.00	20,790.00	concrete-based
MFH	1946-60	C6	Gf	walls	durisol blocks 30	1	110.40	2.75	0.30	262.51	78.75	530	41,738.70	41,738.70	concrete-based
MFH	1946-60	C6	Gf	walls	concrete	1	95.46	2.75	0.14	262.51	36.75	2400	88,202.53	88,202.53	concrete-based
MFH	1946-60	C6	Gf	walls - tie columns	reinf. concrete	30	0.25	3.08	0.25	0.77	0.19	2500	481.25	14,437.50	concrete-based
MFH	1946-60	C6	Gf	walls	durisol blocks 25	1	15.38	2.75	0.25	34.86	8.71	420	3,659.79	3,659.79	concrete-based
MFH	1946-60	C6	Gf	walls	concrete	1	12.67	2.75	0.14	34.86	4.88	2400	11,711.32	11,711.32	concrete-based
MFH	1946-60	C6	Gf	walls	slag-cement blocks	1	16.32	2.75	0.15	42.06	6.31	790	4,984.26	4,984.26	slag-cement-based
MFH	1946-60	C6	Gf	walls	slag-cement blocks	1	63.90	2.75	0.07	151.79	10.63	790	8,393.76	8,393.76	slag-cement-based
MFH	1946-60	C6	Gf	wall covering - plaster	lime-sand plaster	1	357.24	2.75	0.02	982.42	19.65	1800	35,367.11	35,367.11	plaster-based
MFH	1946-60	C6	Gf	stairs	reinf. concrete	20	0.26	0.175	1.20	0.02	0.03	2500	68.25	1,365.00	concrete-based
MFH	1946-60	C6	Gf	stairs - railings	steel	2	6.2	0.016	0.016	0.10	0.002	7860	12.48	24.95	metal-based
MFH	1946-60	C6	Gf	stairs - railings	steel	62	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	104.79	metal-based
MFH	1946-60	C6	Gf	ceiling covering - reed	reed	1	n/a	n/a	0.01	281.53	2.82	150	422.30	422.30	organic - misc.
MFH	1946-60	C6	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	281.53	5.63	1800	10,135.08	10,135.08	plaster-based
MFH	1946-60	C6	Gf	ceiling covering - battens	wood	52	0.03	0.04	9.25	0.001	0.01	455	5.05	260.61	wood-based
MFH	1946-60	C6	Gf	ceiling covering - battens	wood	59	0.03	0.04	7.40	0.001	0.01	455	4.04	237.04	wood-based
MFH	1946-60	C6	Gf	slab	durisol blocks 20	32	0.50	5.00	0.20	2.500	0.50	420	210.00	6,720.00	concrete-based
MFH	1946-60	C6	Gf	slab	durisol blocks 20	32	0.50	4.70	0.20	2.350	0.47	420	197.40	6,316.80	concrete-based
MFH	1946-60	C6	Gf	slab	durisol blocks 20	16	0.50	4.00	0.20	2.000	0.40	420	168.00	2,688.00	concrete-based
MFH	1946-60	C6	Gf	slab	durisol blocks 20	16	0.50	3.60	0.20	1.800	0.36	420	151.20	2,419.20	concrete-based
MFH	1946-60	C6	Gf	slab	concrete	1	n/a	n/a	0.08	216.000	16.42	2400	39,398.40	39,398.40	concrete-based
MFH	1946-60	C6	Gf	slab	cement-sand plaster	1	n/a	n/a	0.02	216.000	4.32	2100	9,072.00	9,072.00	plaster-based
MFH	1946-60	C6	Gf	slab	reinf. concrete	1	12.50	2.65	0.20	33.125	6.63	2500	16,562.50	16,562.50	concrete-based
MFH	1946-60	C6	1st -10th	balcony	reinf. concrete	20	1.10	2.3	0.10	2.53	0.25	2500	632.50	12,650.00	concrete-based
MFH	1946-60	C6	1st -10th	balcony - floor covering	terazzo	20	3.20	1.1	0.05	3.52	0.18	2500	440.00	8,800.00	concrete-based
MFH	1946-60	C6	1st -10th	balcony - floor covering	terazzo	20	2.30	1.1	0.05	2.53	0.13	2500	316.25	6,325.00	concrete-based
MFH	1946-60	C6	1st -10th	balcony - floor covering	terazzo	20	2.00	1.1	0.05	2.20	0.11	2500	275.00	5,500.00	concrete-based
MFH	1946-60	C6	1st -10th	balcony - railings	steel	20	25.95	0.016	0.016	0.42	0.01	7860	52.22	1,044.31	metal-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C6	1st -10th	balcony - railings	steel	2595	0.016	0.016	0.84	0.0003	0.0002	7860	1.69	4,386.11	metal-based
MFH	1946-60	C6	1st -10th	floor covering - magnesite screed	magnesite screed	10	n/a	n/a	0.04	225.08	9.00	1100	9,903.30	99,033.00	concrete-based
MFH	1946-60	C6	1st -10th	floor covering - terazzo	terazzo	10	8.70	2.65	0.05	23.06	1.15	2500	2,881.88	28,818.75	concrete-based
MFH	1946-60	C6	1st -10th	floor covering - terazzo	terazzo	20	4.00	3.6	0.05	14.40	0.72	2500	1,800.00	36,000.00	concrete-based
MFH	1946-60	C6	1st -10th	floor covering - terazzo	terazzo	20	5.00	3.8	0.05	19.00	0.95	2500	2,375.00	47,500.00	concrete-based
MFH	1946-60	C6	1st -10th	floor covering - asphalt	asphalt	10	n/a	n/a	0.01	225.08	1.35	2100	2,835.95	28,359.45	bitumen-based
MFH	1946-60	C6	1st -10th	floor covering - parquet	wood	10	n/a	n/a	0.02	191.68	3.07	455	1,395.39	13,953.94	wood-based
MFH	1946-60	C6	1st -10th	openings - window	glass	10	2.45	2.36	0.004	5.78	0.02	2580	59.67	596.70	glass-based
MFH	1946-60	C6	1st -10th	openings - window	glass	40	1.73	0.92	0.008	1.59	0.01	2580	32.86	1,314.50	glass-based
MFH	1946-60	C6	1st -10th	openings - window	glass	10	1.33	0.92	0.008	1.22	0.01	2580	25.24	252.42	glass-based
MFH	1946-60	C6	1st -10th	openings - window	glass	20	1.03	0.92	0.008	0.95	0.01	2580	19.53	390.54	glass-based
MFH	1946-60	C6	1st -10th	openings - window	glass	50	0.98	0.92	0.008	0.90	0.01	2580	18.57	928.72	glass-based
MFH	1946-60	C6	1st -10th	openings - window	glass	20	0.58	0.92	0.008	0.53	0.004	2580	10.95	219.08	glass-based
MFH	1946-60	C6	1st -10th	openings - window	glass	40	0.48	0.62	0.008	0.30	0.002	2580	6.11	244.32	glass-based
MFH	1946-60	C6	1st -10th	openings - window frame	wood	10	0.14	0.09	768.48	0.01	9.68	455	4,405.70	44,056.96	wood-based
MFH	1946-60	C6	1st -10th	openings - door	glass	20	0.73	2.25	0.008	1.63	0.01	2580	33.59	671.88	glass-based
MFH	1946-60	C6	1st -10th	openings - door	glass	60	0.43	2.25	0.008	0.95	0.01	2580	19.69	1,181.59	glass-based
MFH	1946-60	C6	1st -10th	openings - door	plywood	210	0.81	1.985	0.012	1.61	0.02	427	8.24	1,730.11	wood-based
MFH	1946-60	C6	1st -10th	openings - door	plywood	100	0.71	1.985	0.012	1.41	0.02	427	7.22	722.15	wood-based
MFH	1946-60	C6	1st -10th	openings - door	plywood	20	0.56	1.985	0.012	1.11	0.01	427	5.70	113.92	wood-based
MFH	1946-60	C6	1st -10th	openings - door	cardboard (honeycomb)	10	n/a	n/a	0.030	50.08	1.50	5.8	8.71	87.14	organic - misc.
MFH	1946-60	C6	1st -10th	openings - door frame	wood	10	0.09	0.31	1,961.60	0.03	54.73	455	24,901.53	249,015.31	wood-based
MFH	1946-60	C6	1st -10th	walls - tie columns	reinf. concrete	300	0.30	3.08	0.30	0.92	0.28	2500	693.00	207,900.00	concrete-based
MFH	1946-60	C6	1st -10th	walls	durisol blocks 30	10	110.40	2.75	0.30	128.36	38.51	530	20,409.61	204,096.06	concrete-based
MFH	1946-60	C6	1st -10th	walls	concrete	10	46.68	2.75	0.14	128.36	17.97	2400	43,129.73	431,297.33	concrete-based
MFH	1946-60	C6	1st -10th	walls - tie columns	reinf. concrete	300	0.25	3.08	0.25	0.77	0.19	2500	481.25	144,375.00	concrete-based
MFH	1946-60	C6	1st -10th	walls	durisol blocks 25	10	15.38	2.75	0.25	6.00	1.50	420	629.61	6,296.11	concrete-based
MFH	1946-60	C6	1st -10th	walls	concrete	10	2.18	2.75	0.14	6.00	0.84	2400	2,014.76	20,147.57	concrete-based
MFH	1946-60	C6	1st -10th	walls	slag-cement blocks	10	16.32	2.75	0.15	42.06	6.31	790	4,984.26	49,842.64	slag-cement-based
MFH	1946-60	C6	1st -10th	walls	slag-cement blocks	10	63.90	2.75	0.07	131.78	9.22	790	7,287.27	72,872.74	slag-cement-based
MFH	1946-60	C6	1st -10th	wall covering - plaster	lime-sand plaster	10	224.14	2.75	0.02	616.39	12.33	1800	22,190.18	221,901.84	plaster-based
MFH	1946-60	C6	1st -10th	stairs	reinf. concrete	200	0.26	0.175	1.20	0.02	0.03	2500	68.25	13,650.00	concrete-based
MFH	1946-60	C6	1st -10th	stairs - railings	steel	20	6.2	0.016	0.016	0.10	0.002	7860	12.48	249.51	metal-based
MFH	1946-60	C6	1st -10th	stairs - railings	steel	620	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	1,047.93	metal-based
MFH	1946-60	C6	1st -10th	ceiling covering - reed	reed	10	n/a	n/a	0.01	281.53	2.82	150	422.30	4,222.95	organic - misc.
MFH	1946-60	C6	1st -10th	ceiling covering - plaster	lime-sand plaster	10	n/a	n/a	0.02	281.53	5.63	1800	10,135.08	101,350.80	plaster-based
MFH	1946-60	C6	1st -10th	ceiling covering - battens	wood	516	0.03	0.04	9.25	0.001	0.01	455	5.05	2,606.06	wood-based
MFH	1946-60	C6	1st -10th	ceiling covering - battens	wood	587	0.03	0.04	7.40	0.001	0.01	455	4.04	2,370.37	wood-based
MFH	1946-60	C6	1st -10th	slab	durisol blocks 20	320	0.50	5.00	0.20	2.500	0.50	420	210.00	67,200.00	concrete-based
MFH	1946-60	C6	1st -10th	slab	durisol blocks 20	320	0.50	4.70	0.20	2.350	0.47	420	197.40	63,168.00	concrete-based
MFH	1946-60	C6	1st -10th	slab	durisol blocks 20	160	0.50	4.00	0.20	2.000	0.40	420	168.00	26,880.00	concrete-based
MFH	1946-60	C6	1st -10th	slab	durisol blocks 20	160	0.50	3.60	0.20	1.800	0.36	420	151.20	24,192.00	concrete-based
MFH	1946-60	C6	1st -10th	slab	concrete	10	n/a	n/a	0.08	216.000	16.42	2400	39,398.40	393,984.00	concrete-based
MFH	1946-60	C6	1st -10th	slab	cement-sand plaster	10	n/a	n/a	0.02	216.000	4.32	2100	9,072.00	90,720.00	plaster-based
MFH	1946-60	C6	1st -10th	slab	reinf. concrete	10	12.50	2.65	0.20	33.125	6.63	2500	16,562.50	165,625.00	concrete-based
MFH	1946-60	C6	11th	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	98.78	4.94	2500	12,347.50	12,347.50	concrete-based
MFH	1946-60	C6	11th	openings - window	glass	1	2.45	2.36	0.004	5.78	0.02	2580	59.67	59.67	glass-based
MFH	1946-60	C6	11th	openings - window	glass	14	0.48	0.82	0.008	0.39	0.003	2580	8.07	112.96	glass-based
MFH	1946-60	C6	11th	openings - window frame	wood	1	0.14	0.09	45.96	0.01	0.58	455	263.51	263.51	wood-based
MFH	1946-60	C6	11th	openings - door	plywood	5	0.81	1.99	0.012	1.61	0.02	427	8.24	41.19	wood-based
MFH	1946-60	C6	11th	openings - door	plywood	1	0.71	1.99	0.012	1.41	0.02	427	7.22	7.22	wood-based
MFH	1946-60	C6	11th	openings - door	plywood	1	0.56	1.99	0.012	1.11	0.01	427	5.70	5.70	wood-based
MFH	1946-60	C6	11th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	10.56	0.32	5.8	1.84	1.84	organic - misc.
MFH	1946-60	C6	11th	openings - door frame	wood	1	0.09	0.31	33.11	0.03	0.92	455	420.31	420.31	wood-based
MFH	1946-60	C6	11th	walls - tie columns	reinf. concrete	14	0.19	0.19	2.70	0.04	0.10	2500	243.68	3,411.45	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1946-60	C6	11th	walls	durisol blocks 20	1	72.75	2.45	0.20	160.55	32.11	420	13,486.30	13,486.30	concrete-based
MFH	1946-60	C6	11th	concrete	concrete	1	65.53	2.45	0.14	160.55	22.48	2400	53,945.19	53,945.19	concrete-based
MFH	1946-60	C6	11th	walls	slag-cement blocks	1	14.50	2.45	0.08	31.40	2.35	790	1,860.22	1,860.22	slag-cement-based
MFH	1946-60	C6	11th	wall covering - plaster	lime-sand plaster	1	15.67	24.5	0.02	383.89	7.68	1800	13,820.21	13,820.21	plaster-based
MFH	1946-60	C6	11th	ceiling covering - reed	reed	1	n/a	n/a	0.01	116.50	1.17	150	174.75	174.75	organic - misc.
MFH	1946-60	C6	11th	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	116.50	2.33	1800	4,194.00	4,194.00	plaster-based
MFH	1946-60	C6	11th	ceiling covering - battens	wood	44	0.03	0.04	9.25	0.001	0.01	455	5.05	220.03	wood-based
MFH	1946-60	C6	11th	ceiling covering - battens	wood	32	0.03	0.04	7.40	0.001	0.01	455	4.04	130.24	wood-based
MFH	1946-60	C6	Roof	slab	durisol blocks 20	26	0.50	4.80	0.20	2.400	0.48	420	201.60	5,281.92	concrete-based
MFH	1946-60	C6	Roof	slab	durisol blocks 20	20	0.50	4.50	0.20	2.250	0.45	420	189.00	3,780.00	concrete-based
MFH	1946-60	C6	Roof	slab	concrete	10	n/a	n/a	0.08	136.310	10.36	2400	24,862.94	248,629.44	concrete-based
MFH	1946-60	C6	Roof	slab	cement-sand plaster	10	n/a	n/a	0.02	136.310	2.73	2100	5,725.02	57,250.20	plaster-based
MFH	1946-60	C6	Roof	slab	reinf. concrete	10	43.30	1.3	0.14	56.290	7.88	2500	19,701.50	197,015.00	concrete-based
MFH	1946-60	C6	Roof	floor covering - slag concrete	slag-concrete	1	n/a	n/a	0.05	300.77	15.04	790	11,880.42	11,880.42	slag-cement-based
MFH	1946-60	C6	Roof	floor covering - water-proofing	bitumen	1	n/a	n/a	0.01	300.77	3.01	1500	4,511.55	4,511.55	bitumen-based
MFH	1946-60	C6	Roof	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.015	300.77	4.51	2100	9,474.26	9,474.26	plaster-based
MFH	1946-60	C6	Roof	floor covering - bitumen putty	bitumen putty	1	n/a	n/a	0.025	300.77	7.52	929	6,985.38	6,985.38	bitumen-based
MFH	1946-60	C6	Roof	floor covering - sand	sand	1	n/a	n/a	0.03	300.77	9.02	1300	11,730.03	11,730.03	plaster-based
MFH	1946-60	C6	Roof	floor covering - stone tiles	stone tiles	1	n/a	n/a	0.04	300.77	12.03	2690	32,362.85	32,362.85	stone-based
MFH	1946-60	C6	Roof	gutters	sheet metal	1	148.80	0.2	0.00065	29.76	0.02	7860	152.04	152.04	metal-based
MFH	1961-70	D3	B1-B2	base slab - gravel	gravel	1	19.00	14.1	0.10	267.90	26.79	1850	49,561.50	49,561.50	stone-based
MFH	1961-70	D3	B1-B2	base slab	concrete	1	19.00	14.1	0.10	267.90	26.79	2400	64,296.00	64,296.00	concrete-based
MFH	1961-70	D3	B1-B2	floor covering - water-proofing	bitumen	1	19.00	14.1	0.01	267.90	2.68	1500	4,018.50	4,018.50	bitumen-based
MFH	1961-70	D3	B1-B2	floor covering - screed	cement-sand plaster	1	19.00	14.1	0.05	267.90	13.40	2100	28,129.50	28,129.50	plaster-based
MFH	1961-70	D3	B2	openings - door	sheet metal	8	0.85	1.94	0.04	1.64	0.07	7860	517.11	4,136.88	metal-based
MFH	1961-70	D3	B2	openings - door frame	steel	1	0.10	0.005	37.76	0.001	0.02	7860	148.40	148.40	metal-based
MFH	1961-70	D3	B2	walls	reinf. concrete	1	52.00	2.3	0.70	113.02	79.11	2500	197,786.75	197,786.75	concrete-based
MFH	1961-70	D3	B2	walls	reinf. concrete	1	59.00	2.3	0.30	129.12	38.74	2500	96,840.75	96,840.75	concrete-based
MFH	1961-70	D3	B2	wall covering - plaster	lime-sand plaster	1	105.28	2.3	0.02	242.14	4.84	1800	8,717.11	8,717.11	plaster-based
MFH	1961-70	D3	B2	stairs	reinf. concrete	16	0.15	0.29	1.20	0.02	0.03	2500	65.25	1,044.00	concrete-based
MFH	1961-70	D3	B2	slab	reinf. concrete	1	19.00	14.1	0.20	261.53	52.31	2500	130,765.00	130,765.00	concrete-based
MFH	1961-70	D3	B1	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	138.66	6.93	2100	14,559.30	14,559.30	plaster-based
MFH	1961-70	D3	B1	floor covering - woodcrete	woodcrete	1	n/a	n/a	0.03	106.55	3.20	1000	3,196.50	3,196.50	concrete-based
MFH	1961-70	D3	B1	floor covering - parquet	wood	1	n/a	n/a	0.03	106.55	3.20	455	1,454.41	1,454.41	wood-based
MFH	1961-70	D3	B1	floor covering - terazzo	terazzo	1	n/a	n/a	0.02	138.66	3.05	2500	7,626.30	7,626.30	concrete-based
MFH	1961-70	D3	B1	openings - window	glass	6	1.68	1.32	0.008	2.22	0.02	2580	45.75	274.51	glass-based
MFH	1961-70	D3	B1	openings - window frame	wood	1	0.21	0.09	35.98	0.02	0.68	455	309.43	309.43	wood-based
MFH	1961-70	D3	B1	openings - door	plywood	8	0.85	1.94	0.012	1.64	0.02	427	8.43	67.42	wood-based
MFH	1961-70	D3	B1	openings - door	plywood	2	0.61	1.94	0.012	1.18	0.01	427	6.05	12.10	wood-based
MFH	1961-70	D3	B1	openings - door	plywood	2	0.41	1.94	0.012	0.79	0.01	427	4.07	8.13	wood-based
MFH	1961-70	D3	B1	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	17.11	0.51	5.8	2.98	2.98	organic - misc.
MFH	1961-70	D3	B1	openings - door frame	wood	1	0.09	0.31	55.28	0.03	1.54	455	701.75	701.75	wood-based
MFH	1961-70	D3	B1	walls	reinf. concrete	1	66.00	2.7	0.30	164.90	49.47	2500	123,674.91	123,674.91	concrete-based
MFH	1961-70	D3	B1	walls	reinf. concrete	1	41.55	2.7	0.20	102.32	20.46	2500	51,158.25	51,158.25	concrete-based
MFH	1961-70	D3	B1	walls	reinf. concrete	1	23.36	2.7	0.07	55.84	3.91	2500	9,771.14	9,771.14	concrete-based
MFH	1961-70	D3	B1	wall covering - plaster	lime-sand plaster	1	239.30	2.7	0.02	646.10	12.92	1800	23,259.71	23,259.71	plaster-based
MFH	1961-70	D3	B1	stairs	reinf. concrete	16	0.15	0.29	1.20	0.02	0.03	2500	65.25	1,044.00	concrete-based
MFH	1961-70	D3	B1	stairs - railings	steel	2	6.2	0.016	0.016	0.10	0.002	7860	12.54	25.07	metal-based
MFH	1961-70	D3	B1	stairs - railings	steel	62	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	105.30	metal-based
MFH	1961-70	D3	B2	ceiling covering - reed	reed	1	18.90	14.1	0.01	241.12	2.41	150	361.67	361.67	organic - misc.
MFH	1961-70	D3	B2	ceiling covering - plaster	lime-sand plaster	1	18.90	14.1	0.04	241.12	9.64	1800	17,360.28	17,360.28	plaster-based
MFH	1961-70	D3	B2	ceiling covering - battens	wood	17	0.03	0.04	14.00	0.001	0.02	455	7.64	127.40	wood-based
MFH	1961-70	D3	B2	ceiling covering - battens	wood	37	0.03	0.04	13.80	0.001	0.02	455	7.53	276.28	wood-based
MFH	1961-70	D3	B2	ceiling covering - battens	wood	9	0.03	0.04	4.70	0.001	0.01	455	2.57	22.24	wood-based
MFH	1961-70	D3	B2	slab	prefab. concrete	29	0.07	0.22	5.00	0.02	0.08	2500	192.50	5,582.50	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D3	B2	slab	prefab. concrete	140	0.43	0.07	1.00	0.03	0.03	2500	75.25	10,535.00	concrete-based
MFH	1961-70	D3	B2	slab	prefab. concrete	58	0.07	0.22	5.50	0.02	0.08	2500	211.75	12,281.50	concrete-based
MFH	1961-70	D3	B2	slab	prefab. concrete	308	0.43	0.07	1.00	0.03	0.03	2500	75.25	23,177.00	concrete-based
MFH	1961-70	D3	B2	slab	prefab. concrete	11	0.07	0.22	2.60	0.02	0.04	2500	100.10	1,101.10	concrete-based
MFH	1961-70	D3	B2	slab	prefab. concrete	10	0.43	0.07	1.00	0.03	0.03	2500	75.25	752.50	concrete-based
MFH	1961-70	D3	B2	slab	concrete	1	18.90	14.1	0.02	241.12	4.82	2400	11,573.52	11,573.52	concrete-based
MFH	1961-70	D3	B2	slab	reinf. concrete	1	8.75	2.9	0.10	25.38	2.54	2500	6,343.75	6,343.75	concrete-based
MFH	1961-70	D3	Gf	floor covering - woodcrete	woodcrete	1	18.60	13.7	0.03	230.69	6.92	1000	6,920.70	6,920.70	concrete-based
MFH	1961-70	D3	Gf	floor covering - clay tiles	clay tiles	2	6.70	3.8	0.01	25.46	0.25	1800	458.28	916.56	clay-based
MFH	1961-70	D3	Gf	floor covering - clay tiles	clay tiles	2	4.40	1.4	0.01	6.16	0.06	1800	110.88	221.76	clay-based
MFH	1961-70	D3	Gf	floor covering - terazzo	terazzo	1	2.50	12.2	0.05	24.13	1.21	2500	3,016.25	3,016.25	concrete-based
MFH	1961-70	D3	Gf	floor covering - parquet	wood	1	18.60	13.7	0.02	167.45	3.68	455	1,676.17	1,676.17	wood-based
MFH	1961-70	D3	Gf	openings - window	glass	12	1.68	1.42	0.008	2.38	0.02	2580	49.21	590.53	glass-based
MFH	1961-70	D3	Gf	openings - window frame	wood	1	0.21	0.09	74.36	0.02	1.41	455	639.49	639.49	wood-based
MFH	1961-70	D3	Gf	openings - door	glass	2	2.30	2.69	0.008	6.19	0.05	2580	127.70	255.40	glass-based
MFH	1961-70	D3	Gf	openings - door	plywood	16	0.81	1.94	0.012	1.57	0.02	427	8.03	128.50	wood-based
MFH	1961-70	D3	Gf	openings - door	plywood	4	0.61	1.94	0.012	1.18	0.01	427	6.05	24.19	wood-based
MFH	1961-70	D3	Gf	openings - door	plywood	2	0.41	1.94	0.012	0.79	0.01	427	4.07	8.13	wood-based
MFH	1961-70	D3	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	31.39	0.94	5.8	5.46	5.46	organic - misc.
MFH	1961-70	D3	Gf	openings - door frame	steel	1	0.10	0.005	19.96	0.001	0.01	7860	78.44	78.44	metal-based
MFH	1961-70	D3	Gf	openings - door frame	wood	1	0.09	0.31	101.36	0.03	2.83	455	1,286.71	1,286.71	wood-based
MFH	1961-70	D3	Gf	walls	reinf. concrete	1	45.25	2.7	0.20	115.91	23.18	2500	57,952.80	57,952.80	concrete-based
MFH	1961-70	D3	Gf	walls	durisol blocks 20	1	76.00	2.7	0.20	170.32	34.06	420	14,306.86	14,306.86	concrete-based
MFH	1961-70	D3	Gf	concrete	concrete	1	63.08	2.7	0.14	170.32	23.84	2400	57,227.44	57,227.44	concrete-based
MFH	1961-70	D3	Gf	walls	clay bricks	1	59.80	2.7	0.065	142.61	9.27	1800	16,685.73	16,685.73	clay-based
MFH	1961-70	D3	Gf	wall covering - plaster	lime-sand plaster	1	317.66	2.7	0.002	857.68	1.72	1800	3,087.64	3,087.64	plaster-based
MFH	1961-70	D3	Gf	stairs	reinf. concrete	18	0.17	0.29	1.20	0.02	0.03	2500	73.95	1,331.10	concrete-based
MFH	1961-70	D3	Gf	stairs	reinf. concrete	2	0.10	0.9	2.50	0.05	0.11	2500	281.25	562.50	concrete-based
MFH	1961-70	D3	Gf	stairs - railings	steel	2	6.2	0.016	0.016	0.10	0.002	7860	12.54	25.07	metal-based
MFH	1961-70	D3	Gf	stairs - railings	steel	62	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	105.30	metal-based
MFH	1961-70	D3	Gf	ceiling covering - reed	reed	1	18.90	14.1	0.01	241.12	2.41	150	361.67	361.67	organic - misc.
MFH	1961-70	D3	Gf	ceiling covering - plaster	lime-sand plaster	1	18.90	14.1	0.04	241.12	9.64	1800	17,360.28	17,360.28	plaster-based
MFH	1961-70	D3	Gf	ceiling covering - battens	wood	17	0.03	0.04	14.00	0.001	0.02	455	7.64	127.40	wood-based
MFH	1961-70	D3	Gf	ceiling covering - battens	wood	37	0.03	0.04	13.80	0.001	0.02	455	7.53	276.28	wood-based
MFH	1961-70	D3	Gf	ceiling covering - battens	wood	9	0.03	0.04	4.70	0.001	0.01	455	2.57	22.24	wood-based
MFH	1961-70	D3	Gf	slab	prefab. concrete	29	0.07	0.22	5.00	0.02	0.08	2500	192.50	5,582.50	concrete-based
MFH	1961-70	D3	Gf	slab	prefab. concrete	140	0.43	0.07	1.00	0.03	0.03	2500	75.25	10,535.00	concrete-based
MFH	1961-70	D3	Gf	slab	prefab. concrete	58	0.07	0.22	5.50	0.02	0.08	2500	211.75	12,281.50	concrete-based
MFH	1961-70	D3	Gf	slab	prefab. concrete	308	0.43	0.07	1.00	0.03	0.03	2500	75.25	23,177.00	concrete-based
MFH	1961-70	D3	Gf	slab	prefab. concrete	11	0.07	0.22	2.60	0.02	0.04	2500	100.10	1,101.10	concrete-based
MFH	1961-70	D3	Gf	slab	prefab. concrete	10	0.43	0.07	1.00	0.03	0.03	2500	75.25	752.50	concrete-based
MFH	1961-70	D3	Gf	slab	concrete	1	18.90	14.1	0.02	241.12	4.82	2400	11,573.52	11,573.52	concrete-based
MFH	1961-70	D3	Gf	slab	reinf. concrete	1	8.75	2.9	0.10	25.38	2.54	2500	6,343.75	6,343.75	concrete-based
MFH	1961-70	D3	1st - 4th	balcony	reinf. concrete	8	7.00	0.8	0.10	5.60	0.56	2500	1,400.00	11,200.00	concrete-based
MFH	1961-70	D3	1st - 4th	balcony - railings	steel	4	20.40	0.016	0.02	0.33	0.01	7860	41.05	164.19	metal-based
MFH	1961-70	D3	1st - 4th	balcony - railings	steel	408	0.016	0.016	0.840	0.0003	0.0002	7860	1.69	689.61	metal-based
MFH	1961-70	D3	1st - 4th	floor covering - woodcrete	woodcrete	4	18.60	13.7	0.03	230.69	6.92	1000	6,920.70	27,682.80	concrete-based
MFH	1961-70	D3	1st - 4th	floor covering - clay tiles	clay tiles	8	6.70	3.8	0.01	25.46	0.25	1800	458.28	3,666.24	clay-based
MFH	1961-70	D3	1st - 4th	floor covering - clay tiles	clay tiles	8	4.40	1.4	0.01	6.16	0.06	1800	110.88	887.04	clay-based
MFH	1961-70	D3	1st - 4th	floor covering - terazzo	terazzo	4	2.50	12.2	0.05	24.13	1.21	2500	3,016.25	12,065.00	concrete-based
MFH	1961-70	D3	1st - 4th	floor covering - parquet	wood	4	18.60	13.7	0.02	167.45	3.68	455	1,676.17	6,704.70	wood-based
MFH	1961-70	D3	1st - 4th	openings - window	glass	4	2.08	1.42	0.008	2.95	0.02	2580	60.96	243.84	glass-based
MFH	1961-70	D3	1st - 4th	openings - window	glass	32	1.68	1.42	0.008	2.38	0.02	2580	49.21	1,574.74	glass-based
MFH	1961-70	D3	1st - 4th	openings - window	glass	16	1.03	1.42	0.008	1.46	0.01	2580	30.10	481.68	glass-based
MFH	1961-70	D3	1st - 4th	openings - window frame	wood	4	0.21	0.09	304.63	0.02	5.76	455	2,619.65	10,478.59	wood-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D3	1st - 4th	openings - door	glass	8	0.63	2.32	0.008	1.45	0.01	2580	29.97	239.73	glass-based
MFH	1961-70	D3	1st - 4th	openings - door	glass	16	0.53	2.32	0.008	1.22	0.01	2580	25.17	402.75	glass-based
MFH	1961-70	D3	1st - 4th	openings - door	plywood	64	0.81	1.94	0.012	1.57	0.02	427	8.03	513.99	wood-based
MFH	1961-70	D3	1st - 4th	openings - door	plywood	16	0.61	1.94	0.012	1.18	0.01	427	6.05	96.77	wood-based
MFH	1961-70	D3	1st - 4th	openings - door	plywood	8	0.41	1.94	0.012	0.79	0.01	427	4.07	32.52	wood-based
MFH	1961-70	D3	1st - 4th	openings - door	cardboard (honeycomb)	4	n/a	n/a	0.030	31.39	0.94	5.8	5.46	21.84	organic - misc.
MFH	1961-70	D3	1st - 4th	openings - door frame	wood	4	0.09	0.31	530.34	0.03	14.80	455	6,732.45	26,929.81	wood-based
MFH	1961-70	D3	1st - 4th	walls	reinf. concrete	4	45.25	2.7	0.20	113.00	22.60	2500	56,500.93	226,003.70	concrete-based
MFH	1961-70	D3	1st - 4th	walls	durisol blocks 20	4	76.00	2.7	0.20	162.87	32.57	420	13,681.48	54,725.90	concrete-based
MFH	1961-70	D3	1st - 4th	concrete	concrete	4	60.32	2.7	0.14	162.87	22.80	2400	54,725.90	218,903.61	concrete-based
MFH	1961-70	D3	1st - 4th	walls	clay bricks	4	59.80	2.7	0.065	137.73	8.95	1800	16,114.97	64,459.89	clay-based
MFH	1961-70	D3	1st - 4th	wall covering - plaster	lime-sand plaster	4	306.38	2.7	0.002	827.22	1.65	1800	2,978.00	11,912.01	plaster-based
MFH	1961-70	D3	1st - 4th	ceiling covering - reed	reed	4	18.90	14.1	0.01	241.12	2.41	150	361.67	1,446.69	organic - misc.
MFH	1961-70	D3	4th	ceiling covering - reed	reed	1	7.60	2.6	0.01	19.76	0.20	150	29.64	29.64	organic - misc.
MFH	1961-70	D3	1st - 4th	ceiling covering - plaster	lime-sand plaster	4	18.90	14.1	0.04	241.12	9.64	1800	17,360.28	69,441.12	plaster-based
MFH	1961-70	D3	4th	ceiling covering - plaster	lime-sand plaster	1	7.60	2.6	0.04	19.76	0.79	1800	1,422.72	1,422.72	plaster-based
MFH	1961-70	D3	1st - 4th	ceiling covering - battens	wood	67	0.03	0.04	14.00	0.001	0.02	455	7.64	509.60	wood-based
MFH	1961-70	D3	1st - 4th	ceiling covering - battens	wood	147	0.03	0.04	13.80	0.001	0.02	455	7.53	1,105.10	wood-based
MFH	1961-70	D3	1st - 4th	ceiling covering - battens	wood	35	0.03	0.04	4.70	0.001	0.01	455	2.57	88.96	wood-based
MFH	1961-70	D3	4th	ceiling covering - battens	wood	9	0.03	0.04	7.60	0.001	0.01	455	4.15	35.96	wood-based
MFH	1961-70	D3	1st - 4th	slab	prefab. concrete	116	0.07	0.22	5.00	0.02	0.08	2500	192.50	22,330.00	concrete-based
MFH	1961-70	D3	1st - 4th	slab	prefab. concrete	560	0.43	0.07	1.00	0.03	0.03	2500	75.25	42,140.00	concrete-based
MFH	1961-70	D3	1st - 4th	slab	prefab. concrete	232	0.07	0.22	5.50	0.02	0.08	2500	211.75	49,126.00	concrete-based
MFH	1961-70	D3	1st - 4th	slab	prefab. concrete	1232	0.43	0.07	1.00	0.03	0.03	2500	75.25	92,708.00	concrete-based
MFH	1961-70	D3	1st - 4th	slab	prefab. concrete	60	0.07	0.22	2.60	0.02	0.04	2500	100.10	6,026.02	concrete-based
MFH	1961-70	D3	1st - 4th	slab	prefab. concrete	55	0.43	0.07	1.00	0.03	0.03	2500	75.25	4,153.80	concrete-based
MFH	1961-70	D3	1st - 4th	slab	concrete	4	18.90	14.1	0.02	241.12	4.82	2400	11,573.52	46,294.08	concrete-based
MFH	1961-70	D3	1st - 4th	slab	reinf. concrete	4	8.75	2.9	0.10	25.38	2.54	2500	6,343.75	25,375.00	concrete-based
MFH	1961-70	D3	1st - 4th	stairs	reinf. concrete	72	0.17	0.29	1.20	0.02	0.03	2500	73.95	5,324.40	concrete-based
MFH	1961-70	D3	1st - 4th	stairs - railings	steel	8	6.2	0.016	0.016	0.10	0.002	7860	12.54	100.29	metal-based
MFH	1961-70	D3	1st - 4th	stairs - railings	steel	249	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	421.20	metal-based
MFH	1961-70	D3	Roof	floor covering - mud	earth	1	18.90	14.1	0.05	266.49	13.32	400	5,329.80	5,329.80	soil-based
MFH	1961-70	D3	Roof	roof - beams	wood	2	0.14	0.14	19.00	0.02	0.37	455	169.44	338.88	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	2	0.14	0.14	14.10	0.02	0.28	455	125.74	251.49	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	2	0.14	0.18	11.54	0.03	0.29	455	132.32	264.64	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	2	0.14	0.18	8.50	0.03	0.21	455	97.46	194.92	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	1	0.14	0.18	5.54	0.03	0.14	455	63.52	63.52	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	8	0.14	0.14	1.30	0.02	0.03	455	11.59	92.75	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	2	0.14	0.14	2.50	0.02	0.05	455	22.30	44.59	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	10	0.12	0.14	1.00	0.02	0.02	455	7.64	76.44	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	17	0.10	0.14	8.00	0.01	0.11	455	50.96	866.32	wood-based
MFH	1961-70	D3	Roof	roof - beams	wood	10	0.10	0.14	4.50	0.01	0.06	455	28.67	286.65	wood-based
MFH	1961-70	D3	Roof	roof - battens	wood	27	0.048	0.033	19.00	0.002	0.03	455	13.69	365.16	wood-based
MFH	1961-70	D3	Roof	roof - battens	wood	15	0.048	0.033	14.10	0.002	0.02	455	10.16	152.43	wood-based
MFH	1961-70	D3	Roof	roof covering - cement tiles	cement roof tiles	2568	0.40	0.4	0.005	0.16	0.001	2104	1.68	4,322.46	plaster-based
MFH	1961-70	D3	Roof	gutters	sheet metal	1	99.60	0.2	0.00065	19.92	0.01	7860	101.77	101.77	metal-based
MFH	1961-70	D4	B	base slab - gravel	gravel	1	20.80	7.5	0.10	156.00	15.60	1850	28,860.00	28,860.00	stone-based
MFH	1961-70	D4	B	base slab	reinf. concrete	1	20.80	7.5	0.10	156.00	15.60	2500	39,000.00	39,000.00	concrete-based
MFH	1961-70	D4	B	floor covering - water-proofing	bitumen	1	20.80	7.5	0.01	156.00	1.56	1500	2,340.00	2,340.00	bitumen-based
MFH	1961-70	D4	B	floor covering - screed	cement-sand plaster	1	20.40	7.5	0.05	153.00	7.65	2100	16,065.00	16,065.00	plaster-based
MFH	1961-70	D4	B	walls	reinf. concrete	1	20.80	2.5	0.30	52.00	15.60	2500	39,000.00	39,000.00	concrete-based
MFH	1961-70	D4	B	walls	reinf. concrete	1	67.20	2.5	0.20	168.00	33.60	2500	84,000.00	84,000.00	concrete-based
MFH	1961-70	D4	B	stairs	reinf. concrete	15	0.30	0.18	1.35	0.03	0.04	2500	91.13	1,366.88	concrete-based
MFH	1961-70	D4	B	stairs	reinf. concrete	5	0.30	0.16	1.70	0.02	0.04	2500	102.00	510.00	concrete-based
MFH	1961-70	D4	B	stairs	reinf. concrete	11	0.30	0.16	1.00	0.02	0.02	2500	60.00	660.00	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D4	Gf	stairs - railings	steel	2	6.3	0.016	0.016	0.10	0.002	7860	12.68	25.35	metal-based
MFH	1961-70	D4	Gf	stairs - railings	steel	63	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	106.48	metal-based
MFH	1961-70	D4	B	ceiling covering - plaster	lime-sand plaster	1	20.40	5.8	0.02	118.32	2.37	1800	4,259.52	4,259.52	plaster-based
MFH	1961-70	D4	B	slab	reinf. concrete	1	20.80	10.62	0.14	220.90	30.93	2500	77,313.60	77,313.60	concrete-based
MFH	1961-70	D4	Gf	floor covering - water-proofing	bitumen	1	20.40	2.7	0.01	55.08	0.55	1500	826.20	826.20	bitumen-based
MFH	1961-70	D4	Gf	floor covering - florbit	florbit	1	10.02	17.2	0.03	172.34	5.17	770	3,981.15	3,981.15	bitumen-based
MFH	1961-70	D4	Gf	floor covering - clay tiles	clay tiles	2	3.00	2.3	0.01	6.90	0.07	1800	124.20	248.40	clay-based
MFH	1961-70	D4	Gf	floor covering - clay tiles	clay tiles	2	3.50	2	0.01	7.00	0.07	1800	126.00	252.00	clay-based
MFH	1961-70	D4	Gf	floor covering - terazzo	terazzo	1	6.50	2.8	0.05	18.20	0.91	2500	2,275.00	2,275.00	concrete-based
MFH	1961-70	D4	Gf	floor covering - parquet	wood	1	17.80	7.1	0.022	98.58	2.17	455	986.79	986.79	wood-based
MFH	1961-70	D4	Gf	openings - window	glass	16	1.73	1.22	0.008	2.11	0.02	2580	43.54	696.70	glass-based
MFH	1961-70	D4	Gf	openings - window frame	wood	1	0.14	0.09	94.34	0.01	1.19	455	540.83	540.83	wood-based
MFH	1961-70	D4	Gf	openings - door	glass	1	2.50	2.99	0.004	7.48	0.03	2580	77.14	77.14	glass-based
MFH	1961-70	D4	Gf	openings - door	glass	1	1.60	3.09	0.004	4.94	0.02	2580	51.02	51.02	glass-based
MFH	1961-70	D4	Gf	openings - door	glass	1	1.60	2.59	0.004	4.14	0.02	2580	42.77	42.77	glass-based
MFH	1961-70	D4	Gf	openings - door	glass	1	0.90	3.09	0.004	2.78	0.01	2580	28.70	28.70	glass-based
MFH	1961-70	D4	Gf	openings - door	plywood	12	0.81	2.09	0.012	1.69	0.02	427	8.65	103.84	wood-based
MFH	1961-70	D4	Gf	openings - door	plywood	4	0.61	2.09	0.012	1.27	0.02	427	6.52	26.07	wood-based
MFH	1961-70	D4	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	25.35	0.76	5.8	4.41	4.41	organic - misc.
MFH	1961-70	D4	Gf	openings - door frame	steel	1	0.10	0.005	30.12	0.001	0.02	7860	118.37	118.37	metal-based
MFH	1961-70	D4	Gf	openings - door	wood	1	0.09	0.31	78.88	0.03	2.20	455	1,001.34	1,001.34	wood-based
MFH	1961-70	D4	Gf	columns	reinf. concrete	10	0.20	0.2	2.80	0.04	0.11	2500	280.00	2,800.00	concrete-based
MFH	1961-70	D4	Gf	walls	reinf. concrete	1	21.24	2.8	0.20	56.09	11.22	2500	28,047.15	28,047.15	concrete-based
MFH	1961-70	D4	Gf	walls	prefab. concrete	1	34.40	0.86	0.30	29.58	8.88	2500	22,188.00	22,188.00	concrete-based
MFH	1961-70	D4	Gf	walls	clay blocks	1	34.40	0.86	0.19	29.58	5.62	1000	5,620.96	5,620.96	clay-based
MFH	1961-70	D4	Gf	walls	clay blocks	1	59.80	2.8	0.19	159.00	30.21	1000	30,209.19	30,209.19	clay-based
MFH	1961-70	D4	Gf	walls	clay blocks	1	29.55	2.8	0.07	69.21	4.84	1000	4,844.58	4,844.58	clay-based
MFH	1961-70	D4	Gf	wall covering - plaster	lime-sand plaster	1	167.56	2.8	0.02	469.17	9.38	1800	16,890.09	16,890.09	plaster-based
MFH	1961-70	D4	Gf	wall covering - aggregate plaster	cement-sand plaster	1	34.40	0.86	0.005	29.58	0.15	2100	310.63	310.63	plaster-based
MFH	1961-70	D4	Gf	stairs	reinf. concrete	18	0.16	0.286	1.35	0.02	0.03	2500	77.22	1,389.96	concrete-based
MFH	1961-70	D4	Gf	stairs - railings	steel	2	6.3	0.016	0.016	0.10	0.002	7860	12.68	25.35	metal-based
MFH	1961-70	D4	Gf	stairs - railings	steel	63	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	106.48	metal-based
MFH	1961-70	D4	Gf	ceiling covering - plaster	lime-sand plaster	1	20.40	12.6	0.02	257.04	5.14	1800	9,253.44	9,253.44	plaster-based
MFH	1961-70	D4	Gf	slab	reinf. concrete	1	20.80	12.9	0.20	268.32	53.66	2500	134,160.00	134,160.00	concrete-based
MFH	1961-70	D4	1st - 4th	balcony - railings	prefab. concrete	4	18.10	1.3	0.06	23.53	1.41	2500	3,529.50	14,118.00	concrete-based
MFH	1961-70	D4	1st - 4th	floor covering - florbit	florbit	4	n/a	n/a	0.03	208.22	6.25	770	4,809.88	19,239.53	bitumen-based
MFH	1961-70	D4	1st - 4th	floor covering - clay tiles	clay tiles	8	3.00	2.3	0.01	6.90	0.07	1800	124.20	993.60	clay-based
MFH	1961-70	D4	1st - 4th	floor covering - clay tiles	clay tiles	4	2.00	1.7	0.01	3.40	0.03	1800	61.20	244.80	clay-based
MFH	1961-70	D4	1st - 4th	floor covering - clay tiles	clay tiles	4	3.00	3	0.01	9.00	0.09	1800	162.00	648.00	clay-based
MFH	1961-70	D4	1st - 4th	floor covering - clay tiles	clay tiles	8	3.50	2	0.01	7.00	0.07	1800	126.00	1,008.00	clay-based
MFH	1961-70	D4	1st - 4th	floor covering - terazzo	terazzo	4	1.20	15.7	0.05	18.84	0.94	2500	2,355.00	9,420.00	concrete-based
MFH	1961-70	D4	1st - 4th	floor covering - parquet	wood	4	12.90	20.8	0.022	168.02	3.70	455	1,681.88	6,727.52	wood-based
MFH	1961-70	D4	1st - 4th	openings - window	glass	16	3.78	1.23	0.008	4.64	0.04	2580	95.85	1,533.59	glass-based
MFH	1961-70	D4	1st - 4th	openings - window	glass	4	2.18	2.02	0.004	4.40	0.02	2580	45.42	181.67	glass-based
MFH	1961-70	D4	1st - 4th	openings - window	glass	8	1.78	1.22	0.008	2.17	0.02	2580	44.82	358.55	glass-based
MFH	1961-70	D4	1st - 4th	openings - window	glass	16	1.73	1.22	0.008	2.11	0.02	2580	43.54	696.70	glass-based
MFH	1961-70	D4	1st - 4th	openings - window	glass	12	0.98	1.22	0.008	1.19	0.01	2580	24.61	295.34	glass-based
MFH	1961-70	D4	1st - 4th	openings - window	glass	4	0.49	1.22	0.008	0.59	0.005	2580	12.24	48.97	glass-based
MFH	1961-70	D4	1st - 4th	openings - window frame	wood	4	0.14	0.09	368.90	0.01	4.65	455	2,114.93	8,459.71	wood-based
MFH	1961-70	D4	1st - 4th	openings - door	glass	28	0.48	2.12	0.008	1.01	0.01	2580	20.81	582.79	glass-based
MFH	1961-70	D4	1st - 4th	openings - door	plywood	52	0.81	2.02	0.012	1.64	0.02	427	8.40	436.61	wood-based
MFH	1961-70	D4	1st - 4th	openings - door	plywood	24	0.66	2.02	0.012	1.34	0.02	427	6.84	164.20	wood-based
MFH	1961-70	D4	1st - 4th	openings - door	cardboard (honeycomb)	4	n/a	n/a	0.030	29.31	0.88	5.8	5.10	20.40	organic - misc.
MFH	1961-70	D4	1st - 4th	openings - door frame	wood	4	0.09	0.31	365.46	0.03	10.20	455	4,639.28	18,557.12	wood-based
MFH	1961-70	D4	1st - 4th	columns	reinf. concrete	8	0.20	2.6	0.20	0.52	0.10	2500	260.00	2,080.00	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D4	1st - 4th	walls	reinf. concrete	4	7.20	2.6	0.20	18.72	3.74	2500	9,360.00	37,440.00	concrete-based
MFH	1961-70	D4	1st - 4th	walls	prefab. concrete	4	34.40	0.86	0.30	29.58	8.88	2500	22,188.00	88,752.00	concrete-based
MFH	1961-70	D4	1st - 4th	walls	clay blocks	4	34.40	0.86	0.19	29.58	5.62	1000	5,620.96	22,483.84	clay-based
MFH	1961-70	D4	1st - 4th	walls	clay blocks	4	74.20	2.6	0.19	177.42	33.71	1000	33,709.02	134,836.08	clay-based
MFH	1961-70	D4	1st - 4th	walls	clay blocks	4	29.40	2.6	0.07	61.87	4.33	1000	4,331.21	17,324.83	clay-based
MFH	1961-70	D4	1st - 4th	wall covering - plaster	lime-sand plaster	4	153.39	2.6	0.02	398.81	7.98	1800	14,357.26	57,429.03	plaster-based
MFH	1961-70	D4	1st - 4th	wall covering - mosaic tiles	clay tiles	4	12.80	2.6	0.005	33.28	0.17	1800	299.52	1,198.08	clay-based
MFH	1961-70	D4	1st - 4th	stairs	reinf. concrete	54	0.16	0.286	1.35	0.02	0.03	2500	77.22	4,169.88	concrete-based
MFH	1961-70	D4	1st - 4th	stairs - railings	steel	6	6.3	0.016	0.016	0.10	0.002	7860	12.68	76.06	metal-based
MFH	1961-70	D4	1st - 4th	stairs - railings	steel	189	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	319.45	metal-based
MFH	1961-70	D4	1st - 4th	ceiling covering - plaster	lime-sand plaster	4	20.40	12.6	0.02	257.04	5.14	1800	9,253.44	37,013.76	plaster-based
MFH	1961-70	D4	1st - 4th	slab	reinf. concrete	4	20.80	12.9	0.14	268.32	37.56	2500	93,912.00	375,648.00	concrete-based
MFH	1961-70	D4	Roof	roof covering - thermal insulation	heraklit	1	20.60	13.3	0.05	273.98	13.70	460	6,301.54	6,301.54	wood-based
MFH	1961-70	D4	Roof	roof covering - concrete	concrete	1	20.60	13.3	0.05	273.98	13.70	2400	32,877.60	32,877.60	concrete-based
MFH	1961-70	D4	Roof	roof covering - screed	cement-sand plaster	1	20.60	13.3	0.02	273.98	5.48	2100	11,507.16	11,507.16	plaster-based
MFH	1961-70	D4	Roof	roof covering - water-proofing	bitumen	1	20.60	13.3	0.01	273.98	2.74	1500	4,109.70	4,109.70	bitumen-based
MFH	1961-70	D4	Roof	roof covering - asphalt	asphalt	1	20.60	13.3	0.03	273.98	8.22	2100	17,260.74	17,260.74	bitumen-based
MFH	1961-70	D4	Roof	gutters	sheet metal	1	59.44	0.2	0.00065	11.89	0.01	7860	60.74	60.74	metal-based
MFH	1961-70	D5	B	base slab - gravel	gravel	1	17.80	11.05	0.10	196.69	19.67	1850	36,387.65	36,387.65	stone-based
MFH	1961-70	D5	B	base slab	reinf. concrete	1	17.80	11.05	0.10	196.69	19.67	2500	49,172.50	49,172.50	concrete-based
MFH	1961-70	D5	B	floor covering - water-proofing	bitumen	1	17.80	11.05	0.01	196.69	1.97	1500	2,950.35	2,950.35	bitumen-based
MFH	1961-70	D5	B	floor covering - screed	cement-sand plaster	1	17.80	11.05	0.05	196.69	9.83	2100	20,652.45	20,652.45	plaster-based
MFH	1961-70	D5	B	openings - window	glass	10	1.30	0.49	0.004	0.64	0.003	2580	6.57	65.74	glass-based
MFH	1961-70	D5	B	openings - window frame	steel	1	0.10	0.005	35.800	0.001	0.02	7860	140.69	140.69	metal-based
MFH	1961-70	D5	B	openings - door	glass	4	0.80	2.09	0.004	1.67	0.01	2580	17.26	69.02	glass-based
MFH	1961-70	D5	B	openings - door frame	steel	1	0.10	0.005	23.120	0.001	0.01	7860	90.86	90.86	metal-based
MFH	1961-70	D5	B	walls	clay bricks	1	55.02	2.2	0.38	111.33	42.31	1800	76,149.72	76,149.72	clay-based
MFH	1961-70	D5	B	walls	clay bricks	1	43.75	2.2	0.25	92.91	23.23	1800	41,807.70	41,807.70	clay-based
MFH	1961-70	D5	B	wall covering - plaster	lime-sand plaster	1	185.67	2.2	0.02	408.47	8.17	1800	14,704.99	14,704.99	plaster-based
MFH	1961-70	D5	B	stairs	reinf. concrete	14	0.20	0.29	1.20	0.03	0.03	2500	87.00	1,218.00	concrete-based
MFH	1961-70	D5	B	stairs - railings	steel	2	6.3	0.016	0.016	0.10	0.002	7860	12.68	25.35	metal-based
MFH	1961-70	D5	B	stairs - railings	steel	63	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	106.48	metal-based
MFH	1961-70	D5	B	ceiling covering - plaster	lime-sand plaster	1	18.75	11.8	0.02	219.63	4.39	1800	7,906.54	7,906.54	plaster-based
MFH	1961-70	D5	B	slab	clay blocks	3037	0.25	0.25	0.16	0.06	0.01	1000	10.00	30,369.60	clay-based
MFH	1961-70	D5	B	slab	concrete	1	18.75	11.8	0.04	221.25	8.85	2400	21,240.00	21,240.00	concrete-based
MFH	1961-70	D5	Gf	floor covering - woodcrete	woodcrete	1	18.75	11.8	0.025	178.97	4.47	1000	4,474.25	4,474.25	concrete-based
MFH	1961-70	D5	Gf	floor covering - clay tiles	clay tiles	2	4.30	4	0.01	17.20	0.17	1800	309.60	619.20	clay-based
MFH	1961-70	D5	Gf	floor covering - clay tiles	clay tiles	1	4.00	2.7	0.01	10.80	0.11	1800	194.40	194.40	clay-based
MFH	1961-70	D5	Gf	floor covering - clay tiles	clay tiles	1	2.70	1.2	0.01	3.24	0.03	1800	58.32	58.32	clay-based
MFH	1961-70	D5	Gf	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	9.88	0.49	2500	1,235.00	1,235.00	concrete-based
MFH	1961-70	D5	Gf	floor covering - parquet	wood	1	n/a	n/a	0.02	130.53	2.87	455	1,306.61	1,306.61	wood-based
MFH	1961-70	D5	Gf	openings - window	glass	4	1.68	1.32	0.008	2.22	0.02	2580	45.75	183.01	glass-based
MFH	1961-70	D5	Gf	openings - window	glass	3	1.13	1.32	0.008	1.49	0.01	2580	30.72	92.16	glass-based
MFH	1961-70	D5	Gf	openings - window	glass	1	0.33	1.32	0.008	0.43	0.003	2580	8.87	8.87	glass-based
MFH	1961-70	D5	Gf	openings - window	glass	2	0.33	0.42	0.008	0.14	0.001	2580	2.84	5.67	glass-based
MFH	1961-70	D5	Gf	openings - window frame	wood	1	0.14	0.09	44.96	0.01	0.57	455	257.78	257.78	wood-based
MFH	1961-70	D5	Gf	openings - door	sheet metal	1	3.20	3.4	0.003	10.88	0.03	7860	256.55	256.55	metal-based
MFH	1961-70	D5	Gf	openings - door	glass	2	1.03	2.22	0.008	2.28	0.02	2580	47.03	94.06	glass-based
MFH	1961-70	D5	Gf	openings - door	glass	1	2.30	2.19	0.004	5.04	0.02	2580	51.98	51.98	glass-based
MFH	1961-70	D5	Gf	openings - door	plywood	8	0.81	1.94	0.012	1.57	0.02	427	8.03	64.25	wood-based
MFH	1961-70	D5	Gf	openings - door	plywood	3	0.71	1.94	0.012	1.37	0.02	427	7.04	21.12	wood-based
MFH	1961-70	D5	Gf	openings - door	plywood	6	0.61	1.94	0.012	1.18	0.01	427	6.05	36.29	wood-based
MFH	1961-70	D5	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	23.74	0.71	5.8	4.13	4.13	organic - misc.
MFH	1961-70	D5	Gf	openings - door frame	wood	1	0.09	0.31	89.00	0.03	2.48	455	1,129.84	1,129.84	wood-based
MFH	1961-70	D5	Gf	openings - door frame	steel	1	0.10	0.005	17.62	0.001	0.01	7860	69.25	69.25	metal-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D5	Gf	walls	clay bricks	1	55.02	2.7	0.38	121.93	46.33	1800	83,397.27	83,397.27	clay-based
MFH	1961-70	D5	Gf	walls	clay bricks	1	43.75	2.7	0.25	114.85	28.71	1800	51,683.77	51,683.77	clay-based
MFH	1961-70	D5	Gf	walls	clay bricks	1	57.10	2.7	0.07	136.70	9.57	1800	17,223.82	17,223.82	clay-based
MFH	1961-70	D5	Gf	wall covering - plaster	lime-sand plaster	1	276.65	2.7	0.02	746.95	14.94	1800	26,890.24	26,890.24	plaster-based
MFH	1961-70	D5	Gf	stairs	reinf. concrete	18	0.17	0.29	1.20	0.02	0.03	2500	73.95	1,331.10	concrete-based
MFH	1961-70	D5	Gf	stairs - railings	steel	2	6.3	0.016	0.016	0.10	0.002	7860	12.68	25.35	metal-based
MFH	1961-70	D5	Gf	stairs - railings	steel	63	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	106.48	metal-based
MFH	1961-70	D5	Gf	ceiling covering - plaster	lime-sand plaster	1	21.75	11.8	0.02	256.65	5.13	1800	9,239.40	9,239.40	plaster-based
MFH	1961-70	D5	Gf	slab	clay blocks	3739	0.25	0.25	0.16	0.06	0.01	1000	10.00	37,392.00	clay-based
MFH	1961-70	D5	Gf	slab	concrete	1	21.75	11.8	0.04	256.65	10.27	2400	24,638.40	24,638.40	concrete-based
MFH	1961-70	D5	1st - 5th	balcony - railings	prefab. concrete	5	21.40	1.1	0.070	3.38	0.24	2500	591.50	2,957.50	concrete-based
MFH	1961-70	D5	1st - 5th	balcony - floor covering	terazzo	5	21.40	1.1	0.05	23.54	1.18	2500	2,942.50	14,712.50	concrete-based
MFH	1961-70	D5	1st - 5th	floor covering - woodcrete	woodcrete	5	21.10	11	0.025	224.60	5.62	1000	5,615.00	28,075.00	concrete-based
MFH	1961-70	D5	1st - 5th	floor covering - clay tiles	clay tiles	5	4.30	4	0.01	17.20	0.17	1800	309.60	1,548.00	clay-based
MFH	1961-70	D5	1st - 5th	floor covering - clay tiles	clay tiles	5	4.30	3.4	0.01	14.62	0.15	1800	263.16	1,315.80	clay-based
MFH	1961-70	D5	1st - 5th	floor covering - clay tiles	clay tiles	5	4.80	4.2	0.01	20.16	0.20	1800	362.88	1,814.40	clay-based
MFH	1961-70	D5	1st - 5th	floor covering - terazzo	terazzo	5	3.00	2.5	0.05	7.50	0.38	2500	937.50	4,687.50	concrete-based
MFH	1961-70	D5	1st - 5th	floor covering - parquet	wood	5	21.75	11.8	0.02	204.67	4.50	455	2,048.75	10,243.73	wood-based
MFH	1961-70	D5	1st - 5th	openings - window	glass	5	2.30	1.39	0.008	3.20	0.03	2580	65.99	329.93	glass-based
MFH	1961-70	D5	1st - 5th	openings - window	glass	15	1.68	1.32	0.008	2.22	0.02	2580	45.75	686.29	glass-based
MFH	1961-70	D5	1st - 5th	openings - window	glass	15	1.13	1.32	0.008	1.49	0.01	2580	30.72	460.80	glass-based
MFH	1961-70	D5	1st - 5th	openings - window	glass	5	0.33	1.32	0.008	0.43	0.003	2580	8.87	44.37	glass-based
MFH	1961-70	D5	1st - 5th	openings - window	glass	5	0.33	0.42	0.008	0.14	0.001	2580	2.84	14.19	glass-based
MFH	1961-70	D5	1st - 5th	openings - window frame	wood	5	0.14	0.07	187.36	0.01	1.84	455	835.42	4,177.08	wood-based
MFH	1961-70	D5	1st - 5th	openings - window frame	steel	5	0.10	0.005	36.90	0.001	0.02	7860	145.02	725.09	metal-based
MFH	1961-70	D5	1st - 5th	openings - door	glass	15	1.68	2.22	0.008	3.72	0.03	2580	76.88	1,153.15	glass-based
MFH	1961-70	D5	1st - 5th	openings - door	glass	20	1.03	2.22	0.008	2.28	0.02	2580	47.03	940.60	glass-based
MFH	1961-70	D5	1st - 5th	openings - door	plywood	40	0.81	1.94	0.012	1.57	0.02	427	8.03	321.24	wood-based
MFH	1961-70	D5	1st - 5th	openings - door	plywood	15	0.71	1.94	0.012	1.37	0.02	427	7.04	105.59	wood-based
MFH	1961-70	D5	1st - 5th	openings - door	plywood	40	0.61	1.94	0.012	1.18	0.01	427	6.05	241.92	wood-based
MFH	1961-70	D5	1st - 5th	openings - door	cardboard (honeycomb)	5	n/a	n/a	0.030	26.10	0.78	5.8	4.54	22.71	organic - misc.
MFH	1961-70	D5	1st - 5th	openings - door frame	wood	5	0.09	0.31	636.34	0.03	17.75	455	8,078.05	40,390.25	wood-based
MFH	1961-70	D5	1st - 5th	walls	clay bricks	5	43.50	2.7	0.38	86.84	33.00	1800	59,398.09	296,990.43	clay-based
MFH	1961-70	D5	1st - 5th	walls	clay bricks	5	54.64	2.7	0.25	138.12	34.53	1800	62,155.76	310,778.78	clay-based
MFH	1961-70	D5	1st - 5th	walls	clay bricks	5	75.40	2.7	0.07	183.16	12.82	1800	23,077.70	115,388.48	clay-based
MFH	1961-70	D5	1st - 5th	wall covering - plaster	lime-sand plaster	5	302.31	2.7	0.02	816.24	16.32	1800	29,384.61	146,923.03	plaster-based
MFH	1961-70	D5	1st - 5th	stairs	reinf. concrete	72	0.17	0.29	1.20	0.02	0.03	2500	73.95	5,324.40	concrete-based
MFH	1961-70	D5	1st - 5th	stairs - railings	steel	8	6.3	0.016	0.016	0.10	0.002	7860	12.68	101.41	metal-based
MFH	1961-70	D5	1st - 5th	stairs - railings	steel	252	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	425.93	metal-based
MFH	1961-70	D5	1st - 5th	ceiling covering - plaster	lime-sand plaster	5	21.75	11.8	0.02	256.65	5.13	1800	9,239.40	46,197.00	plaster-based
MFH	1961-70	D5	1st - 5th	slab	clay blocks	18924	0.25	0.25	0.16	0.06	0.01	1000	10.00	189,240.00	clay-based
MFH	1961-70	D5	1st - 5th	slab	concrete	5	21.75	11.8	0.04	256.65	10.27	2400	24,638.40	123,192.00	concrete-based
MFH	1961-70	D5	Roof	roof covering - concrete	concrete	1	21.75	11.8	0.05	256.65	12.83	2400	30,798.00	30,798.00	concrete-based
MFH	1961-70	D5	Roof	roof covering - vapour barrier	tar paper	1	21.75	11.8	0.00008	256.65	0.02	929	19.07	19.07	bitumen-based
MFH	1961-70	D5	Roof	roof covering - thermal insulation	heraklit	1	21.75	11.8	0.05	256.65	12.83	460	5,902.95	5,902.95	wood-based
MFH	1961-70	D5	Roof	floor covering - screed	cement-sand plaster	1	21.75	11.8	0.02	256.65	5.13	2100	10,779.30	10,779.30	plaster-based
MFH	1961-70	D5	Roof	floor covering - water-proofing	bitumen	1	21.75	11.8	0.02	256.65	5.13	1500	7,699.50	7,699.50	bitumen-based
MFH	1961-70	D5	Roof	floor covering - bitumen+gravel	asphalt	1	21.75	11.8	0.02	256.65	5.13	2100	10,779.30	10,779.30	bitumen-based
MFH	1961-70	D5	Roof	gutters	sheet metal	1	59.00	0.2	0.00065	11.80	0.01	7860	60.29	60.29	metal-based
MFH	1961-70	D6	B	base slab - gravel	gravel	1	21.50	15.3	0.1	328.95	32.90	1850	60,855.75	60,855.75	stone-based
MFH	1961-70	D6	B	base slab	reinf. concrete	1	21.50	15.3	0.6	328.95	197.37	2500	493,425.00	493,425.00	concrete-based
MFH	1961-70	D6	B	floor covering - water-proofing	bitumen	1	21.50	15.3	0.01	328.95	3.29	1500	4,934.25	4,934.25	bitumen-based
MFH	1961-70	D6	B	floor covering - screed	cement-sand plaster	1	21.50	15.3	0.05	328.95	16.45	2100	34,539.75	34,539.75	plaster-based
MFH	1961-70	D6	B	openings - window	glass	1	3.00	0.99	0.004	2.97	0.01	2580	30.65	30.65	glass-based
MFH	1961-70	D6	B	openings - window	glass	9	1.85	0.99	0.004	1.83	0.01	2580	18.90	170.11	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D6	B	openings - window frame	steel	1	0.10	0.005	59.100	0.001	0.03	7860	232.26	232.26	metal-based
MFH	1961-70	D6	B	openings - door	sheet metal	1	1.10	2.09	0.003	2.30	0.01	7860	54.21	54.21	metal-based
MFH	1961-70	D6	B	openings - door	sheet metal	7	0.80	2.09	0.003	1.67	0.01	7860	39.43	275.98	metal-based
MFH	1961-70	D6	B	openings - door	sheet metal	2	0.50	2.09	0.003	1.05	0.003	7860	24.64	49.28	metal-based
MFH	1961-70	D6	B	openings - door frame	steel	1	0.10	0.005	49.50	0.001	0.02	7860	194.54	194.54	metal-based
MFH	1961-70	D6	B	walls	reinf. concrete	1	52.60	2.35	0.60	120.27	72.16	2500	180,399.00	180,399.00	concrete-based
MFH	1961-70	D6	B	walls	reinf. concrete	1	74.30	2.35	0.30	150.81	45.24	2500	113,104.88	113,104.88	concrete-based
MFH	1961-70	D6	B	walls	reinf. concrete	1	37.60	2.35	0.22	88.36	19.44	2500	48,598.00	48,598.00	concrete-based
MFH	1961-70	D6	B	stairs	reinf. concrete	16	0.28	0.175	1.200	0.02	0.03	2500	73.50	1,176.00	concrete-based
MFH	1961-70	D6	B	stairs	reinf. concrete	4	0.30	0.175	1.000	0.03	0.03	2500	65.63	262.50	concrete-based
MFH	1961-70	D6	B	slab	reinf. concrete	1	21.50	15.3	0.140	339.70	47.56	2500	118,895.88	118,895.88	concrete-based
MFH	1961-70	D6	Gf	floor covering - thermal insulation	rock wool	1	n/a	n/a	0.020	206.79	4.14	160	661.73	661.73	stone-based
MFH	1961-70	D6	Gf	floor covering - kraft paper	kraft paper	1	n/a	n/a	1.0E-05	206.79	0.00207	648	1.34	1.34	organic - misc.
MFH	1961-70	D6	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.030	206.79	6.20	2100	13,027.77	13,027.77	plaster-based
MFH	1961-70	D6	Gf	floor covering - clay tiles	clay tiles	3	5.30	2.05	0.010	10.87	0.11	1800	195.57	586.71	clay-based
MFH	1961-70	D6	Gf	floor covering - clay tiles	clay tiles	3	2.40	1.5	0.01	3.60	0.04	1800	64.80	194.40	clay-based
MFH	1961-70	D6	Gf	floor covering - clay tiles	clay tiles	3	1.07	1.4	0.01	1.50	0.01	1800	26.96	80.89	clay-based
MFH	1961-70	D6	Gf	floor covering - terazzo	terazzo	1	4.20	1.84	0.05	7.73	0.39	2500	966.00	966.00	concrete-based
MFH	1961-70	D6	Gf	floor covering - terazzo	terazzo	1	1.80	2	0.05	3.60	0.18	2500	450.00	450.00	concrete-based
MFH	1961-70	D6	Gf	floor covering - terazzo	terazzo	2	3.10	1.1	0.05	3.41	0.17	2500	426.25	852.50	concrete-based
MFH	1961-70	D6	Gf	floor covering - terazzo	terazzo	1	4.10	5.8	0.05	23.78	1.19	2500	2,972.50	2,972.50	concrete-based
MFH	1961-70	D6	Gf	floor covering - terazzo	terazzo	1	4.00	9	0.05	36.00	1.80	2500	4,500.00	4,500.00	concrete-based
MFH	1961-70	D6	Gf	floor covering - parquet	wood	1	n/a	n/a	0.020	158.90	3.18	455	1,446.00	1,446.00	wood-based
MFH	1961-70	D6	Gf	openings - window	glass	21	1.71	1.42	0.008	2.43	0.02	2580	50.08	1,051.62	glass-based
MFH	1961-70	D6	Gf	openings - window	glass	6	0.85	2.42	0.008	2.05	0.02	2580	42.26	253.55	glass-based
MFH	1961-70	D6	Gf	openings - window frame	wood	1	0.14	0.09	170.59	0.01	2.15	455	978.00	978.00	wood-based
MFH	1961-70	D6	Gf	openings - door	glass	1	1.78	2.59	0.004	4.61	0.02	2580	47.58	47.58	glass-based
MFH	1961-70	D6	Gf	openings - door	plywood	17	0.81	1.99	0.012	1.61	0.02	427	8.24	140.06	wood-based
MFH	1961-70	D6	Gf	openings - door	plywood	17	0.61	1.99	0.012	1.21	0.01	427	6.20	105.47	wood-based
MFH	1961-70	D6	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	47.92	1.44	5.8	8.34	8.34	organic - misc.
MFH	1961-70	D6	Gf	openings - door frame	wood	1	0.09	0.31	166.080	0.03	4.63	455	2,108.30	2,108.30	wood-based
MFH	1961-70	D6	Gf	columns	reinf. concrete	8	0.14	0.18	2.70	0.03	0.07	2500	170.10	1,360.80	concrete-based
MFH	1961-70	D6	Gf	walls	reinf. concrete	1	31.70	2.7	0.14	68.45	9.58	2500	23,958.54	23,958.54	concrete-based
MFH	1961-70	D6	Gf	walls	reinf. concrete	1	119.34	2.7	0.14	294.05	41.17	2500	102,917.80	102,917.80	concrete-based
MFH	1961-70	D6	Gf	walls	clay blocks	1	37.05	2.7	0.07	80.28	5.62	1000	5,619.90	5,619.90	clay-based
MFH	1961-70	D6	Gf	wall covering - plaster	lime-sand plaster	1	59.47	2.7	0.14	160.57	22.48	1800	40,463.26	40,463.26	plaster-based
MFH	1961-70	D6	Gf	wall covering - gypsum plaster	gypsum plaster	1	31.70	2.7	0.04	68.45	2.74	1043	2,855.86	2,855.86	gypsum-based
MFH	1961-70	D6	Gf	wall covering - reed	reed	1	31.70	2.7	0.01	68.45	0.68	150	102.68	102.68	organic - misc.
MFH	1961-70	D6	Gf	wall covering - plywood	plywood	1	37.49	1.05	0.016	39.36	0.63	427	268.94	268.94	wood-based
MFH	1961-70	D6	Gf	wall covering - al foil	aluminum foil	1	37.49	1.05	1.2E-04	39.36	0.005	2800	13.23	13.23	metal-based
MFH	1961-70	D6	Gf	wall covering - battens	wood	2	37.49	0.05	0.10	1.87	0.19	455	85.29	149.26	wood-based
MFH	1961-70	D6	Gf	wall covering - thermal insulation	rock wool	1	37.49	0.95	0.05	35.62	1.78	160	284.92	284.92	stone-based
MFH	1961-70	D6	Gf	wall covering - corr. metal sheet	sheet metal	1	37.49	1.05	0.003	39.36	0.12	7860	928.21	928.21	metal-based
MFH	1961-70	D6	Gf	stairs	reinf. concrete	16	0.28	0.175	1.200	0.02	0.03	2500	73.50	1,176.00	concrete-based
MFH	1961-70	D6	Gf	stairs	reinf. concrete	8	0.28	0.175	2.000	0.05	0.10	2500	245.00	1,960.00	concrete-based
MFH	1961-70	D6	Gf	stairs - railings	steel	2	9.8	0.016	0.016	0.16	0.003	7860	19.72	39.44	metal-based
MFH	1961-70	D6	Gf	stairs - railings	steel	98	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	165.64	metal-based
MFH	1961-70	D6	Gf	slab	reinf. concrete	1	21.50	15.3	0.140	328.95	46.05	2500	115,132.50	115,132.50	concrete-based
MFH	1961-70	D6	1st - 12th	balcony - slab	reinf. concrete	24	1.00	4.1	0.140	4.10	0.57	2500	1,435.00	34,440.00	concrete-based
MFH	1961-70	D6	1st - 12th	balcony - railings	prefab. concrete	24	4.10	1.06	0.050	4.35	0.2173	2500	543.25	13,038.00	concrete-based
MFH	1961-70	D6	1st - 12th	balcony - railings	steel	48	1.00	0.016	0.016	0.02	0.0003	7860	2.01	96.58	metal-based
MFH	1961-70	D6	1st - 12th	balcony - railings	steel	480	0.84	0.016	0.016	0.01	0.0002	7860	1.69	811.30	metal-based
MFH	1961-70	D6	1st - 12th	floor covering - thermal insulation	rock wool	12	n/a	n/a	0.020	287.14	5.74	160	918.85	11,026.18	stone-based
MFH	1961-70	D6	1st - 12th	floor covering - kraft paper	kraft paper	12	n/a	n/a	1.0E-05	287.14	0.00287	648	1.86	22.33	organic - misc.
MFH	1961-70	D6	1st - 12th	floor covering - screed	cement-sand plaster	12	n/a	n/a	0.030	287.14	8.61	2100	18,089.82	217,077.84	plaster-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D6	1st - 12th	floor covering - clay tiles	clay tiles	24	5.40	4.1	0.010	22.14	0.22	1800	398.52	9,564.48	clay-based
MFH	1961-70	D6	1st - 12th	floor covering - clay tiles	clay tiles	48	2.40	1.4	0.01	3.36	0.03	1800	60.48	2,903.04	clay-based
MFH	1961-70	D6	1st - 12th	floor covering - clay tiles	clay tiles	24	0.80	1.4	0.01	1.12	0.01	1800	20.16	483.84	clay-based
MFH	1961-70	D6	1st - 12th	floor covering - terazzo	terazzo	12	n/a	n/a	0.05	13.83	0.69	2500	1,728.75	20,745.00	concrete-based
MFH	1961-70	D6	1st - 12th	floor covering - terazzo	terazzo	24	1.54	4.02	0.05	6.19	0.31	2500	773.85	18,572.40	concrete-based
MFH	1961-70	D6	1st - 12th	floor covering - parquet	wood	12	21.50	15.3	0.020	227.18	4.54	455	2,067.34	24,808.06	wood-based
MFH	1961-70	D6	1st - 12th	openings - window	glass	216	1.71	1.42	0.008	2.43	0.02	2580	50.08	10,816.65	glass-based
MFH	1961-70	D6	1st - 12th	openings - window	glass	48	1.01	1.42	0.008	1.43	0.01	2580	29.52	1,416.84	glass-based
MFH	1961-70	D6	1st - 12th	openings - window	glass	72	0.85	1.42	0.008	1.20	0.01	2580	24.82	1,786.91	glass-based
MFH	1961-70	D6	1st - 12th	openings - window frame	wood	12	0.14	0.09	1,910.98	0.01	24.08	455	10,955.63	131,467.50	wood-based
MFH	1961-70	D6	1st - 12th	openings - door	glass	48	0.48	1.92	0.008	0.91	0.01	2580	18.85	904.95	glass-based
MFH	1961-70	D6	1st - 12th	openings - door	plywood	216	0.81	1.92	0.012	1.56	0.02	427	7.98	1,723.96	wood-based
MFH	1961-70	D6	1st - 12th	openings - door	plywood	240	0.61	1.92	0.012	1.17	0.01	427	6.01	1,442.55	wood-based
MFH	1961-70	D6	1st - 12th	openings - door	cardboard (honeycomb)	12	n/a	n/a	0.030	51.50	1.54	5.8	8.96	107.53	organic - misc.
MFH	1961-70	D6	1st - 12th	openings - door frame	wood	12	0.09	0.31	2,282.544	0.03	63.68	455	28,975.75	347,709.06	wood-based
MFH	1961-70	D6	1st - 12th	columns	reinf. concrete	96	0.14	0.18	2.60	0.03	0.07	2500	163.80	15,724.80	concrete-based
MFH	1961-70	D6	1st - 12th	walls	reinf. concrete	12	32.80	2.6	0.14	75.21	10.53	2500	26,321.81	315,861.67	concrete-based
MFH	1961-70	D6	1st - 12th	walls	reinf. concrete	12	120.15	2.6	0.14	281.20	39.37	2500	98,419.63	1,181,035.55	concrete-based
MFH	1961-70	D6	1st - 12th	walls	clay blocks	12	43.30	2.6	0.07	92.27	6.46	1000	6,459.12	77,509.42	clay-based
MFH	1961-70	D6	1st - 12th	wall covering - plaster	lime-sand plaster	12	70.98	2.6	0.14	184.55	25.84	1800	46,505.65	558,067.83	plaster-based
MFH	1961-70	D6	1st - 12th	wall covering - gypsum plaster	gypsum plaster	12	32.80	2.6	0.04	75.21	3.01	1043	3,137.56	37,650.71	gypsum-based
MFH	1961-70	D6	1st - 12th	wall covering - reed	reed	12	32.80	2.6	0.01	75.21	0.75	150	112.81	1,353.69	organic - misc.
MFH	1961-70	D6	1st - 12th	wall covering - plywood	plywood	12	31.40	1.05	0.016	32.97	0.53	427	225.25	2,703.01	wood-based
MFH	1961-70	D6	1st - 12th	wall covering - al foil	aluminum foil	12	31.40	1.05	1.2E-04	32.97	0.004	2800	11.08	132.94	metal-based
MFH	1961-70	D6	1st - 12th	wall covering - battens	wood	24	31.40	0.05	0.10	1.57	0.16	455	71.44	1,714.44	wood-based
MFH	1961-70	D6	1st - 12th	wall covering - thermal insulation	rock wool	12	31.40	0.95	0.05	29.83	1.49	160	238.64	2,863.68	stone-based
MFH	1961-70	D6	1st - 12th	wall covering - corr. metal sheet	sheet metal	12	31.40	1.05	0.003	32.97	0.10	7860	777.43	9,329.19	metal-based
MFH	1961-70	D6	1st - 12th	stairs	reinf. concrete	192	0.28	0.175	1.200	0.02	0.03	2500	73.50	14,112.00	concrete-based
MFH	1961-70	D6	1st - 12th	stairs - railings	steel	24	9.8	0.016	0.016	0.16	0.003	7860	19.72	473.26	metal-based
MFH	1961-70	D6	1st - 12th	stairs - railings	steel	1176	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	1,987.69	metal-based
MFH	1961-70	D6	1st - 12th	slab	reinf. concrete	12	21.50	15.3	0.140	328.95	46.05	2500	115,132.50	1,381,590.00	concrete-based
MFH	1961-70	D6	Roof 1	roof covering - thermal insulation	kombi panels	1	n/a	n/a	0.05	139.80	6.99	460	3,215.40	3,215.40	wood-based
MFH	1961-70	D6	Roof 1	roof covering - concrete	concrete	1	n/a	n/a	0.06	139.80	8.39	2400	20,131.20	20,131.20	concrete-based
MFH	1961-70	D6	Roof 1	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	139.80	1.40	1500	2,097.00	2,097.00	bitumen-based
MFH	1961-70	D6	Roof 1	roof covering - screed	cement-sand plaster	1	n/a	n/a	0.03	139.80	4.19	2100	8,807.40	8,807.40	plaster-based
MFH	1961-70	D6	Roof 1	roof covering - asphalt	asphalt	1	n/a	n/a	0.02	139.80	2.80	2100	5,871.60	5,871.60	bitumen-based
MFH	1961-70	D6	13th	floor covering - thermal insulation	rock wool	1	14.86	11	0.02	134.32	2.69	160	429.82	429.82	stone-based
MFH	1961-70	D6	13th	floor covering - kraft paper	kraft paper	1	14.86	11	1.0E-05	134.32	0.00134	648	0.87	0.87	organic - misc.
MFH	1961-70	D6	13th	floor covering - screed	cement-sand plaster	1	14.86	11	0.030	134.32	4.03	2100	8,462.16	8,462.16	plaster-based
MFH	1961-70	D6	13th	floor covering - clay tiles	clay tiles	2	n/a	n/a	0.010	3.79	0.04	1800	68.22	136.44	clay-based
MFH	1961-70	D6	13th	floor covering - clay tiles	clay tiles	2	1.07	2.6	0.01	2.78	0.03	1800	50.08	100.15	clay-based
MFH	1961-70	D6	13th	floor covering - terazzo	terazzo	1	3.10	9.4	0.05	29.14	1.46	2500	3,642.50	3,642.50	concrete-based
MFH	1961-70	D6	13th	floor covering - parquet	wood	1	n/a	n/a	0.020	121.18	2.42	455	1,102.70	1,102.70	wood-based
MFH	1961-70	D6	13th	openings - window	glass	12	1.71	1.42	0.008	2.43	0.02	2580	50.08	600.92	glass-based
MFH	1961-70	D6	13th	openings - window	glass	4	0.71	0.62	0.008	0.44	0.004	2580	9.07	36.26	glass-based
MFH	1961-70	D6	13th	openings - window frame	wood	1	0.14	0.09	85.70	0.01	1.08	455	491.30	491.30	wood-based
MFH	1961-70	D6	13th	openings - door	glass	2	0.73	1.92	0.008	1.39	0.01	2580	28.78	57.55	glass-based
MFH	1961-70	D6	13th	openings - door	plywood	10	0.81	1.99	0.012	1.61	0.02	427	8.24	82.39	wood-based
MFH	1961-70	D6	13th	openings - door	plywood	10	0.71	1.99	0.012	1.41	0.02	427	7.22	72.22	wood-based
MFH	1961-70	D6	13th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	30.17	0.91	5.8	5.25	5.25	organic - misc.
MFH	1961-70	D6	13th	openings - door frame	wood	1	0.09	0.31	103.742	0.03	2.89	455	1,316.95	1,316.95	wood-based
MFH	1961-70	D6	13th	walls	slag-cement blocks	1	54.40	2.6	0.25	107.78	26.95	790	21,286.59	21,286.59	slag-cement-based
MFH	1961-70	D6	13th	walls	reinf. concrete	1	51.44	2.6	0.14	120.88	16.92	2500	42,308.42	42,308.42	concrete-based
MFH	1961-70	D6	13th	walls	clay blocks	1	43.08	2.6	0.07	94.70	6.63	1000	6,628.92	6,628.92	clay-based
MFH	1961-70	D6	13th	wall covering - plaster	lime-sand plaster	1	155.75	2.6	0.14	404.96	56.69	1800	102,049.42	102,049.42	plaster-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1961-70	D6	13th	ceiling covering - reed	reed	1	14.86	11	0.01	163.46	1.63	150	245.19	245.19	organic - misc.
MFH	1961-70	D6	13th	ceiling covering - plaster	lime-sand plaster	1	14.86	11	0.04	163.46	6.54	1800	11,769.12	11,769.12	plaster-based
MFH	1961-70	D6	13th	ceiling covering - battens	wood	53	0.03	0.04	7.55	0.001	0.01	455	4.12	219.86	wood-based
MFH	1961-70	D6	13th	ceiling covering - battens	wood	17	0.03	0.04	3.20	0.001	0.004	455	1.75	30.28	wood-based
MFH	1961-70	D6	13th	ceiling covering - battens	wood	11	0.03	0.04	7.40	0.001	0.01	455	4.04	43.10	wood-based
MFH	1961-70	D6	13th	slab	reinf. concrete	39	0.06	0.08	4.000	0.015	0.06	2500	147.00	5,659.50	concrete-based
MFH	1961-70	D6	13th	slab	reinf. concrete	12	0.06	0.08	3.100	0.015	0.05	2500	113.93	1,358.56	concrete-based
MFH	1961-70	D6	13th	slab	reinf. concrete	8	0.06	0.08	2.800	0.015	0.04	2500	102.90	797.48	concrete-based
MFH	1961-70	D6	13th	slab	reinf. concrete	1	15.40	11.8	0.050	181.72	9.09	2500	22,715.00	22,715.00	concrete-based
MFH	1961-70	D6	Roof 2	roof covering - thermal insulation	kombi panels	1	15.40	11.8	0.05	181.72	9.09	460	4,179.56	4,179.56	wood-based
MFH	1961-70	D6	Roof 2	roof covering - concrete	concrete	1	15.40	11.8	0.06	181.72	10.90	2400	26,167.68	26,167.68	concrete-based
MFH	1961-70	D6	Roof 2	roof covering - water-proofing	bitumen	1	15.40	11.8	0.01	181.72	1.82	1500	2,725.80	2,725.80	bitumen-based
MFH	1961-70	D6	Roof 2	roof covering - screed	cement-sand plaster	1	15.40	11.8	0.03	181.72	5.45	2100	11,448.36	11,448.36	plaster-based
MFH	1961-70	D6	Roof 2	roof covering - asphalt	asphalt	1	15.40	11.8	0.02	181.72	3.63	2100	7,632.24	7,632.24	bitumen-based
MFH	1961-70	D6	Roof 2	gutters	sheet metal	1	156.14	0.2	0.00065	31.23	0.02	7860	159.54	159.54	metal-based
MFH	1971-80	E3	B	base slab - gravel	gravel	1	19.08	11.51	0.10	219.61	21.96	1850	40,628.00	40,628.00	stone-based
MFH	1971-80	E3	B	base slab	reinf. concrete	1	19.08	11.51	0.14	219.61	30.75	2500	76,863.78	76,863.78	concrete-based
MFH	1971-80	E3	B	openings - window	glass	1	1.70	1.29	0.004	2.19	0.009	2580	22.63	22.63	glass-based
MFH	1971-80	E3	B	openings - window	glass	6	1.70	0.55	0.004	0.94	0.004	2580	9.65	57.90	glass-based
MFH	1971-80	E3	B	openings - window	glass	2	0.70	0.55	0.004	0.39	0.002	2580	3.97	7.95	glass-based
MFH	1971-80	E3	B	openings - window frame	steel	1	0.10	0.005	38.0	0.001	0.019	7860	149.26	149.26	metal-based
MFH	1971-80	E3	B	openings - door	glass	1	0.71	1.89	0.004	1.34	0.005	2580	13.81	13.81	glass-based
MFH	1971-80	E3	B	openings - door	sheet metal	6	0.71	1.89	0.003	1.34	0.004	7860	31.56	189.35	metal-based
MFH	1971-80	E3	B	openings - door	plywood	12	0.71	1.89	0.012	1.34	0.016	427	6.86	82.29	wood-based
MFH	1971-80	E3	B	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	16.06	0.482	5.8	2.79	2.79	organic - misc.
MFH	1971-80	E3	B	openings - door frame	wood	1	0.09	0.31	58.240	0.03	1.625	455	739.33	739.33	wood-based
MFH	1971-80	E3	B	openings - door frame	steel	1	0.10	0.05	26.880	0.01	0.134	7860	1,056.38	1,056.38	metal-based
MFH	1971-80	E3	B	walls	reinf. concrete	1	111.74	2.2	0.300	211.83	63.548	2500	158,869.76	158,869.76	concrete-based
MFH	1971-80	E3	B	stairs	reinf. concrete	14	0.30	0.182	1.200	0.03	0.033	2500	81.90	1,146.60	concrete-based
MFH	1971-80	E3	B	stairs - railings	steel	2	4.66	0.016	0.016	0.07	0.001	7860	9.38	18.75	metal-based
MFH	1971-80	E3	B	stairs - railings	steel	47	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	78.76	metal-based
MFH	1971-80	E3	B	ceiling covering - plaster	lime-sand plaster	1	19.08	11.51	0.02	219.61	4.392	1800	7,905.99	7,905.99	plaster-based
MFH	1971-80	E3	B	slab	clay blocks	3203	0.25	0.25	0.16	0.06	0.010	1000	10.00	32,025.60	clay-based
MFH	1971-80	E3	B	slab	concrete	1	19.08	11.5	0.04	219.42	8.777	2400	21,064.32	21,064.32	concrete-based
MFH	1971-80	E3	Gf	floor covering - wooden boards	wooden floor boards	1	19.08	12.2	0.030	216.66	6.500	455	2,957.35	2,957.35	wood-based
MFH	1971-80	E3	Gf	floor covering - clay tiles	clay tiles	2	3.3	3.9	0.010	12.87	0.129	1800	231.66	463.32	clay-based
MFH	1971-80	E3	Gf	floor covering - clay tiles	clay tiles	1	3.70	4.4	0.010	16.28	0.163	1800	293.04	293.04	clay-based
MFH	1971-80	E3	Gf	floor covering - terazzo	terazzo	2	2.60	6.2	0.050	16.12	0.806	2500	2,015.00	4,030.00	concrete-based
MFH	1971-80	E3	Gf	floor covering - asphalt	asphalt	1	n/a	n/a	0.278	174.64	48.549	2100	101,952.50	101,952.50	bitumen-based
MFH	1971-80	E3	Gf	floor covering - parquet	wood	1	n/a	n/a	0.022	174.64	3.842	455	1,748.11	1,748.11	wood-based
MFH	1971-80	E3	Gf	openings - window	glass	9	1.67	1.15	0.008	1.92	0.015	2580	39.64	356.75	glass-based
MFH	1971-80	E3	Gf	openings - window	glass	5	0.56	0.65	0.008	0.36	0.003	2580	7.51	37.56	glass-based
MFH	1971-80	E3	Gf	openings - window frame	wood	1	0.12	0.08	62.86	0.01	0.603	455	274.57	274.57	wood-based
MFH	1971-80	E3	Gf	openings - door	glass	1	2.25	1.85	0.008	4.16	0.033	2580	85.91	85.91	glass-based
MFH	1971-80	E3	Gf	openings - door	glass	4	0.56	2.15	0.008	1.20	0.010	2580	24.85	99.40	glass-based
MFH	1971-80	E3	Gf	openings - door	plywood	2	0.81	1.89	0.012	1.53	0.018	427	7.82	15.65	wood-based
MFH	1971-80	E3	Gf	openings - door	plywood	10	0.71	1.89	0.012	1.34	0.016	427	6.86	68.58	wood-based
MFH	1971-80	E3	Gf	openings - door	plywood	6	0.61	1.89	0.012	1.15	0.014	427	5.89	35.35	wood-based
MFH	1971-80	E3	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	23.34	0.700	5.8	4.06	4.06	organic - misc.
MFH	1971-80	E3	Gf	openings - door frame	wood	1	0.09	0.31	105.630	0.03	2.947	455	1,340.92	1,340.92	wood-based
MFH	1971-80	E3	Gf	walls	reinf. concrete	1	13.40	2.6	0.250	31.79	7.947	2500	19,866.44	19,866.44	concrete-based
MFH	1971-80	E3	Gf	walls - tie columns	reinf. concrete	22	0.25	0.25	2.600	0.06	0.163	2500	406.25	8,937.50	concrete-based
MFH	1971-80	E3	Gf	walls	clay bricks	1	97.03	2.6	0.250	229.16	57.290	1800	103,121.30	103,121.30	clay-based
MFH	1971-80	E3	Gf	walls	clay bricks	1	41.0	2.6	0.065	92.98	6.044	1800	10,879.03	10,879.03	clay-based
MFH	1971-80	E3	Gf	wall covering - plaster	lime-sand plaster	1	247.80	2.6	0.020	644.28	12.886	1800	23,194.20	23,194.20	plaster-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E3	Gf	stairs	reinf. concrete	18	0.16	0.3	1.200	0.02	0.029	2500	71.55	1,287.90	concrete-based
MFH	1971-80	E3	Gf	stairs - railings	steel	2	5.72	0.016	0.016	0.09	0.001	7860	11.51	23.02	metal-based
MFH	1971-80	E3	Gf	stairs - railings	steel	57	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	96.68	metal-based
MFH	1971-80	E3	Gf	ceiling covering - plaster	lime-sand plaster	1	18.58	10.95	0.020	203.45	4.069	1800	7,324.24	7,324.24	plaster-based
MFH	1971-80	E3	Gf	slab	clay blocks	3203	0.25	0.25	0.16	0.06	0.010	1000	10.00	32,025.60	clay-based
MFH	1971-80	E3	Gf	slab	concrete	1	19.08	11.5	0.04	219.42	8.777	2400	21,064.32	21,064.32	concrete-based
MFH	1971-80	E3	1st - 3rd	balcony	reinf. concrete	12	0.50	4	0.10	2.00	0.200	2500	500.00	6,000.00	concrete-based
MFH	1971-80	E3	1st - 3rd	balcony	prefab. concrete	12	4.00	1	0.08	4.00	0.320	2500	800.00	9,600.00	concrete-based
MFH	1971-80	E3	1st - 3rd	balcony	steel	12	7.72	0.016	0.02	0.12	0.002	7860	15.53	186.41	metal-based
MFH	1971-80	E3	1st - 3rd	floor covering - wooden boards	wooden floor boards	3	19.08	12.2	0.030	216.66	6.500	455	2,957.35	8,872.06	wood-based
MFH	1971-80	E3	1st - 3rd	floor covering - clay tiles	clay tiles	6	3.3	3.9	0.010	12.87	0.129	1800	231.66	1,389.96	clay-based
MFH	1971-80	E3	1st - 3rd	floor covering - clay tiles	clay tiles	3	3.70	4.4	0.010	16.28	0.163	1800	293.04	879.12	clay-based
MFH	1971-80	E3	1st - 3rd	floor covering - terazzo	terazzo	12	1.30	4	0.050	5.20	0.260	2500	650.00	7,800.00	concrete-based
MFH	1971-80	E3	1st - 3rd	floor covering - terazzo	terazzo	3	2.60	6.2	0.050	16.12	0.806	2500	2,015.00	6,045.00	concrete-based
MFH	1971-80	E3	1st - 3rd	floor covering - asphalt	asphalt	3	n/a	n/a	0.278	187.51	52.127	2100	109,466.00	328,398.01	bitumen-based
MFH	1971-80	E3	1st - 3rd	floor covering - parquet	wood	3	n/a	n/a	0.022	174.64	3.842	455	1,748.11	5,244.32	wood-based
MFH	1971-80	E3	1st - 3rd	openings - window	glass	2	2.25	2.45	0.008	5.51	0.044	2580	113.78	227.56	glass-based
MFH	1971-80	E3	1st - 3rd	openings - window	glass	1	2.25	3.85	0.008	8.66	0.069	2580	178.79	178.79	glass-based
MFH	1971-80	E3	1st - 3rd	openings - window	glass	27	1.67	1.15	0.008	1.92	0.015	2580	39.64	1,070.26	glass-based
MFH	1971-80	E3	1st - 3rd	openings - window	glass	15	0.56	0.65	0.008	0.36	0.003	2580	7.51	112.69	glass-based
MFH	1971-80	E3	1st - 3rd	openings - window frame	wood	3	0.12	0.08	219.58	0.01	2.108	455	959.13	2,877.38	wood-based
MFH	1971-80	E3	1st - 3rd	openings - door	glass	12	0.56	2.15	0.008	1.20	0.010	2580	24.85	298.21	glass-based
MFH	1971-80	E3	1st - 3rd	openings - door	plywood	6	0.81	1.89	0.012	1.53	0.018	427	7.82	46.94	wood-based
MFH	1971-80	E3	1st - 3rd	openings - door	plywood	30	0.71	1.89	0.012	1.34	0.016	427	6.86	205.73	wood-based
MFH	1971-80	E3	1st - 3rd	openings - door	plywood	18	0.61	1.89	0.012	1.15	0.014	427	5.89	106.05	wood-based
MFH	1971-80	E3	1st - 3rd	openings - door	cardboard (honeycomb)	3	n/a	n/a	0.030	23.34	0.700	5.8	4.06	12.18	organic - misc.
MFH	1971-80	E3	1st - 3rd	openings - door frame	wood	3	0.09	0.31	299.040	0.03	8.343	455	3,796.16	11,388.49	wood-based
MFH	1971-80	E3	1st - 3rd	walls	reinf. concrete	3	13.40	2.6	0.250	31.79	7.947	2500	19,866.44	59,599.31	concrete-based
MFH	1971-80	E3	1st - 3rd	walls - tie columns	reinf. concrete	66	0.25	0.25	2.600	0.06	0.163	2500	406.25	26,812.50	concrete-based
MFH	1971-80	E3	1st - 3rd	walls	clay bricks	3	97.03	2.6	0.250	229.16	57.290	1800	103,121.30	309,363.91	clay-based
MFH	1971-80	E3	1st - 3rd	walls	clay bricks	3	41.0	2.6	0.065	97.00	6.305	1800	11,348.79	34,046.37	clay-based
MFH	1971-80	E3	1st - 3rd	wall covering - plaster	lime-sand plaster	3	250.89	2.6	0.020	652.31	13.046	1800	23,483.28	70,449.84	plaster-based
MFH	1971-80	E3	1st - 3rd	stairs	reinf. concrete	36	0.16	0.3	1.200	0.02	0.029	2500	71.55	2,575.80	concrete-based
MFH	1971-80	E3	1st - 3rd	stairs - railings	steel	6	5.72	0.016	0.016	0.09	0.001	7860	11.51	69.06	metal-based
MFH	1971-80	E3	1st - 3rd	stairs - railings	steel	172	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	290.04	metal-based
MFH	1971-80	E3	1st - 3rd	ceiling covering - plaster	lime-sand plaster	3	18.58	10.95	0.020	203.45	4.069	1800	7,324.24	21,972.71	plaster-based
MFH	1971-80	E3	1st - 3rd	slab	clay blocks	9890	0.25	0.25	0.16	0.06	0.010	1000	10.00	98,904.00	clay-based
MFH	1971-80	E3	1st - 3rd	slab	concrete	3	19.08	11.5	0.04	219.42	8.777	2400	21,064.32	63,192.96	concrete-based
MFH	1971-80	E3	Roof	floor covering - mud and husk	mud and husk	1	19.08	11.5	0.050	219.42	10.971	400	4,388.40	4,388.40	organic - misc.
MFH	1971-80	E3	Roof	floor covering - sand	sand	1	19.08	11.5	0.03	219.42	6.583	1300	8,557.38	8,557.38	plaster-based
MFH	1971-80	E3	Roof	roof - beams	wood	2	0.20	0.2	19.10	0.04	0.764	455	347.62	695.24	wood-based
MFH	1971-80	E3	Roof	roof - beams	wood	2	0.12	0.16	19.10	0.02	0.367	455	166.86	333.72	wood-based
MFH	1971-80	E3	Roof	roof - beams	wood	8	0.16	0.16	1.00	0.03	0.026	455	11.65	93.18	wood-based
MFH	1971-80	E3	Roof	roof - beams	wood	4	0.10	0.12	3.80	0.01	0.046	455	20.75	82.99	wood-based
MFH	1971-80	E3	Roof	roof - beams	wood	8	0.12	0.14	3.00	0.02	0.050	455	22.93	183.46	wood-based
MFH	1971-80	E3	Roof	roof - beams	wood	8	0.10	0.12	4.60	0.01	0.055	455	25.12	200.93	wood-based
MFH	1971-80	E3	Roof	roof - beams	wood	50	0.14	0.16	6.80	0.02	0.152	455	69.31	3,465.28	wood-based
MFH	1971-80	E3	Roof	roof - battens	wood	27	0.08	0.048	19.10	0.004	0.070	455	31.70	862.32	wood-based
MFH	1971-80	E3	Roof	roof covering - corr. cement sheets	asbestos-cement sheets	224	1.25	1.05	0.006	1.31	0.008	1675	13.19	2,958.18	asbestos-cement-based
MFH	1971-80	E3	Roof	gutters	sheet metal	1	115.36	0.2	0.00065	23.07	0.01	7860	117.87	117.87	metal-based
MFH	1971-80	E4	B	base slab	prefab. concrete	35	4.00	3.4	0.100	13.60	1.36	2500	3,400.00	119,000.00	concrete-based
MFH	1971-80	E4	B	base slab	prefab. concrete	35	2.30	2.3	0.200	5.29	1.06	2500	2,645.00	92,575.00	concrete-based
MFH	1971-80	E4	B	openings - window	glass	10	3.10	0.59	0.004	1.83	0.01	2580	18.88	188.75	glass-based
MFH	1971-80	E4	B	openings - window frame	steel	1	0.10	0.005	73.8	0.001	0.04	7860	290.03	290.03	metal-based
MFH	1971-80	E4	B	openings - door	steel	2	0.90	2.19	0.003	1.97	0.01	7860	46.48	92.95	metal-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E4	B	openings - door	sheet metal	6	0.70	2.19	0.003	1.53	0.005	7860	36.15	216.89	metal-based
MFH	1971-80	E4	B	openings - door frame	steel	1	0.10	0.005	41.0	0.001	0.02	7860	161.29	161.29	metal-based
MFH	1971-80	E4	B	columns	prefab. concrete	40	0.34	0.34	2.4	0.12	0.28	2500	693.60	27,744.00	concrete-based
MFH	1971-80	E4	B	walls	reinf. concrete	1	36	2.4	0.300	67.15	20.15	2500	50,362.50	50,362.50	concrete-based
MFH	1971-80	E4	B	walls	prefab. concrete	1	21	2.4	0.200	43.58	8.72	2500	21,792.00	21,792.00	concrete-based
MFH	1971-80	E4	B	walls	prefab. concrete	1	29.40	2.4	0.110	54.43	5.99	2500	14,967.70	14,967.70	concrete-based
MFH	1971-80	E4	B	stairs	reinf. concrete	15	0.30	0.187	1.200	0.03	0.03	2500	84.15	1,262.25	concrete-based
MFH	1971-80	E4	B	stairs - slab	reinf. concrete	1	4.10	1.2	0.100	4.92	0.49	2500	1,230.00	1,230.00	concrete-based
MFH	1971-80	E4	Gf	slab	prefab. concrete	22	4.20	3.6	0.145	15.12	2.19	2500	5,481.00	120,582.00	concrete-based
MFH	1971-80	E4	Gf	slab	concrete	22	4.20	3.6	0.01	15.12	0.15	2400	362.88	7,983.36	concrete-based
MFH	1971-80	E4	Gf	floor covering - kraft paper	kraft paper	2	n/a	n/a	1.0E-05	64.20	0.00064	648	0.42	0.83	organic - misc.
MFH	1971-80	E4	Gf	floor covering - wooden boards	wooden floor boards	2	n/a	n/a	0.03	64.20	1.93	455	876.33	1,752.66	wood-based
MFH	1971-80	E4	Gf	floor covering - screed	cement-sand plaster	2	n/a	n/a	0.03	18.11	0.54	2100	1,140.93	2,281.86	plaster-based
MFH	1971-80	E4	Gf	floor covering - clay tiles	clay tiles	2	n/a	n/a	0.01	18.11	0.18	1800	325.98	651.96	clay-based
MFH	1971-80	E4	Gf	floor covering - parquet	wood	2	n/a	n/a	0.012	64.20	0.77	455	350.53	701.06	wood-based
MFH	1971-80	E4	Gf	floor covering - screed	cement-sand plaster	2	4.20	7.6	0.03	31.92	0.96	2100	2,010.96	4,021.92	plaster-based
MFH	1971-80	E4	Gf	floor covering - terazzo	terazzo	2	4.20	7.6	0.020	31.92	0.64	2500	1,596.00	3,192.00	concrete-based
MFH	1971-80	E4	Gf	openings - window	glass	2	3.16	2.49	0.004	7.87	0.03	2580	81.20	162.40	glass-based
MFH	1971-80	E4	Gf	openings - window	glass	5	2.8	1.32	0.008	3.75	0.03	2580	77.43	387.14	glass-based
MFH	1971-80	E4	Gf	openings - window	glass	2	2.86	2.32	0.004	6.64	0.03	2580	68.56	137.13	glass-based
MFH	1971-80	E4	Gf	openings - window	glass	3	2.0	0.70	0.008	1.37	0.01	2580	28.37	85.12	glass-based
MFH	1971-80	E4	Gf	openings - window	glass	2	1.1	1.42	0.008	1.59	0.01	2580	32.75	65.50	glass-based
MFH	1971-80	E4	Gf	openings - window	glass	2	0.5	0.70	0.008	0.37	0.003	2580	7.62	15.24	glass-based
MFH	1971-80	E4	Gf	openings - window	glass	6	0.4	0.42	0.008	0.17	0.001	2580	3.45	20.69	glass-based
MFH	1971-80	E4	Gf	openings - window frame	steel	1	0.10	0.005	43.33	0.001	0.02	7860	170.29	170.29	metal-based
MFH	1971-80	E4	Gf	openings - window frame	wood	1	0.14	0.09	82.42	0.01	1.04	455	472.49	472.49	wood-based
MFH	1971-80	E4	Gf	openings - door	glass	4	0.91	2.49	0.004	2.27	0.01	2580	23.38	93.54	glass-based
MFH	1971-80	E4	Gf	openings - door	plywood	10	0.81	2.39	0.012	1.93	0.02	427	9.90	98.99	wood-based
MFH	1971-80	E4	Gf	openings - door	plywood	8	0.71	2.39	0.012	1.69	0.02	427	8.68	69.41	wood-based
MFH	1971-80	E4	Gf	openings - door	plywood	4	0.61	2.39	0.012	1.45	0.02	427	7.45	29.82	wood-based
MFH	1971-80	E4	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	38.68	1.16	5.8	6.73	6.73	organic - misc.
MFH	1971-80	E4	Gf	openings - door frame	steel	1	0.10	0.005	23.56	0.001	0.01	7860	92.59	92.59	metal-based
MFH	1971-80	E4	Gf	openings - door frame	wood	1	0.09	0.31	121.16	0.03	3.38	455	1,538.07	1,538.07	wood-based
MFH	1971-80	E4	Gf	columns	prefab. concrete	30	0.34	0.34	2.60	0.12	0.30	2500	751.40	22,542.00	concrete-based
MFH	1971-80	E4	Gf	walls	prefab. concrete	1	34	2.6	0.050	52.68	2.63	2500	6,585.52	6,585.52	concrete-based
MFH	1971-80	E4	Gf	walls	tarolit	1	34	2.6	0.100	52.68	5.27	350	1,843.95	1,843.95	concrete-based
MFH	1971-80	E4	Gf	walls	clay bricks - facing	1	34	2.6	0.120	52.68	6.32	1300	8,218.73	8,218.73	clay-based
MFH	1971-80	E4	Gf	walls	reinf. concrete	1	17	2.6	0.200	38.15	7.63	2500	19,072.85	19,072.85	concrete-based
MFH	1971-80	E4	Gf	walls	clay bricks	1	11	2.6	0.120	20.97	2.52	1800	4,529.30	4,529.30	clay-based
MFH	1971-80	E4	Gf	walls	gypsum board	2	70.20	2.6	0.070	158.81	11.12	732	8,137.58	16,275.17	gypsum-based
MFH	1971-80	E4	Gf	stairs	reinf. concrete	15	0.30	0.187	1.200	0.03	0.03	2500	84.15	1,262.25	concrete-based
MFH	1971-80	E4	Gf	stairs - slab	reinf. concrete	1	4.10	1.2	0.100	4.92	0.49	2500	1,230.00	1,230.00	concrete-based
MFH	1971-80	E4	Gf	slab	prefab. concrete	22	4.20	3.6	0.145	15.12	2.19	2500	5,481.00	120,582.00	concrete-based
MFH	1971-80	E4	Gf	slab	concrete	22	4.20	3.6	0.01	15.12	0.15	2400	362.88	7,983.36	concrete-based
MFH	1971-80	E4	1st - 6th	balcony - slab	prefab. concrete	24	1.00	3.6	0.145	3.60	0.52	2500	1,305.00	31,320.00	concrete-based
MFH	1971-80	E4	1st - 6th	balcony - slab	concrete	24	1.00	3.6	0.01	3.60	0.04	2400	86.40	2,073.60	concrete-based
MFH	1971-80	E4	1st - 6th	balcony - railings	prefab. concrete	6	18.60	1.42	0.080	26.41	2.11	2500	5,282.40	31,694.40	concrete-based
MFH	1971-80	E4	1st - 6th	floor covering - kraft paper	kraft paper	6	n/a	n/a	0.00001	98.40	0.00098	648	0.64	3.83	organic - misc.
MFH	1971-80	E4	1st - 6th	floor covering - wooden boards	wooden floor boards	6	n/a	n/a	0.03	98.40	2.95	455	1,343.16	8,058.96	wood-based
MFH	1971-80	E4	1st - 6th	floor covering - screed	cement-sand plaster	6	n/a	n/a	0.03	69.64	2.09	2100	4,387.32	26,323.92	plaster-based
MFH	1971-80	E4	1st - 6th	floor covering - clay tiles	clay tiles	6	n/a	n/a	0.01	69.64	0.70	1800	1,253.52	7,521.12	clay-based
MFH	1971-80	E4	1st - 6th	floor covering - parquet	wood	6	n/a	n/a	0.012	98.40	1.18	455	537.26	3,223.58	wood-based
MFH	1971-80	E4	1st - 6th	floor covering - screed	cement-sand plaster	6	n/a	n/a	0.03	23.25	0.70	2100	1,464.75	8,788.50	plaster-based
MFH	1971-80	E4	1st - 6th	floor covering - terazzo	terazzo	6	n/a	n/a	0.02	23.25	0.47	2500	1,162.50	6,975.00	concrete-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	18	2.84	0.70	0.008	1.99	0.02	2580	41.14	740.57	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E4	1st - 6th	openings - window	glass	30	1.98	0.70	0.008	1.39	0.01	2580	28.66	859.93	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	24	2.10	2.49	0.004	5.23	0.02	2580	53.96	1,295.12	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	24	1.6	1.42	0.008	2.26	0.02	2580	46.55	1,117.26	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	12	1.5	1.42	0.008	2.17	0.02	2580	44.79	537.48	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	36	1.1	1.42	0.008	1.59	0.01	2580	32.75	1,178.94	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	24	0.53	0.70	0.008	0.37	0.003	2580	7.62	182.82	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	24	0.33	1.42	0.008	0.46	0.004	2580	9.55	229.09	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	36	0.60	0.59	0.004	0.35	0.001	2580	3.65	131.52	glass-based
MFH	1971-80	E4	1st - 6th	openings - window	glass	24	0.30	2.49	0.004	0.75	0.003	2580	7.71	185.02	glass-based
MFH	1971-80	E4	1st - 6th	openings - window frame	steel	6	0.10	0.005	567.31	0.001	0.284	7860	2,229.51	13,377.08	metal-based
MFH	1971-80	E4	1st - 6th	openings - window frame	wood	6	0.14	0.09	701.43	0.01	8.84	455	4,021.30	24,127.79	wood-based
MFH	1971-80	E4	1st - 6th	openings - door	glass	12	0.91	2.49	0.004	2.27	0.01	2580	23.38	280.61	glass-based
MFH	1971-80	E4	1st - 6th	openings - door	glass	24	0.54	2.32	0.008	1.24	0.01	2580	25.65	615.64	glass-based
MFH	1971-80	E4	1st - 6th	openings - door	plywood	120	0.81	2.39	0.012	1.93	0.02	427	9.90	1,187.86	wood-based
MFH	1971-80	E4	1st - 6th	openings - door	plywood	96	0.71	2.39	0.012	1.69	0.02	427	8.68	832.97	wood-based
MFH	1971-80	E4	1st - 6th	openings - door	plywood	24	0.61	2.39	0.012	1.45	0.02	427	7.45	178.91	wood-based
MFH	1971-80	E4	1st - 6th	openings - door	cardboard (honeycomb)	6	n/a	n/a	0.030	71.55	2.15	5.8	12.45	74.70	organic - misc.
MFH	1971-80	E4	1st - 6th	openings - door frame	wood	6	0.09	0.31	1,519.82	0.03	42.40	455	19,293.41	115,760.43	wood-based
MFH	1971-80	E4	1st - 6th	columns	prefab. concrete	180	0.34	0.34	2.60	0.12	0.30	2500	751.40	135,252.00	concrete-based
MFH	1971-80	E4	1st - 6th	walls	prefab. concrete	6	27.44	0.7	0.07	19.21	1.34	2500	3,361.40	20,168.40	concrete-based
MFH	1971-80	E4	1st - 6th	walls	tarolit	6	27.44	0.7	0.10	19.21	1.92	350	672.28	4,033.68	concrete-based
MFH	1971-80	E4	1st - 6th	walls	lime-sand plaster	6	27.44	0.7	0.02	19.21	0.38	1800	691.49	4,148.93	plaster-based
MFH	1971-80	E4	1st - 6th	walls	prefab. concrete	6	20	0.7	0.050	13.66	0.68	2500	1,708.00	10,248.00	concrete-based
MFH	1971-80	E4	1st - 6th	walls	tarolit	6	20	0.7	0.100	13.66	1.37	350	478.24	2,869.44	concrete-based
MFH	1971-80	E4	1st - 6th	walls	prefab. concrete	6	20	0.7	0.070	13.66	0.96	2500	2,391.20	14,347.20	concrete-based
MFH	1971-80	E4	1st - 6th	wall covering - plywood	plywood	6	13.60	0.7	0.016	9.52	0.15	427	65.04	390.24	wood-based
MFH	1971-80	E4	1st - 6th	wall covering - al foil	aluminum foil	6	13.60	0.7	1.2E-04	9.52	0.001	2800	3.20	19.19	metal-based
MFH	1971-80	E4	1st - 6th	wall covering - battens	wood	6	13.60	0.7	0.10	9.52	0.95	455	433.16	2,598.96	wood-based
MFH	1971-80	E4	1st - 6th	wall covering - thermal insulation	rock wool	6	13.60	0.7	0.05	9.52	0.48	160	76.16	456.96	stone-based
MFH	1971-80	E4	1st - 6th	wall covering - corr. asb.-cem. sheets	asbestos-cement sheets	6	13.60	0.7	0.006	9.52	0.06	1675	95.68	574.06	asbestos-cement-based
MFH	1971-80	E4	1st - 6th	walls	reinf. concrete	6	44.40	2.6	0.2	81.68	16.34	2500	40,842.30	245,053.80	concrete-based
MFH	1971-80	E4	1st - 6th	walls	prefab. concrete	6	17	2.6	0.050	37.56	1.88	2500	4,695.58	28,173.45	concrete-based
MFH	1971-80	E4	1st - 6th	walls	tarolit	6	17	2.6	0.100	38.52	3.85	350	1,348.15	8,088.91	concrete-based
MFH	1971-80	E4	1st - 6th	walls	prefab. concrete	6	17	2.6	0.070	39.47	2.76	2500	6,907.71	41,446.23	concrete-based
MFH	1971-80	E4	1st - 6th	walls	clay bricks	6	15	2.6	0.120	40.14	4.82	1800	8,671.10	52,026.62	clay-based
MFH	1971-80	E4	1st - 6th	walls	gypsum board	6	125.08	2.6	0.070	290.39	20.33	732	14,879.43	89,276.58	gypsum-based
MFH	1971-80	E4	1st - 6th	stairs	reinf. concrete	90	0.30	0.187	1.200	0.03	0.03	2500	84.15	7,573.50	concrete-based
MFH	1971-80	E4	1st - 6th	stairs - slab	reinf. concrete	6	4.10	1.2	0.100	4.92	0.49	2500	1,230.00	7,380.00	concrete-based
MFH	1971-80	E4	1st - 6th	slab	prefab. concrete	132	4.20	3.6	0.145	15.12	2.19	2500	5,481.00	723,492.00	concrete-based
MFH	1971-80	E4	1st - 6th	slab	concrete	132	4.20	3.6	0.01	15.12	0.15	2400	362.88	47,900.16	concrete-based
MFH	1971-80	E4	Roof 1	balcony - railings	prefab. concrete	1	35.40	1.42	0.080	50.27	4.02	2500	10,053.60	10,053.60	concrete-based
MFH	1971-80	E4	Roof 1	roof covering - water-proofing	bitumen	1	n/a	n/a	0.005	141.14	0.71	1500	1,058.55	1,058.55	bitumen-based
MFH	1971-80	E4	Roof 1	roof covering - thermal insulation	eps panels	1	n/a	n/a	0.025	141.14	3.53	53	187.01	187.01	polystyrene-based
MFH	1971-80	E4	Roof 1	roof covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	141.14	0.01	929	10.49	10.49	bitumen-based
MFH	1971-80	E4	Roof 1	roof covering	concrete	1	n/a	n/a	0.05	141.14	7.06	2400	16,936.80	16,936.80	concrete-based
MFH	1971-80	E4	Roof 1	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	141.14	1.41	1500	2,117.10	2,117.10	bitumen-based
MFH	1971-80	E4	Roof 1	roof covering	terazzo	1	n/a	n/a	0.05	141.14	7.06	2500	17,642.50	17,642.50	concrete-based
MFH	1971-80	E4	7th	openings - window	glass	8	2.88	0.82	0.008	2.37	0.02	2580	48.85	390.76	glass-based
MFH	1971-80	E4	7th	openings - window	glass	4	2.10	2.49	0.004	5.23	0.02	2580	53.96	215.85	glass-based
MFH	1971-80	E4	7th	openings - window	glass	6	1.73	0.82	0.008	1.42	0.01	2580	29.30	175.81	glass-based
MFH	1971-80	E4	7th	openings - window	glass	4	1.59	0.82	0.008	1.30	0.01	2580	26.92	107.70	glass-based
MFH	1971-80	E4	7th	openings - window	glass	4	1.00	0.82	0.008	0.82	0.01	2580	16.90	67.61	glass-based
MFH	1971-80	E4	7th	openings - window	glass	4	0.49	0.82	0.008	0.40	0.003	2580	8.24	32.95	glass-based
MFH	1971-80	E4	7th	openings - window	glass	4	0.93	2.38	0.004	2.20	0.01	2580	22.75	90.99	glass-based
MFH	1971-80	E4	7th	openings - window	glass	6	0.60	0.59	0.004	0.35	0.001	2580	3.65	21.92	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E4	7th	openings - window	glass	4	0.30	2.49	0.004	0.75	0.003	2580	7.71	30.84	glass-based
MFH	1971-80	E4	7th	openings - window frame	wood	1	0.14	0.09	197.21	0.01	2.48	455	1,130.59	1,130.59	wood-based
MFH	1971-80	E4	7th	openings - window frame	steel	1	0.10	0.005	36.60	0.001	0.02	7860	143.84	143.84	metal-based
MFH	1971-80	E4	7th	openings - door	glass	2	1.13	1.82	0.004	2.05	0.01	2580	21.17	42.33	glass-based
MFH	1971-80	E4	7th	openings - door	glass	14	0.73	1.82	0.004	1.32	0.01	2580	13.64	190.96	glass-based
MFH	1971-80	E4	7th	openings - door frame	wood	1	0.10	0.005	70.74	0.001	0.04	455	16.09	16.09	wood-based
MFH	1971-80	E4	7th	columns	prefab. concrete	10	0.34	0.34	2.50	0.12	0.29	2500	722.50	7,225.00	concrete-based
MFH	1971-80	E4	7th	columns	prefab. concrete	20	0.34	0.2	2.50	0.07	0.17	2500	425.00	8,500.00	concrete-based
MFH	1971-80	E4	7th	walls	reinf. concrete	1	117.16	2.5	0.15	234.98	35.25	2500	88,116.88	88,116.88	concrete-based
MFH	1971-80	E4	7th	walls	prefab. concrete	1	29.24	1.5	0.05	43.86	2.19	2500	5,482.50	5,482.50	concrete-based
MFH	1971-80	E4	7th	walls	tarolit	1	29.24	1.5	0.1	43.86	4.39	350	1,535.10	1,535.10	concrete-based
MFH	1971-80	E4	7th	walls	prefab. concrete	1	29.24	1.5	0.07	43.86	3.07	2500	7,675.50	7,675.50	concrete-based
MFH	1971-80	E4	7th	slab	prefab. concrete	20	4.20	3.6	0.145	15.12	2.19	2500	5,481.00	109,620.00	concrete-based
MFH	1971-80	E4	7th	slab	concrete	20	4.20	3.6	0.01	15.12	0.15	2400	362.88	7,257.60	concrete-based
MFH	1971-80	E4	Roof 2	roof covering - water-proofing	bitumen	1	n/a	n/a	0.005	201.78	1.01	1500	1,513.35	1,513.35	bitumen-based
MFH	1971-80	E4	Roof 2	roof covering - thermal insulation	eps panels	1	n/a	n/a	0.025	201.78	5.04	53	267.36	267.36	polystyrene-based
MFH	1971-80	E4	Roof 2	roof covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	201.78	0.02	929	15.00	15.00	bitumen-based
MFH	1971-80	E4	Roof 2	roof covering	concrete	1	n/a	n/a	0.05	201.78	10.09	2400	24,213.60	24,213.60	concrete-based
MFH	1971-80	E4	Roof 2	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	201.78	2.02	1500	3,026.70	3,026.70	bitumen-based
MFH	1971-80	E4	Roof 2	roof covering	gravel	1	n/a	n/a	0.05	201.78	10.09	1850	18,664.65	18,664.65	stone-based
MFH	1971-80	E4	Roof 2	gutters	sheet metal	1	175.36	0.2	0.00065	35.07	0.02	7860	179.18	179.18	metal-based
MFH	1971-80	E5	B	base slab - gravel	gravel	1	n/a	n/a	0.10	196.80	19.68	1850	36,408.00	36,408.00	stone-based
MFH	1971-80	E5	B	base slab	reinf. concrete	1	n/a	n/a	0.10	196.80	19.68	2500	49,200.00	49,200.00	concrete-based
MFH	1971-80	E5	B	floor covering - water-proofing	bitumen	1	n/a	n/a	0.10	196.80	19.68	1500	29,520.00	29,520.00	bitumen-based
MFH	1971-80	E5	B	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.10	196.80	19.68	2100	41,328.00	41,328.00	plaster-based
MFH	1971-80	E5	B	walls	reinf. concrete	1	12.22	2.3	0.60	28.11	16.86	2500	42,159.00	42,159.00	concrete-based
MFH	1971-80	E5	B	walls	reinf. concrete	1	57.78	2.3	0.25	132.89	33.22	2500	83,058.75	83,058.75	concrete-based
MFH	1971-80	E5	B	stairs	reinf. concrete	15	0.30	0.17	1.25	0.03	0.03	2500	79.69	1,195.31	concrete-based
MFH	1971-80	E5	B	stairs - railings	steel	2	5.15	0.016	0.016	0.0824	0.0013	7860	10.36	20.73	metal-based
MFH	1971-80	E5	B	stairs - railings	steel	52	0.016	0.016	0.840	0.0003	0.0002	7860	1.69	87.05	metal-based
MFH	1971-80	E5	B	slab	reinf. concrete	1	n/a	n/a	0.20	196.80	39.36	2500	98,400.00	98,400.00	concrete-based
MFH	1971-80	E5	Gf	floor covering - perlite concrete	perlite concrete	1	n/a	n/a	0.15	169.43	25.42	500	12,707.56	12,707.56	concrete-based
MFH	1971-80	E5	Gf	floor covering - magnesite screed	magnesite screed	1	n/a	n/a	0.03	169.43	5.08	1100	5,591.33	5,591.33	concrete-based
MFH	1971-80	E5	Gf	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.01	33.29	0.33	1800	599.22	599.22	clay-based
MFH	1971-80	E5	Gf	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	27.37	1.37	2500	3,420.74	3,420.74	concrete-based
MFH	1971-80	E5	Gf	floor covering - parquet	wood	1	n/a	n/a	0.02	136.14	2.72	455	1,238.91	1,238.91	wood-based
MFH	1971-80	E5	Gf	openings - window	glass	4	2.25	1.35	0.008	3.04	0.02	2580	62.69	250.78	glass-based
MFH	1971-80	E5	Gf	openings - window	glass	2	1.62	1.35	0.008	2.19	0.02	2580	45.14	90.28	glass-based
MFH	1971-80	E5	Gf	openings - window	glass	1	1.36	1.35	0.008	1.84	0.01	2580	37.90	37.90	glass-based
MFH	1971-80	E5	Gf	openings - window	glass	1	0.86	1.35	0.008	1.16	0.01	2580	23.96	23.96	glass-based
MFH	1971-80	E5	Gf	openings - window	glass	1	0.46	1.35	0.008	0.62	0.005	2580	12.82	12.82	glass-based
MFH	1971-80	E5	Gf	openings - window	glass	3	0.42	0.45	0.008	0.19	0.002	2580	3.90	11.70	glass-based
MFH	1971-80	E5	Gf	openings - window frame	wood	1	0.12	0.08	59.36	0.01	0.57	455	259.28	259.28	wood-based
MFH	1971-80	E5	Gf	openings - door	glass	2	1.76	2.99	0.004	5.26	0.02	2580	54.31	108.62	glass-based
MFH	1971-80	E5	Gf	openings - door	glass	1	1.76	2.49	0.004	4.38	0.02	2580	45.23	45.23	glass-based
MFH	1971-80	E5	Gf	openings - door	glass	2	1.17	2.35	0.004	2.75	0.01	2580	28.37	56.75	glass-based
MFH	1971-80	E5	Gf	openings - door	glass	2	0.56	2.15	0.008	1.20	0.01	2580	24.85	49.70	glass-based
MFH	1971-80	E5	Gf	openings - door	plywood	8	0.81	2.39	0.012	1.93	0.02	427	9.90	79.19	wood-based
MFH	1971-80	E5	Gf	openings - door	plywood	3	0.81	1.94	0.012	1.57	0.02	427	8.03	24.09	wood-based
MFH	1971-80	E5	Gf	openings - door	plywood	3	0.71	2.39	0.012	1.69	0.02	427	8.68	26.03	wood-based
MFH	1971-80	E5	Gf	openings - door	plywood	1	0.61	2.39	0.012	1.45	0.02	427	7.45	7.45	wood-based
MFH	1971-80	E5	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	26.69	0.80	5.8	4.64	4.64	organic - misc.
MFH	1971-80	E5	Gf	openings - door frame	steel	1	0.10	0.005	22.220	0.001	0.01	7860	87.32	87.32	metal-based
MFH	1971-80	E5	Gf	openings - door frame	wood	1	0.09	0.31	101.960	0.03	2.84	455	1,294.33	1,294.33	wood-based
MFH	1971-80	E5	Gf	walls	reinf. concrete	1	43.54	2.6	0.20	99.59	19.92	2500	49,794.43	49,794.43	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E5	Gf	walls	clay bricks	1	23.02	2.6	0.25	39.14	9.78	1800	17,612.10	17,612.10	clay-based
MFH	1971-80	E5	Gf	walls	clay bricks	1	11.90	2.6	0.25	27.81	6.95	1800	12,512.39	12,512.39	clay-based
MFH	1971-80	E5	Gf	walls	clay bricks	1	49.45	2.6	0.065	102.54	6.66	1800	11,996.73	11,996.73	clay-based
MFH	1971-80	E5	Gf	wall covering - thermal insulation	tarolit	1	53.36	2.6	0.03	138.73	4.16	350	1,456.63	1,456.63	concrete-based
MFH	1971-80	E5	Gf	wall covering - plaster	lime-sand plaster	1	168.67	2.6	0.02	438.55	8.77	1800	15,787.72	15,787.72	plaster-based
MFH	1971-80	E5	Gf	wall covering - clay bricks	clay bricks	1	23.02	0.87	0.065	20.03	1.30	1800	2,343.21	2,343.21	clay-based
MFH	1971-80	E5	Gf	stairs	reinf. concrete	5	0.15	0.3	2.06	0.02	0.05	2500	115.88	579.38	concrete-based
MFH	1971-80	E5	Gf	stairs	reinf. concrete	18	0.16	0.3	1.25	0.02	0.03	2500	75.00	1,350.00	concrete-based
MFH	1971-80	E5	Gf	stairs - railings	steel	2	6.00	0.016	0.016	0.10	0.002	7860	12.07	24.15	metal-based
MFH	1971-80	E5	Gf	stairs - railings	steel	60	0.016	0.016	0.840	0.0003	0.0002	7860	1.69	101.41	metal-based
MFH	1971-80	E5	Gf	slab	reinf. concrete	1	n/a	n/a	0.20	196.67	39.33	2500	98,335.00	98,335.00	concrete-based
MFH	1971-80	E5	1st-4th	balcony	reinf. concrete	4	0.80	1.62	0.20	1.30	0.26	2500	648.00	2,592.00	concrete-based
MFH	1971-80	E5	1st-4th	balcony	reinf. concrete	4	0.57	1.86	0.20	1.06	0.21	2500	530.10	2,120.40	concrete-based
MFH	1971-80	E5	1st-4th	balcony	reinf. concrete	4	2.28	2.16	0.20	4.92	0.98	2500	2,462.40	9,849.60	concrete-based
MFH	1971-80	E5	1st-4th	balcony - railings	prefab. concrete	4	3.45	1.41	0.08	4.86	0.39	2500	972.90	3,891.60	concrete-based
MFH	1971-80	E5	1st-4th	balcony - railings	steel	4	9.14	0.016	0.016	0.15	0.002	7860	18.39	73.56	metal-based
MFH	1971-80	E5	1st-4th	balcony - railings	steel	4	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	6.76	metal-based
MFH	1971-80	E5	1st-4th	balcony - railings	glass	4	1.86	0.84	0.007	1.56	0.01	2580	28.22	112.87	glass-based
MFH	1971-80	E5	1st-4th	floor covering - magnesite screed	magnesite screed	4	n/a	n/a	0.03	169.43	5.08	1100	5,591.33	22,365.30	concrete-based
MFH	1971-80	E5	1st-4th	floor covering - clay tiles	clay tiles	4	n/a	n/a	0.01	39.68	0.40	1800	714.24	2,856.96	clay-based
MFH	1971-80	E5	1st-4th	floor covering - terazzo	terazzo	4	n/a	n/a	0.05	32.07	1.60	2500	4,008.24	16,032.95	concrete-based
MFH	1971-80	E5	1st-4th	floor covering - parquet	wood	4	n/a	n/a	0.02	97.69	1.95	455	888.96	3,555.85	wood-based
MFH	1971-80	E5	1st-4th	openings - window	glass	4	2.50	2.59	0.004	6.48	0.03	2580	66.82	267.29	glass-based
MFH	1971-80	E5	1st-4th	openings - window	glass	16	2.25	1.35	0.008	3.04	0.02	2580	62.69	1,003.10	glass-based
MFH	1971-80	E5	1st-4th	openings - window	glass	8	1.62	1.35	0.008	2.19	0.02	2580	45.14	361.12	glass-based
MFH	1971-80	E5	1st-4th	openings - window	glass	4	1.36	2.35	0.008	3.20	0.03	2580	65.97	263.86	glass-based
MFH	1971-80	E5	1st-4th	openings - window	glass	8	0.86	3.35	0.008	2.88	0.02	2580	59.46	475.71	glass-based
MFH	1971-80	E5	1st-4th	openings - window	glass	4	0.46	4.35	0.008	2.00	0.02	2580	41.30	165.20	glass-based
MFH	1971-80	E5	1st-4th	openings - window	glass	12	0.42	0.45	0.008	0.19	0.002	2580	3.90	46.81	glass-based
MFH	1971-80	E5	1st-4th	openings - window frame	wood	4	0.12	0.08	319.12	0.01	3.06	455	1,393.92	5,575.66	wood-based
MFH	1971-80	E5	1st-4th	openings - window frame	steel	4	0.10	0.005	40.72	0.001	0.02	7860	160.03	640.12	metal-based
MFH	1971-80	E5	1st-4th	openings - door	glass	4	1.17	2.35	0.004	2.75	0.01	2580	28.37	113.50	glass-based
MFH	1971-80	E5	1st-4th	openings - door	glass	12	0.56	2.15	0.008	1.20	0.01	2580	24.85	298.21	glass-based
MFH	1971-80	E5	1st-4th	openings - door	glass	4	0.46	2.15	0.008	0.99	0.01	2580	20.41	81.65	glass-based
MFH	1971-80	E5	1st-4th	openings - door	plywood	12	0.81	1.94	0.012	1.57	0.02	427	8.03	96.37	wood-based
MFH	1971-80	E5	1st-4th	openings - door	plywood	40	0.81	2.39	0.012	1.93	0.02	427	9.90	395.95	wood-based
MFH	1971-80	E5	1st-4th	openings - door	plywood	12	0.71	2.39	0.012	1.69	0.02	427	8.68	104.12	wood-based
MFH	1971-80	E5	1st-4th	openings - door	plywood	4	0.61	2.39	0.012	1.45	0.02	427	7.45	29.82	wood-based
MFH	1971-80	E5	1st-4th	openings - door	cardboard (honeycomb)	4	n/a	n/a	0.030	30.56	0.92	5.8	5.32	21.27	organic - misc.
MFH	1971-80	E5	1st-4th	openings - door frame	wood	4	0.09	0.31	467.480	0.03	13.04	455	5,934.42	23,737.70	wood-based
MFH	1971-80	E5	1st-4th	walls	reinf. concrete	4	43.54	2.6	0.20	98.38	19.68	2500	49,188.23	196,752.90	concrete-based
MFH	1971-80	E5	1st-4th	walls	clay bricks	4	25.23	2.6	0.25	37.70	9.42	1800	16,964.55	67,858.20	clay-based
MFH	1971-80	E5	1st-4th	walls	clay bricks	4	6.70	2.6	0.25	15.85	3.96	1800	7,133.69	28,534.77	clay-based
MFH	1971-80	E5	1st-4th	walls	clay bricks	4	51.32	2.6	0.065	104.83	6.81	1800	12,265.00	49,060.02	clay-based
MFH	1971-80	E5	1st-4th	wall covering - thermal insulation	tarolit	4	52.34	2.6	0.03	136.08	4.08	350	1,428.79	5,715.17	concrete-based
MFH	1971-80	E5	1st-4th	wall covering - plaster	lime-sand plaster	4	159.67	2.6	0.02	415.14	8.30	1800	14,944.97	59,779.86	plaster-based
MFH	1971-80	E5	1st-4th	wall covering - clay bricks	clay bricks	4	25.23	0.87	0.065	21.95	1.43	1800	2,568.16	10,272.65	clay-based
MFH	1971-80	E5	1st-3rd	stairs	reinf. concrete	54	0.16	0.3	1.25	0.02	0.03	2500	75.00	4,050.00	concrete-based
MFH	1971-80	E5	4th	stairs	reinf. concrete	15	0.19	0.3	1.25	0.03	0.04	2500	89.06	1,335.94	concrete-based
MFH	1971-80	E5	1st-4th	stairs - railings	steel	8	6.05	0.016	0.016	0.10	0.002	7860	12.17	97.39	metal-based
MFH	1971-80	E5	1st-4th	stairs - railings	steel	192	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	324.52	metal-based
MFH	1971-80	E5	1st-4th	ceiling covering - plaster	lime-sand plaster	4	n/a	n/a	0.02	196.67	3.93	1800	7,080.12	28,320.48	plaster-based
MFH	1971-80	E5	1st-4th	slab	reinf. concrete	3	n/a	n/a	0.20	196.67	39.33	2500	98,335.00	295,005.00	concrete-based
MFH	1971-80	E5	5th	roof covering - perlite concrete	perlite concrete	1	n/a	n/a	0.05	60.00	3.00	500	1,500.00	1,500.00	concrete-based
MFH	1971-80	E5	5th	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	60.00	0.60	1500	900.00	900.00	bitumen-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E5	5th	roof covering - sand	sand	1	n/a	n/a	0.03	60.00	1.80	1300	2,340.00	2,340.00	plaster-based
MFH	1971-80	E5	5th	roof covering - concrete tiles	concrete	1	n/a	n/a	0.04	60.00	2.40	2400	5,760.00	5,760.00	concrete-based
MFH	1971-80	E5	5th	balcony	reinf. concrete	1	0.80	1.6	0.26	1.28	0.33	2500	832.00	832.00	concrete-based
MFH	1971-80	E5	5th	balcony	reinf. concrete	1	2.50	2.1	0.26	5.25	1.37	2500	3,412.50	3,412.50	concrete-based
MFH	1971-80	E5	5th	floor covering - magnesite screed	magnesite screed	1	n/a	n/a	0.03	108.55	3.26	1100	3,582.15	3,582.15	concrete-based
MFH	1971-80	E5	5th	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	61.52	3.08	2500	7,690.00	7,690.00	concrete-based
MFH	1971-80	E5	5th	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.01	17.47	0.17	1800	314.46	314.46	clay-based
MFH	1971-80	E5	5th	floor covering - parquet	wood	1	n/a	n/a	0.02	47.31	0.95	455	430.52	430.52	wood-based
MFH	1971-80	E5	5th	openings - window	glass	1	2.50	2.59	0.004	6.48	0.03	2580	66.82	66.82	glass-based
MFH	1971-80	E5	5th	openings - window	glass	1	2.25	1.35	0.008	3.04	0.02	2580	62.69	62.69	glass-based
MFH	1971-80	E5	5th	openings - window	glass	2	1.62	1.35	0.008	2.19	0.02	2580	45.14	90.28	glass-based
MFH	1971-80	E5	5th	openings - window	glass	1	1.36	2.35	0.008	3.20	0.03	2580	65.97	65.97	glass-based
MFH	1971-80	E5	5th	openings - window	glass	10	0.46	4.35	0.008	2.00	0.02	2580	41.30	413.01	glass-based
MFH	1971-80	E5	5th	openings - window	glass	4	0.42	0.45	0.008	0.19	0.002	2580	3.90	15.60	glass-based
MFH	1971-80	E5	5th	openings - window frame	wood	1	0.12	0.08	129.66	0.01	1.24	455	566.35	566.35	wood-based
MFH	1971-80	E5	5th	openings - window frame	steel	1	0.10	0.005	10.18	0.001	0.01	7860	40.01	40.01	metal-based
MFH	1971-80	E5	5th	openings - door	glass	1	1.17	2.35	0.004	2.75	0.01	2580	28.37	28.37	glass-based
MFH	1971-80	E5	5th	openings - door	glass	4	0.66	2.05	0.004	1.35	0.01	2580	13.96	55.85	glass-based
MFH	1971-80	E5	5th	openings - door	glass	1	0.56	2.05	0.008	1.15	0.01	2580	23.69	23.69	glass-based
MFH	1971-80	E5	5th	openings - door	glass	1	0.46	2.05	0.008	0.94	0.01	2580	19.46	19.46	glass-based
MFH	1971-80	E5	5th	openings - door	plywood	5	0.81	1.94	0.012	1.57	0.02	427	8.03	40.16	wood-based
MFH	1971-80	E5	5th	openings - door	plywood	3	0.71	1.94	0.012	1.37	0.02	427	7.04	21.12	wood-based
MFH	1971-80	E5	5th	openings - door	plywood	2	0.61	1.94	0.012	1.18	0.01	427	6.05	12.10	wood-based
MFH	1971-80	E5	5th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	14.32	0.43	5.8	2.49	2.49	organic - misc.
MFH	1971-80	E5	5th	openings - door frame	wood	1	0.09	0.31	80.230	0.03	2.24	455	1,018.48	1,018.48	wood-based
MFH	1971-80	E5	5th	walls	reinf. concrete	1	42.91	2.6	0.20	98.19	19.64	2500	49,096.65	49,096.65	concrete-based
MFH	1971-80	E5	5th	walls	clay bricks	1	25.51	2.6	0.25	35.94	8.99	1800	16,174.58	16,174.58	clay-based
MFH	1971-80	E5	5th	walls	clay bricks	1	33.91	2.6	0.065	73.89	4.80	1800	8,644.77	8,644.77	clay-based
MFH	1971-80	E5	5th	wall covering - thermal insulation	tarolit	1	51.59	2.6	0.03	134.14	4.02	350	1,408.44	1,408.44	concrete-based
MFH	1971-80	E5	5th	wall covering - plaster	lime-sand plaster	1	122.25	2.6	0.02	317.85	6.36	1800	11,442.75	11,442.75	plaster-based
MFH	1971-80	E5	5th	wall covering - clay bricks	clay bricks	1	25.51	0.87	0.065	22.19	1.44	1800	2,596.66	2,596.66	clay-based
MFH	1971-80	E5	5th	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.02	125.78	2.52	1800	4,528.08	4,528.08	plaster-based
MFH	1971-80	E5	5th	slab	reinf. concrete	1	n/a	n/a	0.22	199.79	43.95	2500	109,884.50	109,884.50	concrete-based
MFH	1971-80	E5	Roof	roof covering - perlite concrete	perlite concrete	1	n/a	n/a	0.05	199.79	9.99	500	4,994.75	4,994.75	concrete-based
MFH	1971-80	E5	Roof	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	199.79	2.00	1500	2,996.85	2,996.85	bitumen-based
MFH	1971-80	E5	Roof	roof covering - sand	sand	1	n/a	n/a	0.03	199.79	5.99	1300	7,791.81	7,791.81	plaster-based
MFH	1971-80	E5	Roof	roof covering - concrete tiles	concrete	1	n/a	n/a	0.04	199.79	7.99	2400	19,179.84	19,179.84	concrete-based
MFH	1971-80	E5	Roof	gutters	sheet metal	1	65.00	0.2	0.001	13.00	0.008	7860	66.42	66.42	metal-based
MFH	1971-80	E6	B	base slab	reinf. concrete	1	n/a	n/a	0.10	440.66	44.07	2500	110,165.00	110,165.00	concrete-based
MFH	1971-80	E6	B	openings - window	glass	18	1.2	0.65	0.004	0.78	0.003	2580	8.05	144.89	glass-based
MFH	1971-80	E6	B	openings - window frame	steel	1	0.10	0.005	66.60	0.001	0.03	7860	261.74	261.74	metal-based
MFH	1971-80	E6	B	openings - door	sheet metal	6	0.8	2.04	0.004	1.63	0.01	7860	51.31	307.86	metal-based
MFH	1971-80	E6	B	openings - door frame	steel	1	0.10	0.005	34.08	0.001	0.02	7860	133.93	133.93	metal-based
MFH	1971-80	E6	B	columns	prefab. concrete	16	0.40	0.4	2.70	0.16	0.43	2500	1,080.00	17,280.00	concrete-based
MFH	1971-80	E6	B	stairs - slab	prefab. concrete	1	8.10	5.54	0.10	40.55	4.06	2500	10,138.50	10,138.50	concrete-based
MFH	1971-80	E6	B	stairs	prefab. concrete	16	0.18	0.28	1.30	0.03	0.03	2500	81.90	1,310.40	concrete-based
MFH	1971-80	E6	B	stairs - railings	steel	2	23.24	0.016	0.016	0.37	0.01	7860	46.76	93.53	metal-based
MFH	1971-80	E6	B	stairs - railings	steel	232	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	392.81	metal-based
MFH	1971-80	E6	B	slab - hollow-core slab	hollow core slab	32	1.20	8.45	0.18	10.14	1.8252	1360	2,482.27	79,432.70	concrete-based
MFH	1971-80	E6	B	slab - hollow-core slab	hollow core slab	18	1.20	7.2	0.18	8.64	1.5552	1360	2,115.07	38,071.30	concrete-based
MFH	1971-80	E6	Gf	balcony - railings	prefab. concrete	1	28.40	1.45	0.070	41.18	2.88	2500	7,206.50	7,206.50	concrete-based
MFH	1971-80	E6	Gf	floor covering - florbit	florbit	1	18.30	24.5	0.030	388.7	11.66	770	8,978.51	8,978.51	bitumen-based
MFH	1971-80	E6	Gf	floor covering - clay tiles	clay tiles	4	1.60	6.6	0.01	10.56	0.1056	1800	190.08	760.32	clay-based
MFH	1971-80	E6	Gf	floor covering - clay tiles	clay tiles	1	5.50	3.2	0.01	17.60	0.1760	1800	316.80	316.80	clay-based
MFH	1971-80	E6	Gf	floor covering - terazzo	terazzo	1	5.50	8.1	0.050	40.47	2.0235	2500	5,058.75	5,058.75	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E6	Gf	floor covering - terazzo	terazzo	1	3.20	6	0.050	19.20	0.9600	2500	2,400.00	2,400.00	concrete-based
MFH	1971-80	E6	Gf	floor covering - terazzo	terazzo	4	1.00	3.2	0.050	3.20	0.1600	2500	400.00	1,600.00	concrete-based
MFH	1971-80	E6	Gf	floor covering - parquet	wood	1	18.80	25	0.02	328.84	7.2345	455	3,291.69	3,291.69	wood-based
MFH	1971-80	E6	Gf	openings - window	glass	4	2.86	1.32	0.008	3.78	0.03	2580	77.92	311.68	glass-based
MFH	1971-80	E6	Gf	openings - window	glass	5	2.36	1.32	0.008	3.12	0.02	2580	64.30	321.49	glass-based
MFH	1971-80	E6	Gf	openings - window	glass	4	1.90	1.32	0.008	2.51	0.02	2580	51.77	207.06	glass-based
MFH	1971-80	E6	Gf	openings - window	glass	8	1.30	1.32	0.008	1.72	0.01	2580	35.42	283.35	glass-based
MFH	1971-80	E6	Gf	openings - window	glass	1	3.20	3.4	0.004	10.88	0.04	2580	112.28	112.28	glass-based
MFH	1971-80	E6	Gf	openings - window	glass	1	2.40	2.5	0.004	6.00	0.02	2580	61.92	61.92	glass-based
MFH	1971-80	E6	Gf	openings - window frame	steel	1	0.1	0.005	23.00	0.001	0.01	7860	90.39	90.39	metal-based
MFH	1971-80	E6	Gf	openings - window frame	wood	1	0.21	0.09	137.92	0.02	2.61	455	1,186.04	1,186.04	wood-based
MFH	1971-80	E6	Gf	openings - door	glass	4	0.53	2.42	0.004	1.27	0.01	2580	13.13	52.51	glass-based
MFH	1971-80	E6	Gf	openings - door	glass	8	0.53	2.22	0.008	1.17	0.01	2580	24.09	192.71	glass-based
MFH	1971-80	E6	Gf	openings - door	glass	4	0.81	2.04	0.04	1.65	0.07	2580	170.11	680.44	glass-based
MFH	1971-80	E6	Gf	openings - door	plywood	5	0.81	2.04	0.012	1.65	0.02	427	8.45	42.23	wood-based
MFH	1971-80	E6	Gf	openings - door	plywood	15	0.71	2.04	0.012	1.44	0.02	427	7.40	111.05	wood-based
MFH	1971-80	E6	Gf	openings - door	plywood	6	0.64	2.04	0.012	1.30	0.02	427	6.67	40.04	wood-based
MFH	1971-80	E6	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	37.73	1.13	5.8	6.56	6.56	organic - misc.
MFH	1971-80	E6	Gf	openings - door frame	wood	1	0.09	0.31	180.732	0.03	5.04	455	2,294.30	2,294.30	wood-based
MFH	1971-80	E6	Gf	columns	prefab. concrete	16	0.40	0.4	2.600	0.16	0.42	2500	1,040.00	16,640.00	concrete-based
MFH	1971-80	E6	Gf	walls	reinf. concrete	1	46.38	2.6	0.250	104.70	26.17	2500	65,436.19	65,436.19	concrete-based
MFH	1971-80	E6	Gf	walls	prefab. concrete	1	42.50	2.6	0.160	110.50	17.68	2500	44,200.00	44,200.00	concrete-based
MFH	1971-80	E6	Gf	walls	prefab. concrete	1	42.50	2.6	0.060	110.50	6.63	2500	16,575.00	16,575.00	concrete-based
MFH	1971-80	E6	Gf	walls	clay bricks	1	127.97	2.6	0.07	302.28	21.16	1800	38,087.08	38,087.08	clay-based
MFH	1971-80	E6	Gf	wall covering - thermal insulation	eps panels	1	42.50	2.6	0.04	110.50	4.42	53	234.26	234.26	polystyrene-based
MFH	1971-80	E6	Gf	wall covering - plywood	plywood	1	41.24	0.84	0.016	34.64	0.55	427	236.67	236.67	wood-based
MFH	1971-80	E6	Gf	wall covering - al foil	aluminum foil	1	41.24	0.84	1.2E-04	34.64	0.004	2800	11.64	11.64	metal-based
MFH	1971-80	E6	Gf	wall covering - battens	wood	2	41.24	0.1	0.05	4.12	0.21	455	93.82	187.64	wood-based
MFH	1971-80	E6	Gf	wall covering - thermal insulation	rock wool	1	41.24	0.84	0.05	34.64	1.73	160	277.13	277.13	stone-based
MFH	1971-80	E6	Gf	wall covering - asbestos-cement sheets	asbestos-cement sheets	1	41.24	0.84	0.008	34.64	0.28	1675	464.20	464.20	asbestos-cement-based
MFH	1971-80	E6	Gf	stairs	prefab. concrete	16	0.28	0.175	1.30	0.02	0.03	2500	79.63	1,274.00	concrete-based
MFH	1971-80	E6	Gf	stairs - slab	prefab. concrete	1	1.96	2.8	0.10	5.49	0.55	2500	1,372.00	1,372.00	concrete-based
MFH	1971-80	E6	Gf	stairs	prefab. concrete	7	0.30	0.17	3.20	0.03	0.08	2500	205.71	1,440.00	concrete-based
MFH	1971-80	E6	Gf	stairs - slab	prefab. concrete	1	3.20	1.8	0.10	5.76	0.58	2500	1,440.00	1,440.00	concrete-based
MFH	1971-80	E6	Gf	stairs - railings	steel	2	23.24	0.016	0.016	0.37	0.01	7860	46.76	93.53	metal-based
MFH	1971-80	E6	Gf	stairs - railings	steel	232	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	392.81	metal-based
MFH	1971-80	E6	Gf	slab - hollow-core slab	hollow core slab	32	1.20	8.45	0.18	10.1400	1.83	1360	2,482.27	78,605.28	concrete-based
MFH	1971-80	E6	Gf	slab - hollow-core slab	hollow core slab	18	1.20	7.2	0.18	8.6400	1.56	1360	2,115.07	38,071.30	concrete-based
MFH	1971-80	E6	1st - 14th	balcony - railings	prefab. concrete	14	28.40	1.45	0.070	41.18	2.88	2500	7,206.50	100,891.00	concrete-based
MFH	1971-80	E6	1st - 14th	floor covering - florbit	florbit	14	18.30	24.5	0.030	407.9	12.24	770	9,422.03	131,908.39	bitumen-based
MFH	1971-80	E6	1st - 14th	floor covering - terazzo	terazzo	14	5.50	8.1	0.050	40.47	2.0235	2500	5,058.75	70,822.50	concrete-based
MFH	1971-80	E6	1st - 14th	floor covering - terazzo	terazzo	56	3.20	1.5	0.050	4.80	0.2400	2500	600.00	33,600.00	concrete-based
MFH	1971-80	E6	1st - 14th	floor covering - terazzo	terazzo	56	1.40	3.9	0.050	5.46	0.2730	2500	682.50	38,220.00	concrete-based
MFH	1971-80	E6	1st - 14th	floor covering - clay tiles	clay tiles	56	1.60	6.6	0.01	10.56	0.1056	1800	190.08	10,644.48	clay-based
MFH	1971-80	E6	1st - 14th	floor covering - clay tiles	clay tiles	28	5.50	3.2	0.01	17.60	0.1760	1800	316.80	8,870.40	clay-based
MFH	1971-80	E6	1st - 14th	floor covering - parquet	wood	14	n/a	n/a	0.02	330.44	7.2697	455	3,307.70	46,307.86	wood-based
MFH	1971-80	E6	1st - 14th	openings - window	glass	56	2.86	1.32	0.008	3.78	0.03	2580	77.92	4,363.53	glass-based
MFH	1971-80	E6	1st - 14th	openings - window	glass	84	2.36	1.32	0.008	3.12	0.02	2580	64.30	5,401.01	glass-based
MFH	1971-80	E6	1st - 14th	openings - window	glass	56	2.26	2.4	0.008	5.42	0.04	2580	111.95	6,269.28	glass-based
MFH	1971-80	E6	1st - 14th	openings - window	glass	56	1.46	2.4	0.008	3.50	0.03	2580	72.32	4,050.06	glass-based
MFH	1971-80	E6	1st - 14th	openings - window frame	wood	14	0.21	0.09	2,040.64	0.02	38.57	455	17,548.48	245,678.77	wood-based
MFH	1971-80	E6	1st - 14th	openings - door	glass	56	0.53	2.42	0.004	1.27	0.01	2580	13.13	735.16	glass-based
MFH	1971-80	E6	1st - 14th	openings - door	glass	112	0.53	2.22	0.008	1.17	0.01	2580	24.09	2,697.90	glass-based
MFH	1971-80	E6	1st - 14th	openings - door	plywood	308	0.81	2.04	0.012	1.65	0.02	427	8.45	2,601.41	wood-based
MFH	1971-80	E6	1st - 14th	openings - door	plywood	112	0.71	2.04	0.012	1.44	0.02	427	7.40	829.18	wood-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E6	1st - 14th	openings - door	plywood	28	0.64	2.04	0.012	1.30	0.02	427	6.67	186.86	wood-based
MFH	1971-80	E6	1st - 14th	openings - door	cardboard (honeycomb)	14	n/a	n/a	0.030	50.43	1.51	5.8	8.77	122.84	organic - misc.
MFH	1971-80	E6	1st - 14th	openings - door frame	wood	14	0.09	0.31	3,045.728	0.03	84.98	455	38,663.99	541,295.92	wood-based
MFH	1971-80	E6	1st - 14th	columns	prefab. concrete	224	0.40	0.4	2.600	0.16	0.42	2500	1,040.00	232,960.00	concrete-based
MFH	1971-80	E6	1st - 14th	walls	reinf. concrete	14	46.38	2.6	0.250	112.96	28.24	2500	70,597.22	988,361.06	concrete-based
MFH	1971-80	E6	1st - 14th	walls	prefab. concrete	14	42.50	2.6	0.160	110.50	17.68	2500	44,200.00	618,800.00	concrete-based
MFH	1971-80	E6	1st - 14th	walls	prefab. concrete	14	42.50	2.6	0.060	110.50	6.63	2500	16,575.00	232,050.00	concrete-based
MFH	1971-80	E6	1st - 14th	walls	clay bricks	14	137.82	2.6	0.07	322.39	22.57	1800	40,621.53	568,701.43	clay-based
MFH	1971-80	E6	1st - 14th	wall covering - thermal insulation	eps panels	14	42.50	2.6	0.04	110.50	4.42	53	234.26	3,279.64	polystyrene-based
MFH	1971-80	E6	1st - 14th	wall covering - plywood	plywood	14	40.48	0.84	0.016	34.00	0.54	427	232.31	3,252.34	wood-based
MFH	1971-80	E6	1st - 14th	wall covering - al foil	aluminum foil	14	40.48	0.84	1.2E-04	34.00	0.004	2800	11.43	159.95	metal-based
MFH	1971-80	E6	1st - 14th	wall covering - battens	wood	28	40.48	0.1	0.05	4.05	0.20	455	92.09	2,578.58	wood-based
MFH	1971-80	E6	1st - 14th	wall covering - thermal insulation	rock wool	14	40.48	0.84	0.05	34.00	1.70	160	272.03	3,808.36	stone-based
MFH	1971-80	E6	1st - 14th	wall covering - asbestos-cement sheets	asbestos-cement sheets	14	40.48	0.84	0.008	34.00	0.27	1675	455.64	6,379.00	asbestos-cement-based
MFH	1971-80	E6	1st - 14th	stairs	prefab. concrete	224	0.28	0.175	1.30	0.02	0.03	2500	79.63	17,836.00	concrete-based
MFH	1971-80	E6	1st - 14th	stairs - slab	prefab. concrete	14	1.96	2.8	0.10	5.49	0.55	2500	1,372.00	19,208.00	concrete-based
MFH	1971-80	E6	1st - 14th	stairs - railings	steel	28	23.24	0.016	0.016	0.37	0.01	7860	46.76	1,309.35	metal-based
MFH	1971-80	E6	1st - 14th	stairs - railings	steel	3254	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	5,499.28	metal-based
MFH	1971-80	E6	1st - 14th	slab - hollow-core slab	hollow core slab	443	1.20	8.45	0.18	10.14	1.83	1360	2,482.27	1,100,473.92	concrete-based
MFH	1971-80	E6	1st - 14th	slab - hollow-core slab	hollow core slab	252	1.20	7.2	0.18	8.64	1.56	1360	2,115.07	532,998.14	concrete-based
MFH	1971-80	E6	15th	floor covering - florbit	florbit	2	10.10	4.93	0.030	49.8	1.49	770	1,150.22	2,300.44	bitumen-based
MFH	1971-80	E6	15th	floor covering - terazzo	terazzo	1	n/a	n/a	0.050	105.92	5.30	2500	13,240.00	13,240.00	concrete-based
MFH	1971-80	E6	15th	floor covering - clay tiles	clay tiles	2	3.55	3.35	0.01	11.89	0.12	1800	214.07	428.13	clay-based
MFH	1971-80	E6	15th	floor covering - parquet	wood	1	10.50	17.1	0.02	75.80	1.67	455	758.77	758.77	wood-based
MFH	1971-80	E6	15th	floor covering - concrete	concrete	1	n/a	n/a	0.050	227.63	11.38	2400	27,315.60	27,315.60	concrete-based
MFH	1971-80	E6	15th	floor covering - thermal insulation	eps panels	1	n/a	n/a	0.050	227.63	11.38	53	603.22	603.22	polystyrene-based
MFH	1971-80	E6	15th	floor covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	227.63	0.02	929	16.92	16.92	bitumen-based
MFH	1971-80	E6	15th	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.02	227.63	4.55	2100	9,560.46	9,560.46	plaster-based
MFH	1971-80	E6	15th	floor covering - water-proofing	bitumen	1	n/a	n/a	0.01	227.63	2.28	1500	3,414.45	3,414.45	bitumen-based
MFH	1971-80	E6	15th	floor covering - sand	sand	1	n/a	n/a	0.02	227.63	4.55	1300	5,918.38	5,918.38	plaster-based
MFH	1971-80	E6	15th	floor covering - concrete tiles	concrete	1	n/a	n/a	0.03	227.63	6.83	2400	16,389.36	16,389.36	concrete-based
MFH	1971-80	E6	15th	openings - window	glass	4	2.26	2.4	0.008	5.42	0.04	2580	111.95	447.81	glass-based
MFH	1971-80	E6	15th	openings - window	glass	4	1.76	2.4	0.008	4.22	0.03	2580	87.18	348.73	glass-based
MFH	1971-80	E6	15th	openings - window	glass	2	0.58	1.32	0.008	0.76	0.01	2580	15.67	31.33	glass-based
MFH	1971-80	E6	15th	openings - window	glass	2	0.48	2.4	0.008	1.14	0.01	2580	23.53	47.06	glass-based
MFH	1971-80	E6	15th	openings - window frame	wood	1	0.14	0.09	89.64	0.01	1.13	455	513.91	513.91	wood-based
MFH	1971-80	E6	15th	openings - door	glass	1	0.53	2.42	0.004	1.27	0.01	2580	13.13	13.13	glass-based
MFH	1971-80	E6	15th	openings - door	glass	8	0.53	2.22	0.008	1.17	0.01	2580	24.09	192.71	glass-based
MFH	1971-80	E6	15th	openings - door	glass	4	0.63	2.22	0.004	1.39	0.01	2580	14.34	57.35	glass-based
MFH	1971-80	E6	15th	openings - door	glass	2	0.43	2.22	0.008	0.94	0.01	2580	19.50	39.00	glass-based
MFH	1971-80	E6	15th	openings - door	plywood	7	0.81	2.04	0.012	1.65	0.02	427	8.45	59.12	wood-based
MFH	1971-80	E6	15th	openings - door	plywood	4	0.71	2.04	0.012	1.44	0.02	427	7.40	29.61	wood-based
MFH	1971-80	E6	15th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	17.32	0.52	5.8	3.01	3.01	organic - misc.
MFH	1971-80	E6	15th	openings - door frame	wood	1	0.09	0.31	128.445	0.03	3.58	455	1,630.55	1,630.55	wood-based
MFH	1971-80	E6	15th	columns	prefab. concrete	12	0.40	0.4	2.600	0.16	0.42	2500	1,040.00	12,480.00	concrete-based
MFH	1971-80	E6	15th	walls	reinf. concrete	1	31.98	2.6	0.250	75.26	18.81	2500	47,035.22	47,035.22	concrete-based
MFH	1971-80	E6	15th	walls	prefab. concrete	1	37.60	2.6	0.160	97.76	15.64	2500	39,104.00	39,104.00	concrete-based
MFH	1971-80	E6	15th	walls	prefab. concrete	1	37.60	2.6	0.060	97.76	5.87	2500	14,664.00	14,664.00	concrete-based
MFH	1971-80	E6	15th	walls	clay bricks	1	58.60	2.6	0.07	135.04	9.45	1800	17,015.31	17,015.31	clay-based
MFH	1971-80	E6	15th	wall covering - thermal insulation	eps panels	1	37.60	2.6	0.04	97.76	3.91	53	207.25	207.25	polystyrene-based
MFH	1971-80	E6	15th	wall covering - plywood	plywood	1	18.18	0.84	0.016	15.27	0.24	427	104.33	104.33	wood-based
MFH	1971-80	E6	15th	wall covering - al foil	aluminum foil	1	18.18	0.84	1.2E-04	15.27	0.002	2800	5.13	5.13	metal-based
MFH	1971-80	E6	15th	wall covering - battens	wood	1	18.18	0.1	0.05	1.82	0.09	455	41.36	41.36	wood-based
MFH	1971-80	E6	15th	wall covering - thermal insulation	rock wool	1	18.18	0.84	0.05	15.27	0.76	160	122.17	122.17	stone-based
MFH	1971-80	E6	15th	wall covering - asbestos-cement sheets	asbestos-cement sheets	1	18.18	0.84	0.008	15.27	0.12	1675	204.63	204.63	asbestos-cement-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1971-80	E6	15th	slab - hollow-core slab	hollow core slab	27	1.20	5.5	0.18	6.60	1.19	1360	1,615.68	42,815.52	concrete-based
MFH	1971-80	E6	15th	slab - hollow-core slab	hollow core slab	15	1.20	3.6	0.18	4.32	0.78	1360	1,057.54	15,510.53	concrete-based
MFH	1971-80	E6	Roof	roof covering - concrete	concrete	1	n/a	n/a	0.05	243.70	12.19	2400	29,244.00	29,244.00	concrete-based
MFH	1971-80	E6	Roof	roof covering - thermal insulation	eps panels	1	n/a	n/a	0.05	243.70	12.19	53	645.81	645.81	polystyrene-based
MFH	1971-80	E6	Roof	roof covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	243.70	0.02	929	18.11	18.11	bitumen-based
MFH	1971-80	E6	Roof	roof covering - screed	cement-sand plaster	1	n/a	n/a	0.02	243.70	4.87	2100	10,235.40	10,235.40	plaster-based
MFH	1971-80	E6	Roof	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	243.70	2.44	1500	3,655.50	3,655.50	bitumen-based
MFH	1971-80	E6	Roof	roof covering - sand	sand	1	n/a	n/a	0.02	243.70	4.87	1300	6,336.20	6,336.20	plaster-based
MFH	1971-80	E6	Roof	roof covering - concrete tiles	concrete	1	n/a	n/a	0.03	243.70	7.31	2400	17,546.40	17,546.40	concrete-based
MFH	1971-80	E6	Roof	gutters	sheet metal	1	167.22	0.2	0.001	33.44	0.022	7860	170.87	170.87	metal-based
MFH	1981-90	F3	B	base slab - gravel	gravel	1	n/a	n/a	0.10	465.26	46.53	1850	86,073.10	86,073.10	stone-based
MFH	1981-90	F3	B	base slab	concrete	1	n/a	n/a	0.08	465.26	37.22	2400	89,329.92	89,329.92	concrete-based
MFH	1981-90	F3	B	floor covering - water-proofing	bitumen	1	n/a	n/a	0.01	465.26	4.65	1500	6,978.90	6,978.90	bitumen-based
MFH	1981-90	F3	B	base slab	concrete	1	n/a	n/a	0.06	465.26	27.92	2400	66,997.44	66,997.44	concrete-based
MFH	1981-90	F3	B	base slab	reinf. concrete	1	n/a	n/a	0.40	465.26	186.10	2500	465,260.00	465,260.00	concrete-based
MFH	1981-90	F3	B	floor covering - thermal insulation	rock wool	1	n/a	n/a	0.04	465.26	18.61	160	2,977.66	2,977.66	stone-based
MFH	1981-90	F3	B	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.04	465.26	18.61	2100	39,081.84	39,081.84	plaster-based
MFH	1981-90	F3	B	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.01	377.13	3.77	1800	6,788.34	6,788.34	clay-based
MFH	1981-90	F3	B	openings - window	glass	6	2.05	0.45	0.008	0.92	0.01	2580	19.04	114.24	glass-based
MFH	1981-90	F3	B	openings - window	glass	9	1.56	0.45	0.008	0.70	0.01	2580	14.49	130.40	glass-based
MFH	1981-90	F3	B	openings - window	glass	3	1.16	0.45	0.008	0.52	0.004	2580	10.77	32.32	glass-based
MFH	1981-90	F3	B	openings - window frame	wood	1	0.12	0.08	75.84	0.010	0.73	455	331.27	331.27	wood-based
MFH	1981-90	F3	B	openings - door	sheet metal	2	0.87	1.75	0.004	1.52	0.01	7860	47.73	95.46	metal-based
MFH	1981-90	F3	B	openings - door	sheet metal	1	0.77	1.75	0.004	1.34	0.01	7860	42.24	42.24	metal-based
MFH	1981-90	F3	B	openings - door	sheet metal	2	0.63	1.75	0.004	1.10	0.004	7860	34.56	69.13	metal-based
MFH	1981-90	F3	B	openings - door frame	steel	1	0.10	0.005	21.22	0.001	0.01	7860	83.39	83.39	metal-based
MFH	1981-90	F3	B	walls	reinf. concrete	1	99.57	1.77	0.15	176.24	26.44	2500	66,089.59	66,089.59	concrete-based
MFH	1981-90	F3	B	walls	clay bricks	1	99.57	1.77	0.065	176.24	11.46	1800	20,619.95	20,619.95	clay-based
MFH	1981-90	F3	B	walls	reinf. concrete	1	99.57	0.73	0.15	59.27	8.89	2500	22,225.16	22,225.16	concrete-based
MFH	1981-90	F3	B	walls	clay bricks	1	n/a	n/a	0.065	59.27	3.85	1800	6,934.25	6,934.25	clay-based
MFH	1981-90	F3	B	walls	reinf. concrete	1	103.38	2.6	0.15	262.21	39.33	2500	98,328.51	98,328.51	concrete-based
MFH	1981-90	F3	B	walls	reinf. concrete	1	51.95	2.6	0.07	135.07	9.45	2500	23,637.25	23,637.25	concrete-based
MFH	1981-90	F3	B	wall covering - thermal insulation	eps panels	1	99.57	1.77	0.05	176.24	8.81	53	467.03	467.03	polystyrene-based
MFH	1981-90	F3	B	wall covering - water-proofing	bitumen	1	99.57	1.77	0.01	176.24	1.76	1500	2,643.58	2,643.58	bitumen-based
MFH	1981-90	F3	B	wall covering - thermal insulation	eps panels	1	n/a	n/a	0.05	59.27	2.96	53	157.06	157.06	polystyrene-based
MFH	1981-90	F3	B	wall covering - water-proofing	bitumen	1	n/a	n/a	0.01	59.27	0.59	1500	889.01	889.01	bitumen-based
MFH	1981-90	F3	B	wall covering - plaster	cement-sand plaster	1	n/a	n/a	0.020	59.27	1.19	2100	2,489.22	2,489.22	plaster-based
MFH	1981-90	F3	B	stairs	reinf. concrete	17	0.175	0.28	1.200	0.02	0.03	2500	73.50	1,249.50	concrete-based
MFH	1981-90	F3	B	stairs - railings	steel	2	4.50	0.016	0.016	0.07	0.001	7860	9.05	18.11	metal-based
MFH	1981-90	F3	B	stairs - railings	steel	45	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	76.06	metal-based
MFH	1981-90	F3	B	ceiling covering - thermal insulation	eps panels	1	n/a	n/a	0.14	456.64	63.93	53	3,388.29	3,388.29	polystyrene-based
MFH	1981-90	F3	B	ceiling covering - plaster	cement-sand plaster	1	n/a	n/a	0.14	456.64	63.93	2100	134,252.90	134,252.90	plaster-based
MFH	1981-90	F3	B	slab	reinf. concrete	1	n/a	n/a	0.14	465.32	65.14	2500	162,862.00	162,862.00	concrete-based
MFH	1981-90	F3	Gf	floor covering - thermal insulation	rock wool	1	n/a	n/a	0.02	430.05	8.60	160	1,376.16	1,376.16	stone-based
MFH	1981-90	F3	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.04	462.65	18.51	2100	38,862.81	38,862.81	plaster-based
MFH	1981-90	F3	Gf	floor covering - vinyl flooring	vinyl flooring	2	n/a	n/a	0.005	12.81	0.06	2152	137.84	275.67	plastic-based
MFH	1981-90	F3	Gf	floor covering - vinyl flooring	vinyl flooring	4	n/a	n/a	0.005	11.03	0.06	2152	118.68	474.73	plastic-based
MFH	1981-90	F3	Gf	floor covering - clay tiles	clay tiles	6	1.90	2.15	0.10	4.09	0.41	1800	735.30	4,411.80	clay-based
MFH	1981-90	F3	Gf	floor covering - terazzo	terazzo	1	12.90	3.2	0.05	41.28	2.06	2500	5,160.00	5,160.00	concrete-based
MFH	1981-90	F3	Gf	floor covering - terazzo	terazzo	2	3.20	1.2	0.05	3.84	0.19	2500	480.00	960.00	concrete-based
MFH	1981-90	F3	Gf	floor covering - terazzo	terazzo	4	1.40	2.7	0.05	3.78	0.19	2500	472.50	1,890.00	concrete-based
MFH	1981-90	F3	Gf	floor covering - terazzo	terazzo	3	1.20	3.5	0.05	4.20	0.21	2500	525.00	1,575.00	concrete-based
MFH	1981-90	F3	Gf	floor covering - parquet	wood	1	n/a	n/a	0.01	300.40	3.00	455	1,366.82	1,366.82	wood-based
MFH	1981-90	F3	Gf	openings - window	glass	6	2.35	2.45	0.008	5.76	0.05	2580	118.83	713.01	glass-based
MFH	1981-90	F3	Gf	openings - window	glass	8	1.56	1.55	0.008	2.42	0.02	2580	49.91	399.26	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F3	Gf	openings - window	glass	3	1.16	1.55	0.008	1.80	0.01	2580	37.11	111.33	glass-based
MFH	1981-90	F3	Gf	openings - window frame	wood	1	0.12	0.08	123.62	0.01	1.19	455	539.97	539.97	wood-based
MFH	1981-90	F3	Gf	openings - door	glass	2	3.15	2.95	0.004	9.29	0.04	2580	95.90	191.80	glass-based
MFH	1981-90	F3	Gf	openings - door	glass	3	1.56	2.05	0.004	3.20	0.01	2580	33.00	99.01	glass-based
MFH	1981-90	F3	Gf	openings - door	plywood	14	0.87	1.99	0.012	1.73	0.02	427	8.85	123.88	wood-based
MFH	1981-90	F3	Gf	openings - door	plywood	12	0.77	1.99	0.012	1.53	0.02	427	7.83	93.98	wood-based
MFH	1981-90	F3	Gf	openings - door	plywood	8	0.67	1.99	0.012	1.33	0.02	427	6.81	54.52	wood-based
MFH	1981-90	F3	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	53.16	1.59	5.8	9.25	9.25	organic - misc.
MFH	1981-90	F3	Gf	openings - door frame	wood	1	0.09	0.31	196.840	0.03	5.49	455	2,498.79	2,498.79	wood-based
MFH	1981-90	F3	Gf	walls	prefab. concrete	1	44.81	2.7	0.08	101.64	8.13	2500	20,328.60	20,328.60	concrete-based
MFH	1981-90	F3	Gf	walls	prefab. concrete	1	44.81	2.7	0.06	101.64	6.10	2500	15,246.45	15,246.45	concrete-based
MFH	1981-90	F3	Gf	walls	reinf. concrete	1	43.48	2.7	0.15	112.00	16.80	2500	42,000.75	42,000.75	concrete-based
MFH	1981-90	F3	Gf	walls	prefab. concrete	1	43.48	2.7	0.06	112.00	6.72	2500	16,800.30	16,800.30	concrete-based
MFH	1981-90	F3	Gf	walls	clay bricks	1	23.40	2.7	0.065	63.18	4.11	1800	7,392.06	7,392.06	clay-based
MFH	1981-90	F3	Gf	walls	clay bricks - facing	1	23.40	2.7	0.12	63.18	7.58	1300	9,856.08	9,856.08	clay-based
MFH	1981-90	F3	Gf	walls	reinf. concrete	1	29.30	2.7	0.15	68.75	10.31	2500	25,780.61	25,780.61	concrete-based
MFH	1981-90	F3	Gf	walls	reinf. concrete	1	88.47	2.7	0.15	215.94	32.39	2500	80,978.34	80,978.34	concrete-based
MFH	1981-90	F3	Gf	walls	prefab. concrete	6	11.20	2.7	0.07	22.26	1.56	2500	3,895.55	23,373.32	concrete-based
MFH	1981-90	F3	Gf	walls	clay bricks	1	21.65	2.7	0.065	46.23	3.00	1800	5,408.61	5,408.61	clay-based
MFH	1981-90	F3	Gf	wall covering - thermal insulation	eps panels	1	44.81	2.7	0.08	101.64	8.13	53	430.97	430.97	polystyrene-based
MFH	1981-90	F3	Gf	wall covering - pebbledash	pebbledash	1	44.81	2.7	0.03	101.64	3.05	1800	5,488.72	5,488.72	plaster-based
MFH	1981-90	F3	Gf	wall covering - thermal insulation	eps panels	1	43.48	2.7	0.06	112.00	6.72	53	356.17	356.17	polystyrene-based
MFH	1981-90	F3	Gf	wall covering - plaster	lime-sand plaster	1	23.40	2.7	0.02	63.18	1.26	1800	2,274.48	2,274.48	plaster-based
MFH	1981-90	F3	Gf	wall covering - thermal insulation	eps panels	1	23.40	2.7	0.04	63.18	2.53	53	133.94	133.94	polystyrene-based
MFH	1981-90	F3	Gf	wall covering - plaster	perlite plaster	1	29.30	2.7	0.02	68.75	1.37	338	464.74	464.74	plaster-based
MFH	1981-90	F3	Gf	stairs	reinf. concrete	17	0.175	0.28	1.200	0.02	0.03	2500	73.50	1,249.50	concrete-based
MFH	1981-90	F3	Gf	stairs - railings	steel	2	4.50	0.016	0.016	0.07	0.001	7860	9.05	18.11	metal-based
MFH	1981-90	F3	Gf	stairs - railings	steel	45	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	76.06	metal-based
MFH	1981-90	F3	Gf	stairs	reinf. concrete	5	0.17	0.3	2.00	0.03	0.05	2500	127.50	637.50	concrete-based
MFH	1981-90	F3	Gf	stairs - slab	reinf. concrete	1	1.20	2	0.10	2.40	0.24	2500	600.00	600.00	concrete-based
MFH	1981-90	F3	Gf	ceiling covering - plaster	cement-sand plaster	1	n/a	n/a	0.02	456.64	9.13	2100	19,178.99	19,178.99	plaster-based
MFH	1981-90	F3	Gf	slab	reinf. concrete	1	n/a	n/a	0.14	465.32	65.14	2500	162,862.00	162,862.00	concrete-based
MFH	1981-90	F3	1st - 4th	floor covering - thermal insulation	rock wool	4	n/a	n/a	0.02	430.05	8.60	160	1,376.16	5,504.64	stone-based
MFH	1981-90	F3	1st - 4th	floor covering - screed	cement-sand plaster	4	n/a	n/a	0.04	462.65	18.51	2100	38,862.81	155,451.24	plaster-based
MFH	1981-90	F3	1st - 4th	floor covering - vinyl flooring	vinyl flooring	8	n/a	n/a	0.005	12.81	0.06	2152	137.84	1,102.68	plastic-based
MFH	1981-90	F3	1st - 4th	floor covering - vinyl flooring	vinyl flooring	16	n/a	n/a	0.005	11.03	0.06	2152	118.68	1,898.92	plastic-based
MFH	1981-90	F3	1st - 4th	floor covering - clay tiles	clay tiles	24	1.90	2.15	0.10	4.09	0.41	1800	735.30	17,647.20	clay-based
MFH	1981-90	F3	1st - 4th	floor covering - terazzo	terazzo	4	n/a	n/a	0.05	40.89	2.04	2500	5,111.25	20,445.00	concrete-based
MFH	1981-90	F3	1st - 4th	floor covering - terazzo	terazzo	16	1.40	2.7	0.05	3.78	0.19	2500	472.50	7,560.00	concrete-based
MFH	1981-90	F3	1st - 4th	floor covering - terazzo	terazzo	16	1.20	3.5	0.05	4.20	0.21	2500	525.00	8,400.00	concrete-based
MFH	1981-90	F3	1st - 4th	floor covering - parquet	wood	4	n/a	n/a	0.01	336.48	3.36	455	1,531.00	6,123.98	wood-based
MFH	1981-90	F3	1st - 4th	openings - window	glass	24	2.35	2.45	0.008	5.76	0.05	2580	118.83	2,852.04	glass-based
MFH	1981-90	F3	1st - 4th	openings - window	glass	32	1.56	1.55	0.008	2.42	0.02	2580	49.91	1,597.04	glass-based
MFH	1981-90	F3	1st - 4th	openings - window	glass	12	1.16	1.55	0.008	1.80	0.01	2580	37.11	445.33	glass-based
MFH	1981-90	F3	1st - 4th	openings - window frame	wood	4	0.12	0.08	494.48	0.01	4.75	455	2,159.89	8,639.55	wood-based
MFH	1981-90	F3	1st - 4th	openings - door	glass	16	1.56	2.05	0.004	3.20	0.01	2580	33.00	528.05	glass-based
MFH	1981-90	F3	1st - 4th	openings - door	plywood	56	0.87	1.99	0.012	1.73	0.02	427	8.85	495.54	wood-based
MFH	1981-90	F3	1st - 4th	openings - door	plywood	52	0.77	1.99	0.012	1.53	0.02	427	7.83	407.25	wood-based
MFH	1981-90	F3	1st - 4th	openings - door	plywood	32	0.67	1.99	0.012	1.33	0.02	427	6.81	218.07	wood-based
MFH	1981-90	F3	1st - 4th	openings - door	cardboard (honeycomb)	4	n/a	n/a	0.030	67.48	2.02	5.8	11.74	46.97	organic - misc.
MFH	1981-90	F3	1st - 4th	openings - door frame	wood	4	0.09	0.31	756.560	0.03	21.11	455	9,604.15	38,416.60	wood-based
MFH	1981-90	F3	1st - 3rd	walls	prefab. concrete	4	44.81	2.7	0.08	86.44	6.92	2500	17,288.40	69,153.60	concrete-based
MFH	1981-90	F3	1st - 3rd	walls	prefab. concrete	4	44.81	2.7	0.06	86.44	5.19	2500	12,966.30	51,865.20	concrete-based
MFH	1981-90	F3	1st - 3rd	walls	reinf. concrete	4	43.48	2.7	0.15	112.00	16.80	2500	42,000.75	168,003.00	concrete-based
MFH	1981-90	F3	1st - 4th	walls	prefab. concrete	4	43.48	2.7	0.06	112.00	6.72	2500	16,800.30	67,201.20	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F3	1st - 4th	walls	clay bricks	4	15.76	2.7	0.065	42.55	2.77	1800	4,978.58	19,914.34	clay-based
MFH	1981-90	F3	1st - 4th	walls	clay bricks - facing	4	15.76	2.7	0.12	42.55	5.11	1300	6,638.11	26,552.45	clay-based
MFH	1981-90	F3	1st - 4th	walls	reinf. concrete	4	33.00	2.7	0.15	78.74	11.81	2500	29,526.86	118,107.45	concrete-based
MFH	1981-90	F3	1st - 4th	walls	reinf. concrete	4	97.37	2.7	0.15	238.25	35.74	2500	89,341.99	357,367.95	concrete-based
MFH	1981-90	F3	1st - 4th	walls	prefab. concrete	24	11.20	2.7	0.07	22.26	1.56	2500	3,895.55	93,493.26	concrete-based
MFH	1981-90	F3	1st - 4th	walls	clay bricks	4	21.65	2.7	0.065	46.23	3.00	1800	5,408.61	21,634.42	clay-based
MFH	1981-90	F3	1st - 3rd	wall covering - thermal insulation	eps panels	4	44.81	2.7	0.08	86.44	6.92	53	366.51	1,466.06	polystyrene-based
MFH	1981-90	F3	1st - 3rd	wall covering - pebbledash	pebbledash	4	44.81	2.7	0.03	86.44	2.59	1800	4,667.87	18,671.47	plaster-based
MFH	1981-90	F3	1st - 3rd	wall covering - thermal insulation	eps panels	4	43.48	2.7	0.06	112.00	6.72	53	356.17	1,424.67	polystyrene-based
MFH	1981-90	F3	1st - 4th	wall covering - plaster	lime-sand plaster	4	15.76	2.7	0.02	42.55	0.85	1800	1,531.87	6,127.49	plaster-based
MFH	1981-90	F3	1st - 4th	wall covering - thermal insulation	eps panels	4	15.76	2.7	0.04	42.55	1.70	53	90.21	360.84	polystyrene-based
MFH	1981-90	F3	1st - 4th	wall covering - plaster	perlite plaster	4	33.00	2.7	0.02	78.74	1.57	338	532.27	2,129.08	plaster-based
MFH	1981-90	F3	1st - 3rd	stairs	reinf. concrete	51	0.175	0.28	1.200	0.02	0.03	2500	73.50	3,748.50	concrete-based
MFH	1981-90	F3	1st - 3rd	stairs - railings	steel	6	4.50	0.016	0.016	0.07	0.001	7860	9.05	54.33	metal-based
MFH	1981-90	F3	1st - 3rd	stairs - railings	steel	135	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	228.18	metal-based
MFH	1981-90	F3	1st - 4th	ceiling covering - plaster	cement-sand plaster	4	n/a	n/a	0.02	456.64	9.13	2100	19,178.99	76,715.94	plaster-based
MFH	1981-90	F3	1st - 4th	slab	reinf. concrete	4	n/a	n/a	0.14	465.32	65.14	2500	162,862.00	651,448.00	concrete-based
MFH	1981-90	F3	4th	walls	reinf. concrete	1	94.52	3.2	0.08	243.18	19.45	2500	48,636.20	48,636.20	concrete-based
MFH	1981-90	F3	4th	wall covering - thermal insulation	eps panels	1	94.52	3.2	0.08	243.18	19.45	53	1,031.09	1,031.09	polystyrene-based
MFH	1981-90	F3	4th	wall covering - steel frame	sheet metal	315	5.69	0.005	0.005	0.028	0.0001	7860	1.12	352.27	metal-based
MFH	1981-90	F3	4th	wall covering - battens	wood	3	94.52	0.05	0.025	4.73	0.12	455	53.76	161.27	wood-based
MFH	1981-90	F3	4th	wall covering - corr. metal sheet	sheet metal	1	94.52	3.2	0.0008	243.18	0.19	7860	1,529.12	1,529.12	metal-based
MFH	1981-90	F3	4th	floor covering - thermal insulation	rock wool	1	n/a	n/a	0.06	465.32	27.92	160	4,467.07	4,467.07	stone-based
MFH	1981-90	F3	Roof	roof - beams	wood	76	0.10	0.14	6.30	0.01	0.09	455	40.13	3,039.92	wood-based
MFH	1981-90	F3	Roof	roof - boards	wood	1	n/a	n/a	0.024	357.54	8.58	455	3,904.34	3,904.34	wood-based
MFH	1981-90	F3	Roof	roof covering - corr. metal sheets	sheet metal	1	n/a	n/a	0.003	357.54	1.07	7860	8,430.79	8,430.79	metal-based
MFH	1981-90	F3	Roof	gutters	sheet metal	1	48.00	0.2	0.001	9.60	0.006	7860	49.05	49.05	metal-based
MFH	1981-90	F4	B	base slab - gravel	gravel	1	n/a	n/a	0.50	235.73	117.86	1850	218,049.79	218,049.79	stone-based
MFH	1981-90	F4	B	base slab	concrete	1	n/a	n/a	0.08	235.73	18.86	2400	45,260.06	45,260.06	concrete-based
MFH	1981-90	F4	B	base slab	reinf. concrete	1	n/a	n/a	0.40	235.73	94.29	2500	235,729.50	235,729.50	concrete-based
MFH	1981-90	F4	B	floor covering - water-proofing	bitumen	1	n/a	n/a	0.01	235.73	2.36	1500	3,535.94	3,535.94	bitumen-based
MFH	1981-90	F4	B	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.05	235.73	11.79	2100	24,751.60	24,751.60	plaster-based
MFH	1981-90	F4	B	openings - door	sheet metal	5	0.86	1.75	0.004	1.50	0.01	7860	47.18	235.91	metal-based
MFH	1981-90	F4	B	openings - door frame	steel	1	0.10	0.005	21.75	0.001	0.01	7860	85.48	85.48	metal-based
MFH	1981-90	F4	B	walls	reinf. concrete	1	58.07	2.7	0.15	155.29	23.29	2500	58,233.11	58,233.11	concrete-based
MFH	1981-90	F4	B	walls	silicate bricks	1	58.07	2.7	0.12	155.29	18.63	1900	35,405.73	35,405.73	lime-sand-based
MFH	1981-90	F4	B	walls	reinf. concrete	1	9.88	2.7	0.15	26.68	4.00	2500	10,003.50	10,003.50	concrete-based
MFH	1981-90	F4	B	walls	reinf. concrete	1	30.58	2.7	0.15	75.06	11.26	2500	28,148.44	28,148.44	concrete-based
MFH	1981-90	F4	B	wall covering - thermal insulation	rock wool	1	58.07	2.7	0.05	155.29	7.76	160	1,242.31	1,242.31	stone-based
MFH	1981-90	F4	B	stairs	reinf. concrete	16	0.28	0.175	1.07	0.02	0.03	2500	65.54	1,048.60	concrete-based
MFH	1981-90	F4	B	stairs	reinf. concrete	5	0.28	0.2	1.80	0.03	0.05	2500	126.00	630.00	concrete-based
MFH	1981-90	F4	B	stairs - railings	steel	2	5.32	0.16	0.16	0.85	0.14	7860	1,070.47	2,140.94	metal-based
MFH	1981-90	F4	B	stairs - railings	steel	53	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	89.92	metal-based
MFH	1981-90	F4	B	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.021	231.43	4.86	1800	8,748.05	8,748.05	plaster-based
MFH	1981-90	F4	B	ceiling covering - metal lath	metal lath	1	n/a	n/a	0.009	231.43	2.08	178.88889	372.60	372.60	metal-based
MFH	1981-90	F4	B	ceiling covering - thermal insulation	eps panels	1	n/a	n/a	0.04	156.74	6.27	53	332.29	332.29	polystyrene-based
MFH	1981-90	F4	B	slab	prefab. concrete	1	n/a	n/a	0.04	207.89	8.32	2500	20,789.00	20,789.00	concrete-based
MFH	1981-90	F4	B	slab	concrete	1	n/a	n/a	0.15	231.43	34.71	2400	83,314.80	83,314.80	concrete-based
MFH	1981-90	F4	Gf	balcony - slab	reinf. concrete	2	4.20	1.6	0.14	6.72	0.94	2500	2,352.00	4,704.00	concrete-based
MFH	1981-90	F4	Gf	balcony - slab	reinf. concrete	1	1.54	2.24	0.14	3.45	0.48	2500	1,207.36	1,207.36	concrete-based
MFH	1981-90	F4	Gf	balcony - railings	steel	2	5.74	0.16	0.16	0.92	0.15	7860	1,154.98	2,309.96	metal-based
MFH	1981-90	F4	Gf	balcony - railings	steel	57	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	97.02	metal-based
MFH	1981-90	F4	Gf	floor covering - sound insulation	cork panels	1	n/a	n/a	0.01	207.89	2.08	150	311.84	311.84	wood-based
MFH	1981-90	F4	Gf	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.04	207.89	8.32	2100	17,462.76	17,462.76	plaster-based
MFH	1981-90	F4	Gf	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.010	26.60	0.27	1800	478.80	478.80	clay-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F4	Gf	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	21.31	1.07	2500	2,663.75	2,663.75	concrete-based
MFH	1981-90	F4	Gf	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	16.30	0.82	2500	2,037.50	2,037.50	concrete-based
MFH	1981-90	F4	Gf	floor covering - parquet	wood	1	n/a	n/a	0.01	181.29	1.81	455	824.87	824.87	wood-based
MFH	1981-90	F4	Gf	openings - window	glass	1	2.30	2.39	0.004	5.50	0.02	2580	56.73	56.73	glass-based
MFH	1981-90	F4	Gf	openings - window	glass	3	1.16	1.25	0.008	1.45	0.01	2580	29.93	89.78	glass-based
MFH	1981-90	F4	Gf	openings - window	glass	4	0.76	1.25	0.008	0.95	0.01	2580	19.61	78.43	glass-based
MFH	1981-90	F4	Gf	openings - window	glass	4	0.90	1.39	0.004	1.25	0.01	2580	12.91	51.64	glass-based
MFH	1981-90	F4	Gf	openings - window	glass	3	0.56	1.25	0.008	0.70	0.01	2580	14.45	43.34	glass-based
MFH	1981-90	F4	Gf	openings - window	glass	5	0.30	2.29	0.004	0.69	0.003	2580	7.09	35.45	glass-based
MFH	1981-90	F4	Gf	openings - window frame	steel	1	0.10	0.005	53.60	0.001	0.03	7860	210.65	210.65	metal-based
MFH	1981-90	F4	Gf	openings - window frame	wood	1	0.12	0.08	41.40	0.01	0.40	455	180.84	180.84	wood-based
MFH	1981-90	F4	Gf	openings - door	glass	1	1.70	3.39	0.004	5.76	0.02	2580	59.47	59.47	glass-based
MFH	1981-90	F4	Gf	openings - door	glass	1	1.70	2.59	0.004	4.40	0.02	2580	45.44	45.44	glass-based
MFH	1981-90	F4	Gf	openings - door	glass	5	0.90	3.39	0.004	3.05	0.01	2580	31.49	157.43	glass-based
MFH	1981-90	F4	Gf	openings - door	glass	2	1.16	2.15	0.008	2.49	0.02	2580	51.48	102.95	glass-based
MFH	1981-90	F4	Gf	openings - door	glass	1	0.56	2.15	0.008	1.20	0.01	2580	24.85	24.85	glass-based
MFH	1981-90	F4	Gf	openings - door	plywood	2	0.81	2.49	0.012	2.01	0.02	427	10.31	20.63	wood-based
MFH	1981-90	F4	Gf	openings - door	plywood	2	0.81	1.99	0.012	1.61	0.02	427	8.24	16.48	wood-based
MFH	1981-90	F4	Gf	openings - door	plywood	10	0.71	2.49	0.012	1.76	0.02	427	9.04	90.41	wood-based
MFH	1981-90	F4	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	24.88	0.75	5.8	4.33	4.33	organic - misc.
MFH	1981-90	F4	Gf	openings - door frame	steel	1	0.10	0.005	61.66	0.001	0.03	7860	242.32	242.32	metal-based
MFH	1981-90	F4	Gf	openings - door frame	wood	1	0.09	0.31	77.920	0.03	2.17	455	989.16	989.16	wood-based
MFH	1981-90	F4	Gf	walls	reinf. concrete	1	28.16	2.7	0.15	73.38	11.01	2500	27,517.88	27,517.88	concrete-based
MFH	1981-90	F4	Gf	wall covering - thermal insulation	rock wool	1	28.16	2.7	0.05	73.38	3.67	160	587.05	587.05	stone-based
MFH	1981-90	F4	Gf	walls	silicate bricks	1	28.16	2.7	0.12	73.38	8.81	1900	16,730.87	16,730.87	lime-sand-based
MFH	1981-90	F4	Gf	walls	gypsum board	1	35.10	2.7	0.07	67.37	4.72	732	3,451.79	3,451.79	gypsum-based
MFH	1981-90	F4	Gf	wall covering - tar paper	tar paper	1	35.10	2.7	0.00008	67.37	0.01	929	5.01	5.01	bitumen-based
MFH	1981-90	F4	Gf	wall covering - thermal insulation	rock wool	1	35.10	2.7	0.05	67.37	3.37	160	538.92	538.92	stone-based
MFH	1981-90	F4	Gf	walls	silicate bricks	1	35.10	2.7	0.12	67.37	8.08	1900	15,359.25	15,359.25	lime-sand-based
MFH	1981-90	F4	Gf	walls	aac blocks	1	10.36	2.7	0.25	27.97	6.99	550	3,846.15	3,846.15	concrete-based
MFH	1981-90	F4	Gf	wall covering - plaster	lime-sand plaster	1	10.36	2.7	0.02	27.97	0.56	1800	1,006.99	1,006.99	plaster-based
MFH	1981-90	F4	Gf	walls	reinf. concrete	1	40.52	2.7	0.15	102.35	15.35	2500	38,380.61	38,380.61	concrete-based
MFH	1981-90	F4	Gf	walls	gypsum board	1	39.02	2.7	0.07	87.71	6.14	732	4,494.29	4,494.29	gypsum-based
MFH	1981-90	F4	Gf	stairs	reinf. concrete	16	0.28	0.175	1.07	0.02	0.03	2500	65.54	1,048.60	concrete-based
MFH	1981-90	F4	Gf	stairs - railings	steel	2	5.32	0.16	0.16	0.85	0.14	7860	1,070.47	2,140.94	metal-based
MFH	1981-90	F4	Gf	stairs - railings	steel	53	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	89.92	metal-based
MFH	1981-90	F4	Gf	ceiling covering - wood panels	wood panels	1	4.05	10.36	0.01	41.96	0.42	455	190.91	190.91	wood-based
MFH	1981-90	F4	Gf	ceiling covering - battens	wood	21	0.05	0.14	4.25	0.01	0.03	455	13.54	280.47	wood-based
MFH	1981-90	F4	Gf	ceiling covering - thermal insulation	eps panels	1	4.25	10.36	0.05	44.03	2.20	53	116.68	116.68	polystyrene-based
MFH	1981-90	F4	Gf	ceiling covering - metal lath	metal lath	1	4.25	10.36	0.009	44.03	0.40	178.88889	70.89	70.89	metal-based
MFH	1981-90	F4	Gf	ceiling covering - plaster	lime-sand plaster	1	4.25	10.36	0.021	44.03	0.92	1800	1,664.33	1,664.33	plaster-based
MFH	1981-90	F4	Gf	slab	prefab. concrete	1	n/a	n/a	0.04	239.57	9.58	2500	23,956.60	23,956.60	concrete-based
MFH	1981-90	F4	Gf	slab	concrete	1	n/a	n/a	0.15	254.56	38.18	2400	91,641.60	91,641.60	concrete-based
MFH	1981-90	F4	1st - 4th	balcony - slab	reinf. concrete	8	4.20	1.6	0.14	6.72	0.94	2500	2,352.00	18,816.00	concrete-based
MFH	1981-90	F4	1st - 4th	balcony - floor covering	clay tiles	8	4.20	1.6	0.012	6.72	0.08	1800	145.15	1,161.22	clay-based
MFH	1981-90	F4	1st - 4th	balcony - floor covering	cement-sand plaster	8	4.20	1.6	0.04	6.72	0.27	2100	564.48	4,515.84	plaster-based
MFH	1981-90	F4	1st - 4th	balcony - floor covering	clay tiles	4	1.54	2.3	0.012	3.54	0.04	1800	76.51	306.03	clay-based
MFH	1981-90	F4	1st - 4th	balcony - railings	steel	4	11.48	0.16	0.16	1.84	0.29	7860	2,309.96	9,239.84	metal-based
MFH	1981-90	F4	1st - 4th	balcony - railings	steel	459	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	776.15	metal-based
MFH	1981-90	F4	1st - 4th	floor covering - sound insulation	cork panels	4	n/a	n/a	0.01	239.57	2.40	150	359.35	1,437.40	wood-based
MFH	1981-90	F4	1st - 4th	floor covering - screed	cement-sand plaster	4	n/a	n/a	0.04	239.57	9.58	2100	20,123.54	80,494.18	plaster-based
MFH	1981-90	F4	1st - 4th	floor covering - clay tiles	clay tiles	4	n/a	n/a	0.012	45.68	0.55	1800	986.69	3,946.75	clay-based
MFH	1981-90	F4	1st - 4th	floor covering - terazzo	terazzo	4	n/a	n/a	0.05	14.28	0.71	2500	1,785.00	7,140.00	concrete-based
MFH	1981-90	F4	1st - 4th	floor covering - parquet	wood	4	n/a	n/a	0.01	193.89	1.94	455	882.18	3,528.73	wood-based
MFH	1981-90	F4	1st - 4th	openings - window	glass	8	1.16	1.25	0.008	1.45	0.01	2580	29.93	239.42	glass-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F4	1st - 4th	openings - window	glass	32	0.76	1.25	0.008	0.95	0.01	2580	19.61	627.46	glass-based
MFH	1981-90	F4	1st - 4th	openings - window	glass	4	0.90	2.29	0.004	2.06	0.01	2580	21.27	85.08	glass-based
MFH	1981-90	F4	1st - 4th	openings - window	glass	16	0.38	1.25	0.008	0.47	0.004	2580	9.68	154.80	glass-based
MFH	1981-90	F4	1st - 4th	openings - window	glass	4	0.38	1.25	0.008	0.47	0.004	2580	9.68	38.70	glass-based
MFH	1981-90	F4	1st - 4th	openings - window	glass	20	0.30	2.29	0.004	0.69	0.003	2580	7.09	141.80	glass-based
MFH	1981-90	F4	1st - 4th	openings - window frame	steel	4	0.10	0.005	129.12	0.001	0.06	7860	507.44	2,029.77	metal-based
MFH	1981-90	F4	1st - 4th	openings - window frame	wood	4	0.12	0.08	232.20	0.01	2.23	455	1,014.25	4,057.00	wood-based
MFH	1981-90	F4	1st - 4th	openings - door	glass	8	1.16	2.15	0.008	2.49	0.02	2580	51.48	411.81	glass-based
MFH	1981-90	F4	1st - 4th	openings - door	glass	8	0.56	2.15	0.008	1.20	0.01	2580	24.85	198.80	glass-based
MFH	1981-90	F4	1st - 4th	openings - door	plywood	8	0.81	2.49	0.012	2.01	0.02	427	10.31	82.51	wood-based
MFH	1981-90	F4	1st - 4th	openings - door	plywood	12	0.81	1.99	0.012	1.61	0.02	427	8.24	98.86	wood-based
MFH	1981-90	F4	1st - 4th	openings - door	plywood	64	0.71	2.49	0.012	1.76	0.02	427	9.04	578.59	wood-based
MFH	1981-90	F4	1st - 4th	openings - door	cardboard (honeycomb)	4	n/a	n/a	0.030	37.08	1.11	5.8	6.45	25.81	organic - misc.
MFH	1981-90	F4	1st - 4th	openings - door frame	wood	4	0.09	0.31	549.680	0.03	15.34	455	6,977.91	27,911.65	wood-based
MFH	1981-90	F4	1st - 4th	walls	reinf. concrete	4	13.60	2.7	0.15	32.76	4.91	2500	12,284.63	49,138.50	concrete-based
MFH	1981-90	F4	1st - 4th	wall covering - thermal insulation	rock wool	4	13.60	2.7	0.05	32.76	1.64	160	262.07	1,048.29	stone-based
MFH	1981-90	F4	1st - 4th	walls	silicate bricks	4	13.60	2.7	0.12	32.76	3.93	1900	7,469.05	29,876.21	lime-sand-based
MFH	1981-90	F4	1st - 4th	walls	gypsum board	4	36.45	2.7	0.07	82.93	5.80	732	4,249.18	16,996.72	gypsum-based
MFH	1981-90	F4	1st - 4th	wall covering - tar paper	tar paper	4	36.45	2.7	0.00008	82.93	0.01	929	6.16	24.65	bitumen-based
MFH	1981-90	F4	1st - 4th	wall covering - thermal insulation	rock wool	4	36.45	2.7	0.05	82.93	4.15	160	663.42	2,653.66	stone-based
MFH	1981-90	F4	1st - 4th	walls	silicate bricks	4	36.45	2.7	0.12	82.93	9.95	1900	18,907.36	75,629.42	lime-sand-based
MFH	1981-90	F4	1st - 4th	walls	aac blocks	4	17.47	2.7	0.25	47.17	11.79	550	6,485.74	25,942.95	concrete-based
MFH	1981-90	F4	1st - 4th	wall covering - plaster	lime-sand plaster	4	17.47	2.7	0.02	47.17	0.94	1800	1,698.08	6,792.34	plaster-based
MFH	1981-90	F4	1st - 4th	walls	reinf. concrete	4	60.32	2.7	0.15	154.67	23.20	2500	57,999.73	231,998.93	concrete-based
MFH	1981-90	F4	1st - 4th	walls	gypsum board	4	53.55	2.7	0.07	121.65	8.52	732	6,233.27	24,933.07	gypsum-based
MFH	1981-90	F4	1st - 4th	stairs	reinf. concrete	64	0.28	0.04375	1.07	0.01	0.01	2500	16.38	1,048.60	concrete-based
MFH	1981-90	F4	1st - 4th	stairs - railings	steel	8	5.32	0.16	0.16	0.85	0.14	7860	1,070.47	8,563.75	metal-based
MFH	1981-90	F4	1st - 4th	stairs - railings	steel	213	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	359.68	metal-based
MFH	1981-90	F4	1st - 4th	slab	prefab. concrete	4	n/a	n/a	0.04	239.57	9.58	2500	23,956.60	95,826.40	concrete-based
MFH	1981-90	F4	1st - 4th	slab	concrete	4	n/a	n/a	0.15	254.56	38.18	2400	91,641.60	366,566.40	concrete-based
MFH	1981-90	F4	5th	floor covering - sound insulation	cork panels	1	n/a	n/a	0.01	239.57	2.40	150	359.35	359.35	wood-based
MFH	1981-90	F4	5th	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.04	239.57	9.58	2100	20,123.54	20,123.54	plaster-based
MFH	1981-90	F4	5th	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.012	45.68	0.55	1800	986.69	986.69	clay-based
MFH	1981-90	F4	5th	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	14.28	0.71	2500	1,785.00	1,785.00	concrete-based
MFH	1981-90	F4	5th	floor covering - parquet	wood	1	n/a	n/a	0.01	193.89	1.94	455	882.18	882.18	wood-based
MFH	1981-90	F4	5th	openings - window	glass	2	1.16	1.25	0.008	1.45	0.01	2580	29.93	59.86	glass-based
MFH	1981-90	F4	5th	openings - window	glass	8	0.76	1.25	0.008	0.95	0.01	2580	19.61	156.86	glass-based
MFH	1981-90	F4	5th	openings - window	glass	4	0.38	1.25	0.008	0.47	0.004	2580	9.68	38.70	glass-based
MFH	1981-90	F4	5th	openings - window	glass	2	0.38	1.25	0.008	0.47	0.004	2580	9.68	19.35	glass-based
MFH	1981-90	F4	5th	openings - window frame	wood	1	0.12	0.08	61.30	0.01	0.59	455	267.76	267.76	wood-based
MFH	1981-90	F4	5th	openings - door	glass	2	1.16	2.15	0.008	2.49	0.02	2580	51.48	102.95	glass-based
MFH	1981-90	F4	5th	openings - door	glass	2	0.56	2.15	0.008	1.20	0.01	2580	24.85	49.70	glass-based
MFH	1981-90	F4	5th	openings - door	plywood	2	0.81	2.49	0.012	2.01	0.02	427	10.31	20.63	wood-based
MFH	1981-90	F4	5th	openings - door	plywood	3	0.81	1.99	0.012	1.61	0.02	427	8.24	24.72	wood-based
MFH	1981-90	F4	5th	openings - door	plywood	14	0.71	2.49	0.012	1.76	0.02	427	9.04	126.57	wood-based
MFH	1981-90	F4	5th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	33.55	1.01	5.8	5.84	5.84	organic - misc.
MFH	1981-90	F4	5th	openings - door frame	wood	1	0.09	0.31	127.680	0.03	3.56	455	1,620.83	1,620.83	wood-based
MFH	1981-90	F4	5th	walls	reinf. concrete	1	13.60	2.66	0.15	34.28	5.14	2500	12,853.50	12,853.50	concrete-based
MFH	1981-90	F4	5th	wall covering - thermal insulation	rock wool	1	13.60	2.66	0.05	34.28	1.71	160	274.21	274.21	stone-based
MFH	1981-90	F4	5th	wall covering - beams	wood	23	0.10	0.14	3	0.014	0.04	455	19.11	433.16	wood-based
MFH	1981-90	F4	5th	wall covering - battens	wood	3	0.05	0.03	13.60	0.002	0.02	455	9.28	27.85	wood-based
MFH	1981-90	F4	5th	wall covering	fibre-cement sheets	1	13.60	3.00	0.012	38.90	0.47	1860	868.25	868.25	cement-based
MFH	1981-90	F4	5th	walls	gypsum board	4	36.45	2.7	0.07	78.64	5.51	732	4,029.72	16,118.87	gypsum-based
MFH	1981-90	F4	5th	wall covering - tar paper	tar paper	4	36.45	2.7	0.00008	78.64	0.01	929	5.84	23.38	bitumen-based
MFH	1981-90	F4	5th	wall covering - thermal insulation	rock wool	4	36.45	2.7	0.05	78.64	3.93	160	629.15	2,516.61	stone-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F4	5th	walls	silicate bricks	4	36.45	2.7	0.12	78.64	9.44	1900	17,930.83	71,723.33	lime-sand-based
MFH	1981-90	F4	5th	wall covering - beams	wood	61	0.10	0.14	3	0.014	0.04	455	19.11	1,160.93	wood-based
MFH	1981-90	F4	5th	wall covering - battens	wood	3	0.05	0.03	36.45	0.002	0.05	455	24.88	74.63	wood-based
MFH	1981-90	F4	5th	wall covering	fibre-cement sheets	1	36.45	3.00	0.012	89.58	1.07	1860	1,999.40	1,999.40	cement-based
MFH	1981-90	F4	5th	walls	aac blocks	1	20.00	2.66	0.25	53.20	13.30	550	7,315.00	7,315.00	concrete-based
MFH	1981-90	F4	5th	wall covering - plaster	lime-sand plaster	1	20.00	2.66	0.02	53.20	1.06	1800	1,915.20	1,915.20	plaster-based
MFH	1981-90	F4	5th	walls	reinf. concrete	1	60.32	2.66	0.15	153.21	22.98	2500	57,453.68	57,453.68	concrete-based
MFH	1981-90	F4	5th	walls	gypsum board	1	53.55	2.66	0.07	117.74	8.24	732	6,033.11	6,033.11	gypsum-based
MFH	1981-90	F4	5th	stairs	reinf. concrete	16	0.28	0.175	1.07	0.02	0.03	2500	65.54	1,048.60	concrete-based
MFH	1981-90	F4	5th	stairs - railings	steel	2	5.32	0.16	0.16	0.85	0.14	7860	1,070.47	2,140.94	metal-based
MFH	1981-90	F4	5th	stairs - railings	steel	53	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	89.92	metal-based
MFH	1981-90	F4	5th	slab	prefab. concrete	1	n/a	n/a	0.04	239.57	9.58	2500	23,956.60	23,956.60	concrete-based
MFH	1981-90	F4	5th	slab	concrete	1	n/a	n/a	0.15	254.56	38.18	2400	91,641.60	91,641.60	concrete-based
MFH	1981-90	F4	6th	floor covering - sound insulation	cork panels	1	n/a	n/a	0.01	115.78	1.16	150	173.67	173.67	wood-based
MFH	1981-90	F4	6th	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.04	115.78	4.63	2100	9,725.52	9,725.52	plaster-based
MFH	1981-90	F4	6th	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.012	18.49	0.22	1800	399.38	399.38	clay-based
MFH	1981-90	F4	6th	floor covering - terazzo	terazzo	1	n/a	n/a	0.05	39.60	1.98	2500	4,950.00	4,950.00	concrete-based
MFH	1981-90	F4	6th	floor covering - parquet	wood	1	n/a	n/a	0.01	97.29	0.97	455	442.67	442.67	wood-based
MFH	1981-90	F4	6th	floor covering - thermal insulation	rock wool	1	n/a	n/a	0.060	118.37	7.10	160	1,136.35	1,136.35	stone-based
MFH	1981-90	F4	6th	floor covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	118.37	0.01	929	8.80	8.80	bitumen-based
MFH	1981-90	F4	6th	openings - door	plywood	2	0.81	2.49	0.012	2.01	0.02	427	10.31	20.63	wood-based
MFH	1981-90	F4	6th	openings - door	plywood	1	0.81	1.99	0.012	1.61	0.02	427	8.24	8.24	wood-based
MFH	1981-90	F4	6th	openings - door	plywood	6	0.71	2.49	0.012	1.76	0.02	427	9.04	54.24	wood-based
MFH	1981-90	F4	6th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	16.22	0.49	5.8	2.82	2.82	organic - misc.
MFH	1981-90	F4	6th	openings - door frame	wood	1	0.09	0.31	50.420	0.03	1.41	455	640.06	640.06	wood-based
MFH	1981-90	F4	6th	walls	aac blocks	1	49.62	1.50	0.250	74.43	18.61	550	10,234.13	10,234.13	concrete-based
MFH	1981-90	F4	6th	wall covering - plaster	lime-sand plaster	1	49.62	1.50	0.020	74.43	1.49	1800	2,679.48	2,679.48	plaster-based
MFH	1981-90	F4	6th	walls	reinf. concrete	1	20.26	2.60	0.250	51.07	12.77	2500	31,917.59	31,917.59	concrete-based
MFH	1981-90	F4	6th	wall covering - plaster	lime-sand plaster	1	20.26	2.60	0.020	51.07	1.02	1800	1,838.45	1,838.45	plaster-based
MFH	1981-90	F4	6th	walls	gypsum board	1	22.20	2.60	0.070	48.90	3.42	732	2,505.55	2,505.55	gypsum-based
MFH	1981-90	F4	Roof	roof covering	gypsum board	1	n/a	n/a	0.010	296.51	2.97	732	2,170.45	2,170.45	gypsum-based
MFH	1981-90	F4	Roof	roof covering - pvc foil	pvc foil	1	n/a	n/a	0.001	296.51	0.30	1400	415.11	415.11	plastic-based
MFH	1981-90	F4	Roof	roof - battens	wood	37	0.03	0.05	19.850	0.002	0.03	455	13.55	501.26	wood-based
MFH	1981-90	F4	Roof	roof covering - thermal insulation	rock wool	1	n/a	n/a	0.100	296.51	29.65	160	4,744.16	4,744.16	stone-based
MFH	1981-90	F4	Roof	roof - beams	wood	2	0.12	0.14	19.850	0.02	0.33	455	151.73	303.47	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	8	0.12	0.14	2.000	0.02	0.03	455	15.29	122.30	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	2	0.12	0.12	19.850	0.01	0.29	455	130.06	260.11	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	2	0.10	0.14	19.850	0.01	0.28	455	126.44	252.89	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	20	0.18	0.24	1.7	0.04	0.07	455	33.42	663.29	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	20	0.10	0.14	2.2	0.01	0.03	455	14.01	278.18	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	31	0.10	0.14	1.200	0.01	0.02	455	7.64	235.44	wood-based
MFH	1981-90	F4	Roof	roof - beams	wood	40	0.10	0.14	6.300	0.01	0.09	455	40.13	1,593.20	wood-based
MFH	1981-90	F4	Roof	roof - boards	wood	1	n/a	n/a	0.025	296.51	7.41	455	3,372.80	3,372.80	wood-based
MFH	1981-90	F4	Roof	roof covering - water-proofing	bitumen	1	n/a	n/a	0.010	296.51	2.97	1500	4,447.65	4,447.65	bitumen-based
MFH	1981-90	F4	Roof	roof - battens	wood	64	0.048	0.033	3.200	0.002	0.01	455	2.31	147.60	wood-based
MFH	1981-90	F4	Roof	roof - battens	wood	84	0.048	0.033	3.200	0.002	0.01	455	2.31	193.73	wood-based
MFH	1981-90	F4	Roof	roof covering	fibre-cement sheets	1	n/a	n/a	0.012	296.51	3.56	1860	6,618.10	6,618.10	cement-based
MFH	1981-90	F4	Roof	gutters	sheet metal	1	60.00	0.2	0.001	12.00	0.01	7860	61.31	61.31	metal-based
MFH	1981-90	F5	B	base slab - gravel	gravel	1	n/a	n/a	0.150	282.50	42.38	1850	78,393.75	78,393.75	stone-based
MFH	1981-90	F5	B	base slab	concrete	1	n/a	n/a	0.100	282.50	28.25	2400	67,800.00	67,800.00	concrete-based
MFH	1981-90	F5	B	floor covering - water-proofing	bitumen	1	n/a	n/a	0.010	282.50	2.83	1500	4,237.50	4,237.50	bitumen-based
MFH	1981-90	F5	B	base slab	concrete	1	n/a	n/a	0.050	282.50	14.13	2400	33,900.00	33,900.00	concrete-based
MFH	1981-90	F5	B	base slab	reinf. concrete	1	n/a	n/a	0.400	282.50	113.00	2500	282,500.00	282,500.00	concrete-based
MFH	1981-90	F5	B	floor covering - sand	sand	1	n/a	n/a	0.400	282.50	113.00	1300	146,900.00	146,900.00	plaster-based
MFH	1981-90	F5	B	floor covering - tiles	concrete	1	n/a	n/a	0.100	282.50	28.25	2400	67,800.00	67,800.00	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F5	B	floor covering - screed	cement screed	1	n/a	n/a	0.050	282.50	14.13	2100	29,662.50	29,662.50	plaster-based
MFH	1981-90	F5	B	openings - window	glass	2	1.80	0.99	0.004	1.78	0.01	2580	18.39	36.78	glass-based
MFH	1981-90	F5	B	openings - window	glass	4	1.60	0.99	0.004	1.58	0.01	2580	16.35	65.39	glass-based
MFH	1981-90	F5	B	openings - window	glass	3	0.90	0.99	0.004	0.89	0.004	2580	9.20	27.59	glass-based
MFH	1981-90	F5	B	openings - window	glass	1	0.70	0.99	0.004	0.69	0.003	2580	7.15	7.15	glass-based
MFH	1981-90	F5	B	openings - window	glass	10	0.50	0.59	0.004	0.30	0.001	2580	3.04	30.44	glass-based
MFH	1981-90	F5	B	openings - window frame	steel	1	0.10	0.005	68.40	0.001	0.03	7860	268.81	268.81	metal-based
MFH	1981-90	F5	B	openings - door	glass	2	1.80	2.19	0.004	3.94	0.02	2580	40.68	81.36	glass-based
MFH	1981-90	F5	B	openings - door	glass	1	1.20	2.19	0.004	2.63	0.01	2580	27.12	27.12	glass-based
MFH	1981-90	F5	B	openings - door	glass	2	0.90	2.19	0.004	1.97	0.01	2580	20.34	40.68	glass-based
MFH	1981-90	F5	B	openings - door	glass	7	0.80	2.19	0.004	1.75	0.01	2580	18.08	126.56	glass-based
MFH	1981-90	F5	B	openings - door	plywood	6	0.51	2.09	0.012	1.06	0.013	427	5.45	32.69	wood-based
MFH	1981-90	F5	B	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	6.38	0.191	5.8	1.11	1.11	organic - misc.
MFH	1981-90	F5	B	openings - door frame	steel	1	0.10	0.005	64.760	0.001	0.03	7860	254.51	254.51	metal-based
MFH	1981-90	F5	B	openings - door frame	wood	1	0.09	0.31	28.080	0.03	0.78	455	356.46	356.46	wood-based
MFH	1981-90	F5	B	columns	reinf. concrete	7	0.25	0.25	2.600	0.06	0.16	2500	406.25	2,843.75	concrete-based
MFH	1981-90	F5	B	walls	reinf. concrete	1	105.95	2.60	0.250	261.04	65.26	2500	163,147.50	163,147.50	concrete-based
MFH	1981-90	F5	B	wall covering - thermal insulation	glass wool	1	105.95	2.60	0.050	261.04	13.05	130	1,696.73	1,696.73	glass-based
MFH	1981-90	F5	B	wall covering - plaster	lime-sand plaster	1	105.95	2.60	0.025	261.04	6.53	1800	11,746.62	11,746.62	plaster-based
MFH	1981-90	F5	B	wall covering - water-proofing	bitumen	1	105.95	2.60	0.010	261.04	2.61	1500	3,915.54	3,915.54	bitumen-based
MFH	1981-90	F5	B	walls	clay bricks	1	105.95	2.60	0.120	261.04	31.32	1800	56,383.78	56,383.78	clay-based
MFH	1981-90	F5	B	walls	reinf. concrete	1	60.85	2.60	0.250	137.63	34.41	2500	86,016.66	86,016.66	concrete-based
MFH	1981-90	F5	B	walls	reinf. concrete	1	8.60	2.60	0.150	22.36	3.35	2500	8,385.00	8,385.00	concrete-based
MFH	1981-90	F5	B	walls	reinf. concrete	1	60.85	2.60	0.250	138.28	34.57	2500	86,422.28	86,422.28	concrete-based
MFH	1981-90	F5	B	walls	clay bricks	1	19.05	2.60	0.120	37.89	4.55	1800	8,185.08	8,185.08	clay-based
MFH	1981-90	F5	B	stairs	reinf. concrete	16	0.30	0.175	1.400	0.03	0.04	2500	91.88	1,470.00	concrete-based
MFH	1981-90	F5	B	stairs	reinf. concrete	16	0.32	0.175	1.150	0.03	0.03	2500	80.50	1,288.00	concrete-based
MFH	1981-90	F5	B	stairs	reinf. concrete	16	0.30	0.175	1.400	0.03	0.04	2500	91.88	1,470.00	concrete-based
MFH	1981-90	F5	B	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.020	251.54	5.03	1800	9,055.44	9,055.44	plaster-based
MFH	1981-90	F5	B	slab	reinf. concrete	1	n/a	n/a	0.140	278.70	39.02	2500	97,545.00	97,545.00	concrete-based
MFH	1981-90	F5	Gf	floor covering - screed	cement screed	1	n/a	n/a	0.040	251.54	10.06	2100	21,129.36	21,129.36	plaster-based
MFH	1981-90	F5	Gf	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.010	94.44	0.94	1800	1,699.92	1,699.92	clay-based
MFH	1981-90	F5	Gf	floor covering - parquet	wood	1	n/a	n/a	0.012	157.10	1.89	455	857.77	857.77	wood-based
MFH	1981-90	F5	Gf	openings - window	glass	5	1.75	1.36	0.008	2.38	0.02	2580	49.12	245.62	glass-based
MFH	1981-90	F5	Gf	openings - window	glass	4	1.55	1.36	0.008	2.11	0.02	2580	43.51	174.04	glass-based
MFH	1981-90	F5	Gf	openings - window	glass	4	0.85	1.36	0.008	1.16	0.01	2580	23.86	95.44	glass-based
MFH	1981-90	F5	Gf	openings - window	glass	7	0.45	0.46	0.008	0.21	0.002	2580	4.27	29.91	glass-based
MFH	1981-90	F5	Gf	openings - window frame	steel	1	0.10	0.005	84.80	0.001	0.04	7860	333.26	333.26	metal-based
MFH	1981-90	F5	Gf	openings - door	glass	2	2.30	2.59	0.004	5.96	0.02	2580	61.48	122.95	glass-based
MFH	1981-90	F5	Gf	openings - door	glass	3	2.10	2.59	0.004	5.44	0.02	2580	56.13	168.39	glass-based
MFH	1981-90	F5	Gf	openings - door	glass	3	1.30	2.59	0.004	3.37	0.01	2580	34.75	104.24	glass-based
MFH	1981-90	F5	Gf	openings - door	glass	2	1.15	2.59	0.004	2.98	0.01	2580	30.74	61.48	glass-based
MFH	1981-90	F5	Gf	openings - door	glass	1	0.90	2.59	0.004	2.33	0.01	2580	24.06	24.06	glass-based
MFH	1981-90	F5	Gf	openings - door	plywood	1	0.80	2.09	0.012	1.67	0.02	427	8.57	8.57	wood-based
MFH	1981-90	F5	Gf	openings - door	plywood	10	0.51	1.99	0.012	1.01	0.01	427	5.19	51.87	wood-based
MFH	1981-90	F5	Gf	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	11.80	0.35	5.8	2.05	2.05	organic - misc.
MFH	1981-90	F5	Gf	openings - door frame	steel	1	0.10	0.005	79.960	0.001	0.04	7860	314.24	314.24	metal-based
MFH	1981-90	F5	Gf	openings - door frame	wood	1	0.09	0.31	44.800	0.03	1.25	455	568.71	568.71	wood-based
MFH	1981-90	F5	Gf	columns	reinf. concrete	11	0.25	0.25	2.850	0.06	0.18	2500	445.31	4,898.44	concrete-based
MFH	1981-90	F5	Gf	wall covering - plaster	lime-sand plaster	1	54.10	2.85	0.020	135.13	2.70	1800	4,864.50	4,864.50	plaster-based
MFH	1981-90	F5	Gf	walls	clay bricks	1	54.10	2.85	0.250	135.13	33.78	1800	60,806.25	60,806.25	clay-based
MFH	1981-90	F5	Gf	wall covering - thermal insulation	rock wool	1	54.10	2.85	0.030	135.13	4.05	160	648.60	648.60	stone-based
MFH	1981-90	F5	Gf	walls	clay bricks - facing	1	54.10	2.85	0.120	135.13	16.22	1300	21,079.50	21,079.50	clay-based
MFH	1981-90	F5	Gf	wall covering - plaster	lime-sand plaster	1	35.40	2.85	0.020	173.38	3.47	1800	6,241.54	6,241.54	plaster-based
MFH	1981-90	F5	Gf	walls	clay bricks	1	35.40	2.85	0.250	86.69	21.67	1800	39,009.60	39,009.60	clay-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F5	Gf	wall covering - plaster	lime-sand plaster	1	35.40	2.85	0.020	173.38	3.47	1800	6,241.54	6,241.54	plaster-based
MFH	1981-90	F5	Gf	walls	reinf. concrete	1	29.30	2.85	0.250	58.98	14.74	2500	36,860.00	36,860.00	concrete-based
MFH	1981-90	F5	Gf	walls	clay bricks	1	19.45	2.85	0.120	45.31	5.44	1800	9,786.74	9,786.74	clay-based
MFH	1981-90	F5	Gf	wall covering - plaster	lime-sand plaster	1	19.45	2.85	0.020	90.62	1.81	1800	3,262.25	3,262.25	plaster-based
MFH	1981-90	F5	Gf	stairs	reinf. concrete	5	0.20	0.28	1.450	0.03	0.04	2500	101.50	507.50	concrete-based
MFH	1981-90	F5	Gf	stairs	reinf. concrete	18	0.169	0.34	1.200	0.03	0.03	2500	86.42	1,555.50	concrete-based
MFH	1981-90	F5	Gf	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.020	251.54	5.03	1800	9,055.44	9,055.44	plaster-based
MFH	1981-90	F5	Gf	ceiling covering - thermal insulation	rock wool	1	n/a	n/a	0.100	64.14	6.41	160	1,026.24	1,026.24	stone-based
MFH	1981-90	F5	Gf	slab	clay blocks	4752	0.25	0.25	0.16	0.06	0.01	1000	10.00	47,524.24	clay-based
MFH	1981-90	F5	Gf	slab	concrete	1	n/a	n/a	0.04	278.70	11.15	2400	26,755.20	26,755.20	concrete-based
MFH	1981-90	F5	1st - 3rd	floor covering - sound insulation	cork panels	3	n/a	n/a	0.010	251.54	2.52	150	377.31	1,131.93	wood-based
MFH	1981-90	F5	1st - 3rd	floor covering - screed	cement-sand plaster	3	n/a	n/a	0.030	251.54	7.55	2100	15,847.02	47,541.06	plaster-based
MFH	1981-90	F5	1st - 3rd	floor covering - clay tiles	clay tiles	3	n/a	n/a	0.100	110.49	11.05	1800	19,888.20	59,664.60	clay-based
MFH	1981-90	F5	1st - 3rd	floor covering - parquet	wood	3	n/a	n/a	0.010	141.05	1.41	455	641.78	1,925.33	wood-based
MFH	1981-90	F5	1st - 3rd	openings - window	glass	9	1.15	1.36	0.008	1.56	0.01	2580	32.28	290.53	glass-based
MFH	1981-90	F5	1st - 3rd	openings - window	glass	15	1.10	1.36	0.008	1.50	0.01	2580	30.88	463.16	glass-based
MFH	1981-90	F5	1st - 3rd	openings - window	glass	12	0.85	1.36	0.008	1.16	0.01	2580	23.86	286.32	glass-based
MFH	1981-90	F5	1st - 3rd	openings - window	glass	6	0.65	1.36	0.008	0.88	0.01	2580	18.25	109.47	glass-based
MFH	1981-90	F5	1st - 3rd	openings - window	glass	33	0.45	0.46	0.008	0.21	0.002	2580	4.27	140.99	glass-based
MFH	1981-90	F5	1st - 3rd	openings - window frame	wood	3	0.08	0.07	256.20	0.006	1.43	455	652.80	1,958.39	wood-based
MFH	1981-90	F5	1st - 3rd	openings - door	glass	3	1.30	2.22	0.008	2.89	0.02	2580	59.57	178.70	glass-based
MFH	1981-90	F5	1st - 3rd	openings - door	glass	12	0.65	2.22	0.008	1.44	0.01	2580	29.78	357.40	glass-based
MFH	1981-90	F5	1st - 3rd	openings - door	plywood	12	0.81	1.89	0.012	1.53	0.02	427	7.82	93.88	wood-based
MFH	1981-90	F5	1st - 3rd	openings - door	plywood	24	0.71	2.57	0.012	1.82	0.02	427	9.33	223.96	wood-based
MFH	1981-90	F5	1st - 3rd	openings - door	plywood	27	0.61	2.57	0.012	1.56	0.02	427	8.02	216.47	wood-based
MFH	1981-90	F5	1st - 3rd	openings - door	plywood	12	0.51	2.57	0.012	1.31	0.02	427	6.70	80.44	wood-based
MFH	1981-90	F5	1st - 3rd	openings - door	cardboard (honeycomb)	3	n/a	n/a	0.030	39.99	1.20	5.8	6.96	20.88	organic - misc.
MFH	1981-90	F5	1st - 3rd	openings - door frame	wood	3	0.09	0.31	496.080	0.03	13.84	455	6,297.49	18,892.46	wood-based
MFH	1981-90	F5	1st - 3rd	columns	reinf. concrete	6	0.25	0.25	2.850	0.06	0.18	2500	445.31	2,671.88	concrete-based
MFH	1981-90	F5	1st - 3rd	wall covering - plaster	lime-sand plaster	3	6.50	2.85	0.020	13.63	0.27	1800	490.64	1,471.93	plaster-based
MFH	1981-90	F5	1st - 3rd	walls	clay bricks	3	6.50	2.85	0.250	13.63	3.41	1800	6,133.05	18,399.15	clay-based
MFH	1981-90	F5	1st - 3rd	wall covering - thermal insulation	rock wool	3	6.50	2.85	0.030	13.63	0.41	160	65.42	196.26	stone-based
MFH	1981-90	F5	1st - 3rd	walls	silicate bricks	3	6.50	2.85	0.120	13.63	1.64	1900	3,107.41	9,322.24	lime-sand-based
MFH	1981-90	F5	1st - 3rd	wall covering - plaster	lime-sand plaster	3	61.50	2.85	0.020	150.67	3.01	1800	5,424.19	16,272.58	plaster-based
MFH	1981-90	F5	1st - 3rd	walls	clay bricks	3	61.50	2.85	0.250	150.67	37.67	1800	67,802.40	203,407.20	clay-based
MFH	1981-90	F5	1st - 3rd	wall covering - thermal insulation	glass wool	3	61.50	2.85	0.030	150.67	4.52	130	587.62	1,762.86	glass-based
MFH	1981-90	F5	1st - 3rd	walls	clay bricks - facing	3	61.50	2.85	0.120	150.67	18.08	1300	23,504.83	70,514.50	clay-based
MFH	1981-90	F5	1st - 3rd	wall covering - plaster	cement-sand plaster	3	61.50	2.85	0.020	150.67	3.01	2100	6,328.22	18,984.67	plaster-based
MFH	1981-90	F5	1st - 3rd	walls	clay bricks	3	30.95	2.85	0.250	82.10	20.53	1800	36,945.05	110,835.14	clay-based
MFH	1981-90	F5	1st - 3rd	wall covering - plaster	lime-sand plaster	3	30.95	2.85	0.020	167.25	3.35	1800	6,021.14	18,063.42	plaster-based
MFH	1981-90	F5	1st - 3rd	walls	reinf. concrete	3	8.58	2.85	0.250	24.45	6.11	2500	15,283.13	45,849.38	concrete-based
MFH	1981-90	F5	1st - 3rd	walls	clay bricks	3	74.20	2.85	0.120	181.23	21.75	1800	39,145.39	117,436.17	clay-based
MFH	1981-90	F5	1st - 3rd	wall covering - plaster	lime-sand plaster	3	74.20	2.85	0.020	362.46	7.25	1800	13,048.46	39,145.39	plaster-based
MFH	1981-90	F5	1st - 3rd	stairs	reinf. concrete	54	0.06	0.34	1.200	0.01	0.01	2500	28.81	1,555.50	concrete-based
MFH	1981-90	F5	1st - 3rd	ceiling covering - plaster	lime-sand plaster	3	n/a	n/a	0.020	251.54	5.03	1800	9,055.44	27,166.32	plaster-based
MFH	1981-90	F5	1st - 3rd	ceiling covering - thermal insulation	rock wool	3	n/a	n/a	0.020	20.64	0.41	160	66.05	198.14	stone-based
MFH	1981-90	F5	1st - 3rd	slab	clay blocks	13495	0.25	0.25	0.16	0.06	0.01	1000	10.00	134,952.00	clay-based
MFH	1981-90	F5	1st - 3rd	slab	concrete	3	n/a	n/a	0.04	278.70	11.15	2400	26,755.20	80,265.60	concrete-based
MFH	1981-90	F5	1st - 4th	balcony - railings	steel	8	10.25	0.016	0.016	0.16	0.003	7860	20.62	165.00	metal-based
MFH	1981-90	F5	1st - 4th	balcony - railings	steel	410	0.84	0.016	0.016	0.01	0.0002	7860	1.69	692.99	metal-based
MFH	1981-90	F5	4th	floor covering - water-proofing	bitumen	1	n/a	n/a	0.010	20.64	0.21	1500	309.60	309.60	bitumen-based
MFH	1981-90	F5	4th	floor covering - terazzo	terazzo	1	n/a	n/a	0.030	20.64	0.62	2500	1,548.00	1,548.00	concrete-based
MFH	1981-90	F5	4th	floor covering - sound insulation	cork panels	1	n/a	n/a	0.010	230.90	2.31	150	346.35	346.35	wood-based
MFH	1981-90	F5	4th	floor covering - screed	cement screed	1	n/a	n/a	0.040	230.90	9.24	2100	19,395.60	19,395.60	plaster-based
MFH	1981-90	F5	4th	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.100	110.49	11.05	1800	19,888.20	19,888.20	clay-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F5	4th	floor covering - parquet	wood	1	n/a	n/a	0.010	120.41	1.20	455	547.87	547.87	wood-based
MFH	1981-90	F5	4th	openings - window	glass	2	1.25	1.36	0.008	1.70	0.01	2580	35.09	70.18	glass-based
MFH	1981-90	F5	4th	openings - window	glass	2	1.10	1.36	0.008	1.50	0.01	2580	30.88	61.75	glass-based
MFH	1981-90	F5	4th	openings - window	glass	6	0.85	1.36	0.008	1.16	0.01	2580	23.86	143.16	glass-based
MFH	1981-90	F5	4th	openings - window	glass	2	0.65	1.36	0.008	0.88	0.01	2580	18.25	36.49	glass-based
MFH	1981-90	F5	4th	openings - window	glass	11	0.45	0.46	0.008	0.21	0.002	2580	4.27	47.00	glass-based
MFH	1981-90	F5	4th	openings - window frame	wood	1	0.08	0.07	74.86	0.006	0.42	455	190.74	190.74	wood-based
MFH	1981-90	F5	4th	openings - door	glass	1	1.30	2.22	0.008	2.89	0.02	2580	59.57	59.57	glass-based
MFH	1981-90	F5	4th	openings - door	glass	4	0.65	2.22	0.008	1.44	0.01	2580	29.78	119.13	glass-based
MFH	1981-90	F5	4th	openings - door	plywood	4	0.81	1.89	0.012	1.53	0.02	427	7.82	31.29	wood-based
MFH	1981-90	F5	4th	openings - door	plywood	8	0.71	2.57	0.012	1.82	0.02	427	9.33	74.65	wood-based
MFH	1981-90	F5	4th	openings - door	plywood	9	0.61	2.57	0.012	1.56	0.02	427	8.02	72.16	wood-based
MFH	1981-90	F5	4th	openings - door	plywood	4	0.51	2.57	0.012	1.31	0.02	427	6.70	26.81	wood-based
MFH	1981-90	F5	4th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	39.99	1.20	5.8	6.96	6.96	organic - misc.
MFH	1981-90	F5	4th	openings - door frame	wood	1	0.09	0.31	165.360	0.03	4.61	455	2,099.16	2,099.16	wood-based
MFH	1981-90	F5	4th	wall covering - plaster	lime-sand plaster	1	48.92	2.80	0.020	128.99	2.58	1800	4,643.53	4,643.53	plaster-based
MFH	1981-90	F5	4th	walls	clay bricks	1	48.92	2.80	0.250	128.99	32.25	1800	58,044.15	58,044.15	clay-based
MFH	1981-90	F5	4th	wall covering - thermal insulation	glass wool	1	48.92	2.80	0.030	128.99	3.87	130	503.05	503.05	glass-based
MFH	1981-90	F5	4th	walls	clay bricks - facing	1	48.92	2.80	0.120	128.99	15.48	1300	20,121.97	20,121.97	clay-based
MFH	1981-90	F5	4th	wall covering - plaster	cement-sand plaster	1	48.92	2.80	0.020	128.99	2.58	2100	5,417.45	5,417.45	plaster-based
MFH	1981-90	F5	4th	walls	clay bricks	1	32.66	2.80	0.250	91.45	22.86	1800	41,151.60	41,151.60	clay-based
MFH	1981-90	F5	4th	wall covering - plaster	lime-sand plaster	1	32.66	2.80	0.020	182.90	3.66	1800	6,584.26	6,584.26	plaster-based
MFH	1981-90	F5	4th	walls	reinf. concrete	1	8.58	2.85	0.250	24.45	6.11	2500	15,283.13	15,283.13	concrete-based
MFH	1981-90	F5	4th	walls	clay bricks	1	74.20	2.85	0.120	177.59	21.31	1800	38,358.65	38,358.65	clay-based
MFH	1981-90	F5	4th	wall covering - plaster	lime-sand plaster	1	74.20	2.85	0.020	355.17	7.10	1800	12,786.22	12,786.22	plaster-based
MFH	1981-90	F5	4th	stairs	reinf. concrete	18	0.17	0.34	1.200	0.03	0.03	2500	86.42	1,555.50	concrete-based
MFH	1981-90	F5	4th	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.020	251.54	5.03	1800	9,055.44	9,055.44	plaster-based
MFH	1981-90	F5	4th	slab	clay blocks	4498	0.25	0.25	0.16	0.06	0.01	1000	10.00	44,984.00	clay-based
MFH	1981-90	F5	4th	slab	concrete	1	n/a	n/a	0.04	278.70	11.15	2400	26,755.20	26,755.20	concrete-based
MFH	1981-90	F5	Roof	roof covering - thermal insulation	rock wool	1	n/a	n/a	0.050	278.70	13.94	160	2,229.60	2,229.60	stone-based
MFH	1981-90	F5	Roof	roof covering - vapour barrier	PE foil	1	n/a	n/a	0.001	278.70	0.28	940	261.98	261.98	plastic-based
MFH	1981-90	F5	Roof	roof covering - screed	cement screed	1	n/a	n/a	0.030	278.70	8.36	2100	17,558.10	17,558.10	plaster-based
MFH	1981-90	F5	Roof	roof covering	fibre-cement sheets	1	n/a	n/a	0.010	369.90	3.70	1860	6,880.14	6,880.14	cement-based
MFH	1981-90	F5	Roof	roof covering - vapour barrier	PE foil	1	n/a	n/a	0.001	369.90	0.37	940	347.71	347.71	plastic-based
MFH	1981-90	F5	Roof	roof - battens	wood	74	0.03	0.05	12.590	0.0015	0.02	455	8.59	632.42	wood-based
MFH	1981-90	F5	Roof	roof - battens	wood	168	0.03	0.05	5.500	0.0015	0.01	455	3.75	630.13	wood-based
MFH	1981-90	F5	Roof	roof covering - thermal insulation	rock wool	1	n/a	n/a	0.120	369.90	44.39	160	7,102.08	7,102.08	stone-based
MFH	1981-90	F5	Roof	roof - beams	wood	1	0.17	0.2	75.54	0.03	2.57	455	1,168.60	1,168.60	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	12	0.17	0.2	2.00	0.03	0.07	455	30.94	371.28	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	8	0.08	0.14	3.60	0.01	0.04	455	18.35	146.76	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	8	0.08	0.14	3.15	0.01	0.04	455	16.05	128.42	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	8	0.08	0.14	3.40	0.01	0.04	455	17.33	138.61	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	2	0.08	0.14	1.80	0.01	0.02	455	9.17	18.35	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	16	0.10	0.12	1.10	0.01	0.01	455	6.01	96.10	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	8	0.10	0.12	1.10	0.01	0.01	455	6.01	48.05	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	31	0.10	0.14	6.72	0.01	0.09	455	42.81	1,347.33	wood-based
MFH	1981-90	F5	Roof	roof - beams	wood	31	0.10	0.14	5.14	0.01	0.07	455	32.74	1,030.55	wood-based
MFH	1981-90	F5	Roof	roof - boards	wood	1	n/a	n/a	0.03	369.90	9.25	455	4,207.61	4,207.61	wood-based
MFH	1981-90	F5	Roof	roof covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	369.90	0.03	929	27.49	27.49	bitumen-based
MFH	1981-90	F5	Roof	roof covering - copper sheets	copper sheets	1	n/a	n/a	0.0007	369.90	0.26	9000	2,330.37	2,330.37	copper-based
MFH	1981-90	F5	Roof	gutters	sheet metal	1	73.38	0.2	0.001	14.68	0.01	7860	74.98	74.98	metal-based
MFH	1981-90	F6	Gf1	base slab - gravel	gravel	1	n/a	n/a	0.100	634.41	63.44	1850	117,365.85	117,365.85	stone-based
MFH	1981-90	F6	Gf1	base slab	reinf. concrete	1	n/a	n/a	0.215	411.64	88.50	2500	221,256.50	221,256.50	concrete-based
MFH	1981-90	F6	Gf1	base slab	reinf. concrete	1	n/a	n/a	0.160	222.77	35.64	2500	89,108.00	89,108.00	concrete-based
MFH	1981-90	F6	Gf1	openings - window	glass	1	1.20	0.79	0.004	0.95	0.004	2580	9.78	9.78	glass-based

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MFH	1981-90	F6	Gf1	openings - window	glass	2	1.10	0.59	0.004	0.65	0.003	2580	6.70	13.40	glass-based
MFH	1981-90	F6	Gf1	openings - window	glass	1	0.80	0.59	0.004	0.47	0.002	2580	4.87	4.87	glass-based
MFH	1981-90	F6	Gf1	openings - window	glass	5	0.70	0.59	0.004	0.41	0.002	2580	4.26	21.31	glass-based
MFH	1981-90	F6	Gf1	openings - window frame	steel	1	0.10	0.005	19.66	0.001	0.01	7860	77.26	77.26	metal-based
MFH	1981-90	F6	Gf1	openings - door	glass	1	1.00	2.09	0.004	2.09	0.01	2580	21.57	21.57	glass-based
MFH	1981-90	F6	Gf1	openings - door	sheet metal	5	2.00	2.09	0.003	4.18	0.01	7860	98.56	492.82	metal-based
MFH	1981-90	F6	Gf1	openings - door	glass	1	1.10	2.09	0.003	2.30	0.01	2580	17.79	17.79	glass-based
MFH	1981-90	F6	Gf1	openings - door	sheet metal	4	0.90	2.09	0.003	1.88	0.01	7860	44.35	177.42	metal-based
MFH	1981-90	F6	Gf1	openings - door frame	steel	1	0.10	0.005	61.680	0.001	0.03	7860	242.40	242.40	metal-based
MFH	1981-90	F6	Gf1	walls	prefab. concrete	1	42.00	2.60	0.160	106.95	17.11	2500	42,781.60	42,781.60	concrete-based
MFH	1981-90	F6	Gf1	wall covering - thermal insulation	eps panels	1	42.00	2.60	0.060	106.95	6.42	53	340.11	340.11	polystyrene-based
MFH	1981-90	F6	Gf1	walls	prefab. concrete	1	42.00	2.60	0.060	106.95	6.42	2500	16,043.10	16,043.10	concrete-based
MFH	1981-90	F6	Gf1	walls	prefab. concrete	1	14.40	2.60	0.080	35.38	2.83	2500	7,075.00	7,075.00	concrete-based
MFH	1981-90	F6	Gf1	wall covering - thermal insulation	eps panels	1	14.40	2.60	0.060	35.38	2.12	53	112.49	112.49	polystyrene-based
MFH	1981-90	F6	Gf1	walls	prefab. concrete	1	14.40	2.60	0.060	35.38	2.12	2500	5,306.25	5,306.25	concrete-based
MFH	1981-90	F6	Gf1	walls	reinf. concrete	1	21.60	2.60	0.160	33.17	5.31	2500	13,268.00	13,268.00	concrete-based
MFH	1981-90	F6	Gf1	walls	eps panels	1	21.60	2.60	0.040	33.17	1.33	53	70.32	70.32	polystyrene-based
MFH	1981-90	F6	Gf1	walls	clay bricks - facing	1	21.60	2.60	0.120	33.17	3.98	1300	5,174.52	5,174.52	clay-based
MFH	1981-90	F6	Gf1	wall covering - plaster	termon plaster	1	20.40	2.60	0.020	52.57	1.05	280	294.38	294.38	plaster-based
MFH	1981-90	F6	Gf1	walls	reinf. concrete	1	20.40	2.60	0.190	52.57	9.99	2500	24,969.80	24,969.80	concrete-based
MFH	1981-90	F6	Gf1	wall covering - plaster	termon plaster	1	20.40	2.60	0.040	52.57	2.10	280	588.76	588.76	plaster-based
MFH	1981-90	F6	Gf1	walls	reinf. concrete	1	29.80	2.60	0.220	67.66	14.88	2500	37,211.35	37,211.35	concrete-based
MFH	1981-90	F6	Gf1	walls	reinf. concrete	1	47.00	2.60	0.160	122.20	19.55	2500	48,880.00	48,880.00	concrete-based
MFH	1981-90	F6	Gf1	stairs	reinf. concrete	16	0.30	0.175	1.070	0.03	0.03	2500	70.22	1,123.50	concrete-based
MFH	1981-90	F6	Gf1	stairs - railings	steel	1	4.20	0.16	0.16	0.6720	0.11	7860	845.11	845.11	metal-based
MFH	1981-90	F6	Gf1	stairs - railings	steel	42	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	70.99	metal-based
MFH	1981-90	F6	Gf1	stairs	reinf. concrete	12	0.30	0.18	2.600	0.03	0.07	2500	170.63	2,047.50	concrete-based
MFH	1981-90	F6	Gf1	stairs	reinf. concrete	13	0.30	0.18	2.400	0.03	0.06	2500	157.50	2,047.50	concrete-based
MFH	1981-90	F6	Gf1	stairs	reinf. concrete	11	0.30	0.18	2.100	0.03	0.06	2500	137.81	1,515.94	concrete-based
MFH	1981-90	F6	Gf1	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.020	365.14	7.30	1800	13,145.04	13,145.04	plaster-based
MFH	1981-90	F6	Gf1	ceiling covering - thermal insulation	eps panels	1	n/a	n/a	0.040	365.14	14.61	53	774.10	774.10	polystyrene-based
MFH	1981-90	F6	Gf1	slab	reinf. concrete	1	n/a	n/a	0.200	630.43	126.09	2500	315,215.00	315,215.00	concrete-based
MFH	1981-90	F6	Gf2	balcony - railings	prefab. concrete	4	3.50	1.20	0.090	4.20	0.38	2500	945.00	3,780.00	concrete-based
MFH	1981-90	F6	Gf2	balcony - railings	steel	8	1.67	0.16	0.160	0.27	0.04	7860	336.03	2,688.25	metal-based
MFH	1981-90	F6	Gf2	balcony - railings	steel	67	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	112.91	metal-based
MFH	1981-90	F6	Gf2	floor covering - sound insulation	cork panels	1	n/a	n/a	0.015	333.03	5.00	150	749.32	749.32	wood-based
MFH	1981-90	F6	Gf2	floor covering - PVC foil	pvc foil	1	n/a	n/a	0.001	333.03	0.33	1400	466.24	466.24	plastic-based
MFH	1981-90	F6	Gf2	floor covering - florbit	florbit	1	n/a	n/a	0.020	333.03	6.66	770	5,128.66	5,128.66	bitumen-based
MFH	1981-90	F6	Gf2	floor covering - vinyl-asbestsos tiles	vinyl-asbestos tiles	1	n/a	n/a	0.005	10.33	0.05	2152	111.15	111.15	plastic-based
MFH	1981-90	F6	Gf2	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.008	46.54	0.37	1800	670.18	670.18	clay-based
MFH	1981-90	F6	Gf2	floor covering - concrete tiles	concrete	1	n/a	n/a	0.040	288.96	11.56	2400	27,740.16	27,740.16	concrete-based
MFH	1981-90	F6	Gf2	floor covering - parquet	wood	1	n/a	n/a	0.01	286.49	2.86	455	1,303.53	1,303.53	wood-based
MFH	1981-90	F6	Gf2	openings - window	glass	2	5.05	1.35	0.008	6.82	0.05	2580	140.71	281.43	glass-based
MFH	1981-90	F6	Gf2	openings - window	glass	2	4.35	1.35	0.008	5.87	0.05	2580	121.21	242.42	glass-based
MFH	1981-90	F6	Gf2	openings - window	glass	5	1.05	1.35	0.008	1.42	0.01	2580	29.26	146.29	glass-based
MFH	1981-90	F6	Gf2	openings - window	glass	1	0.86	1.35	0.008	1.16	0.01	2580	23.96	23.96	glass-based
MFH	1981-90	F6	Gf2	openings - window frame	wood	1	0.18	0.08	52.82	0.01	0.76	455	346.08	346.08	wood-based
MFH	1981-90	F6	Gf2	openings - door	glass	1	8.00	2.59	0.004	20.72	0.08	2580	213.83	213.83	glass-based
MFH	1981-90	F6	Gf2	openings - door	glass	2	1.16	2.15	0.008	2.49	0.02	2580	51.48	102.95	glass-based
MFH	1981-90	F6	Gf2	openings - door	glass	1	1.10	2.59	0.004	2.85	0.01	2580	29.40	29.40	glass-based
MFH	1981-90	F6	Gf2	openings - door	glass	2	0.46	2.15	0.008	0.99	0.01	2580	20.41	40.83	glass-based
MFH	1981-90	F6	Gf2	openings - door	plywood	2	0.81	1.89	0.012	1.53	0.02	427	7.82	15.65	wood-based
MFH	1981-90	F6	Gf2	openings - door	plywood	4	0.71	1.89	0.012	1.34	0.02	427	6.86	27.43	wood-based
MFH	1981-90	F6	Gf2	openings - door	plywood	4	0.61	1.89	0.012	1.15	0.01	427	5.89	23.57	wood-based
MFH	1981-90	F6	Gf2	openings - door	plywood	5	0.51	1.89	0.012	0.96	0.01	427	4.93	24.63	wood-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F6	Gf2	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	17.81	0.53	5.8	3.10	3.10	organic - misc.
MFH	1981-90	F6	Gf2	openings - door frame	steel	1	0.10	0.005	28.56	0.001	0.01	7860	112.24	112.24	metal-based
MFH	1981-90	F6	Gf2	openings - door frame	wood	1	0.09	0.31	71.240	0.03	1.99	455	904.36	904.36	wood-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	1	25.40	2.60	0.160	64.88	10.38	2500	25,951.60	25,951.60	concrete-based
MFH	1981-90	F6	Gf2	wall covering - thermal insulation	eps panels	1	25.40	2.60	0.060	64.88	3.89	53	206.32	206.32	polystyrene-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	1	25.40	2.60	0.060	64.88	3.89	2500	9,731.85	9,731.85	concrete-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	1	14.60	2.60	0.080	25.88	2.07	2500	5,176.90	5,176.90	concrete-based
MFH	1981-90	F6	Gf2	wall covering - thermal insulation	eps panels	1	14.60	2.60	0.060	25.88	1.55	53	82.31	82.31	polystyrene-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	1	14.60	2.60	0.060	25.88	1.55	2500	3,882.68	3,882.68	concrete-based
MFH	1981-90	F6	Gf2	wall covering - plaster	termon plaster	1	18.60	2.60	0.020	48.36	0.97	280	270.82	270.82	plaster-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	1	18.60	2.60	0.190	48.36	9.19	2500	22,971.00	22,971.00	concrete-based
MFH	1981-90	F6	Gf2	wall covering - plaster	termon plaster	1	18.60	2.60	0.040	48.36	1.93	280	541.63	541.63	plaster-based
MFH	1981-90	F6	Gf2	walls	reinf. concrete	1	19.20	2.60	0.160	49.92	7.99	2500	19,968.00	19,968.00	concrete-based
MFH	1981-90	F6	Gf2	wall covering - thermal insulation	eps panels	1	19.20	2.60	0.040	49.92	2.00	53	105.83	105.83	polystyrene-based
MFH	1981-90	F6	Gf2	walls	clay bricks - facing	1	19.20	2.60	0.120	49.92	5.99	1300	7,787.52	7,787.52	clay-based
MFH	1981-90	F6	Gf2	walls	reinf. concrete	1	29.80	2.60	0.220	74.43	16.37	2500	40,934.47	40,934.47	concrete-based
MFH	1981-90	F6	Gf2	walls	reinf. concrete	1	32.70	2.60	0.160	85.02	13.60	2500	34,008.00	34,008.00	concrete-based
MFH	1981-90	F6	Gf2	walls	gypsum board	1	19.40	2.60	0.080	42.79	3.42	732	2,505.60	2,505.60	gypsum-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	2	11.02	2.60	0.080	26.73	2.14	2500	5,345.86	10,691.72	concrete-based
MFH	1981-90	F6	Gf2	walls	prefab. concrete	2	6.20	2.60	0.080	14.97	1.20	2500	2,994.03	5,988.06	concrete-based
MFH	1981-90	F6	Gf2	stairs	reinf. concrete	16	0.30	0.175	1.070	0.03	0.03	2500	70.22	1,123.50	concrete-based
MFH	1981-90	F6	Gf2	stairs - railings	steel	1	4.20	0.16	0.16	0.6720	0.11	7860	845.11	845.11	metal-based
MFH	1981-90	F6	Gf2	stairs - railings	steel	42	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	70.99	metal-based
MFH	1981-90	F6	Gf2	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.020	393.28	7.87	1800	14,158.08	14,158.08	plaster-based
MFH	1981-90	F6	Gf2	slab	reinf. concrete	1	n/a	n/a	0.165	406.14	67.01	2500	167,532.75	167,532.75	concrete-based
MFH	1981-90	F6	1st - 12th	balcony - railings	prefab. concrete	48	3.50	1.20	0.090	4.20	0.38	2500	945.00	45,360.00	concrete-based
MFH	1981-90	F6	1st - 12th	balcony - railings	steel	96	1.67	0.16	0.160	0.27	0.04	7860	336.03	32,258.95	metal-based
MFH	1981-90	F6	1st - 12th	balcony - railings	steel	802	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	1,354.88	metal-based
MFH	1981-90	F6	1st - 12th	floor covering - sound insulation	cork panels	12	n/a	n/a	0.015	365.20	5.48	150	821.70	9,860.40	wood-based
MFH	1981-90	F6	1st - 12th	floor covering - PVC foil	pvc foil	12	n/a	n/a	0.001	365.20	0.37	1400	511.28	6,135.36	plastic-based
MFH	1981-90	F6	1st - 12th	floor covering - florbit	florbit	12	n/a	n/a	0.020	365.20	7.30	770	5,624.08	67,488.96	bitumen-based
MFH	1981-90	F6	1st - 12th	floor covering - vinyl-asbestsos tiles	vinyl-asbestos tiles	12	n/a	n/a	0.005	50.03	0.25	2152	538.32	6,459.87	plastic-based
MFH	1981-90	F6	1st - 12th	floor covering - clay tiles	clay tiles	12	n/a	n/a	0.008	21.40	0.17	1800	308.16	3,697.92	clay-based
MFH	1981-90	F6	1st - 12th	floor covering - parquet	wood	12	n/a	n/a	0.01	293.77	2.94	455	1,336.65	16,039.84	wood-based
MFH	1981-90	F6	1st - 12th	openings - window	glass	192	1.16	1.35	0.008	1.57	0.01	2580	32.32	6,205.87	glass-based
MFH	1981-90	F6	1st - 12th	openings - window	glass	36	0.86	1.35	0.008	1.16	0.01	2580	23.96	862.67	glass-based
MFH	1981-90	F6	1st - 12th	openings - window frame	wood	12	0.12	0.008	1,122.96	0.001	1.08	455	490.51	5,886.11	wood-based
MFH	1981-90	F6	1st - 12th	openings - door	glass	48	1.16	2.15	0.008	2.49	0.02	2580	51.48	2,470.86	glass-based
MFH	1981-90	F6	1st - 12th	openings - door	plywood	60	0.81	1.89	0.012	1.53	0.02	427	7.82	469.41	wood-based
MFH	1981-90	F6	1st - 12th	openings - door	plywood	192	0.71	1.89	0.012	1.34	0.02	427	6.86	1,316.68	wood-based
MFH	1981-90	F6	1st - 12th	openings - door	plywood	96	0.61	1.89	0.012	1.15	0.01	427	5.89	565.62	wood-based
MFH	1981-90	F6	1st - 12th	openings - door	plywood	36	0.51	1.89	0.012	0.96	0.01	427	4.93	177.33	wood-based
MFH	1981-90	F6	1st - 12th	openings - door	cardboard (honeycomb)	12	n/a	n/a	0.030	41.13	1.23	5.8	7.16	85.88	organic - misc.
MFH	1981-90	F6	1st - 12th	openings - door frame	wood	12	0.09	0.31	1,971.600	0.03	55.01	455	25,028.48	300,341.71	wood-based
MFH	1981-90	F6	1st - 12th	walls	prefab. concrete	12	38.60	2.60	0.160	96.88	15.50	2500	38,750.80	465,009.60	concrete-based
MFH	1981-90	F6	1st - 12th	wall covering - thermal insulation	eps panels	12	38.60	2.60	0.060	96.88	5.81	53	308.07	3,696.83	polystyrene-based
MFH	1981-90	F6	1st - 12th	walls	prefab. concrete	12	38.60	2.60	0.060	96.88	5.81	2500	14,531.55	174,378.60	concrete-based
MFH	1981-90	F6	1st - 12th	walls	prefab. concrete	12	45.00	2.60	0.080	81.97	6.56	2500	16,393.60	196,723.20	concrete-based
MFH	1981-90	F6	1st - 12th	wall covering - thermal insulation	eps panels	12	45.00	2.60	0.060	81.97	4.92	53	260.66	3,127.90	polystyrene-based
MFH	1981-90	F6	1st - 12th	walls	prefab. concrete	12	45.00	2.60	0.060	81.97	4.92	2500	12,295.20	147,542.40	concrete-based
MFH	1981-90	F6	1st - 12th	walls	prefab. concrete	12	9.00	2.60	0.190	23.40	4.45	2500	11,115.00	133,380.00	concrete-based
MFH	1981-90	F6	1st - 12th	walls	reinf. concrete	12	30.60	2.60	0.220	71.93	15.82	2500	39,559.16	474,709.95	concrete-based
MFH	1981-90	F6	1st - 12th	walls	reinf. concrete	12	34.40	2.60	0.160	87.52	14.00	2500	35,006.92	420,083.04	concrete-based
MFH	1981-90	F6	1st - 12th	walls	gypsum board	12	52.09	2.60	0.080	114.21	9.14	732	6,688.07	80,256.88	gypsum-based
MFH	1981-90	F6	1st - 12th	walls	prefab. concrete	60	8.33	2.60	0.080	20.51	1.64	2500	4,101.63	246,097.80	concrete-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F6	1st - 12th	stairs	reinf. concrete	192	0.30	0.175	1.070	0.03	0.03	2500	70.22	13,482.00	concrete-based
MFH	1981-90	F6	1st - 12th	stairs - slab	reinf. concrete	12	1.07	4.20	0.100	4.49	0.45	2500	1,123.50	13,482.00	concrete-based
MFH	1981-90	F6	1st - 12th	stairs - railings	steel	12	4.20	0.16	0.16	0.6720	0.11	7860	845.11	10,141.29	metal-based
MFH	1981-90	F6	1st - 12th	stairs - railings	steel	504	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	851.87	metal-based
MFH	1981-90	F6	1st - 12th	ceiling covering - plaster	lime-sand plaster	12	n/a	n/a	0.020	393.28	7.87	1800	14,158.08	169,896.96	plaster-based
MFH	1981-90	F6	1st - 12th	slab	reinf. concrete	12	n/a	n/a	0.165	406.14	67.01	2500	167,532.75	2,010,393.00	concrete-based
MFH	1981-90	F6	Roof 1	roof covering - concrete	concrete	1	n/a	n/a	0.030	169.81	5.09	2400	12,226.32	12,226.32	concrete-based
MFH	1981-90	F6	Roof 1	roof covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	169.81	0.01	929	12.62	12.62	bitumen-based
MFH	1981-90	F6	Roof 1	roof covering - thermal insulation	eps panels	1	n/a	n/a	0.06	169.81	10.19	53	540.00	540.00	polystyrene-based
MFH	1981-90	F6	Roof 1	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	169.81	1.70	1500	2,547.15	2,547.15	bitumen-based
MFH	1981-90	F6	Roof 1	roof covering - sand	sand	1	n/a	n/a	0.03	169.81	5.09	1300	6,622.59	6,622.59	plaster-based
MFH	1981-90	F6	Roof 1	roof covering - concrete tiles	concrete	1	n/a	n/a	0.04	169.81	6.79	2400	16,301.76	16,301.76	concrete-based
MFH	1981-90	F6	13th	balcony - railings	prefab. concrete	3	3.50	1.20	0.090	4.20	0.38	2500	945.00	2,835.00	concrete-based
MFH	1981-90	F6	13th	balcony - railings	prefab. concrete	1	43.10	1.20	0.090	51.72	4.65	2500	11,637.00	11,637.00	concrete-based
MFH	1981-90	F6	13th	balcony - railings	steel	8	1.67	0.16	0.160	0.27	0.04	7860	336.03	2,688.25	metal-based
MFH	1981-90	F6	13th	balcony - railings	steel	67	0.02	0.016	0.840	0.0003	0.0002	7860	1.69	112.91	metal-based
MFH	1981-90	F6	13th	floor covering - sound insulation	cork panels	12	n/a	n/a	0.015	62.04	0.93	150	139.59	1,675.08	wood-based
MFH	1981-90	F6	13th	floor covering - PVC foil	pvc foil	12	n/a	n/a	0.001	62.04	0.06	1400	86.86	1,042.27	plastic-based
MFH	1981-90	F6	13th	floor covering - florbit	florbit	1	n/a	n/a	0.020	62.04	1.24	770	955.42	955.42	bitumen-based
MFH	1981-90	F6	13th	floor covering - screed	cement-sand plaster	1	n/a	n/a	0.020	133.66	2.67	2100	5,613.72	5,613.72	plaster-based
MFH	1981-90	F6	13th	floor covering - vinyl-asbestsos tiles	vinyl-asbestos tiles	1	n/a	n/a	0.005	10.43	0.05	2152	112.23	112.23	plastic-based
MFH	1981-90	F6	13th	floor covering - clay tiles	clay tiles	1	1.50	2.70	0.008	4.05	0.03	1800	58.32	58.32	clay-based
MFH	1981-90	F6	13th	floor covering - clay tiles	clay tiles	1	n/a	n/a	0.008	133.66	1.07	1800	1,924.70	1,924.70	clay-based
MFH	1981-90	F6	13th	floor covering - parquet	wood	1	n/a	n/a	0.01	47.56	0.48	455	216.40	216.40	wood-based
MFH	1981-90	F6	13th	openings - window	glass	7	1.16	1.35	0.008	1.57	0.01	2580	32.32	226.26	glass-based
MFH	1981-90	F6	13th	openings - window	glass	3	0.86	1.35	0.008	1.16	0.01	2580	23.96	71.89	glass-based
MFH	1981-90	F6	13th	openings - window frame	wood	1	0.12	0.008	48.40	0.001	0.05	455	21.14	21.14	wood-based
MFH	1981-90	F6	13th	openings - door	glass	2	1.16	2.15	0.008	2.494	0.02	2580	51.48	102.95	glass-based
MFH	1981-90	F6	13th	openings - door	glass	2	0.66	2.15	0.004	1.419	0.01	2580	14.64	29.29	glass-based
MFH	1981-90	F6	13th	openings - door	glass	6	0.56	2.15	0.004	1.204	0.005	2580	12.43	74.55	glass-based
MFH	1981-90	F6	13th	openings - door	plywood	1	0.81	1.89	0.012	1.527	0.02	427	7.82	7.82	wood-based
MFH	1981-90	F6	13th	openings - door	plywood	2	0.71	1.89	0.012	1.338	0.02	427	6.86	13.72	wood-based
MFH	1981-90	F6	13th	openings - door	plywood	2	0.61	1.89	0.012	1.150	0.01	427	5.89	11.78	wood-based
MFH	1981-90	F6	13th	openings - door	plywood	1	0.51	1.89	0.012	0.961	0.01	427	4.93	4.93	wood-based
MFH	1981-90	F6	13th	openings - door	cardboard (honeycomb)	1	n/a	n/a	0.030	7.465	0.22	5.8	1.30	1.30	organic - misc.
MFH	1981-90	F6	13th	openings - door frame	wood	1	0.09	0.31	76.580	0.028	2.14	455	972.14	972.14	wood-based
MFH	1981-90	F6	13th	walls	prefab. concrete	1	19.00	2.60	0.160	48.24	7.72	2500	19,295.60	19,295.60	concrete-based
MFH	1981-90	F6	13th	wall covering - thermal insulation	eps panels	1	19.00	2.60	0.060	48.24	2.89	53	153.40	153.40	polystyrene-based
MFH	1981-90	F6	13th	walls	prefab. concrete	1	19.00	2.60	0.060	48.24	2.89	2500	7,235.85	7,235.85	concrete-based
MFH	1981-90	F6	13th	walls	prefab. concrete	1	21.10	2.60	0.080	38.91	3.11	2500	7,782.00	7,782.00	concrete-based
MFH	1981-90	F6	13th	wall covering - thermal insulation	eps panels	1	21.10	2.60	0.060	38.91	2.33	53	123.73	123.73	polystyrene-based
MFH	1981-90	F6	13th	walls	prefab. concrete	1	21.10	2.60	0.060	38.91	2.33	2500	5,836.50	5,836.50	concrete-based
MFH	1981-90	F6	13th	walls	prefab. concrete	1	5.40	2.60	0.190	14.04	2.67	2500	6,669.00	6,669.00	concrete-based
MFH	1981-90	F6	13th	walls	reinf. concrete	1	28.80	2.60	0.160	73.72	11.80	2500	29,487.60	29,487.60	concrete-based
MFH	1981-90	F6	13th	wall covering - thermal insulation	eps panels	1	28.80	2.60	0.040	73.72	2.95	53	156.28	156.28	polystyrene-based
MFH	1981-90	F6	13th	walls	clay bricks - facing	1	28.80	2.60	0.120	73.72	8.85	1300	11,500.16	11,500.16	clay-based
MFH	1981-90	F6	13th	walls	reinf. concrete	1	14.80	2.60	0.220	37.28	8.20	2500	20,501.80	20,501.80	concrete-based
MFH	1981-90	F6	13th	walls	reinf. concrete	1	10.13	2.60	0.160	25.38	4.06	2500	10,150.66	10,150.66	concrete-based
MFH	1981-90	F6	13th	walls	gypsum board	1	17.80	2.60	0.080	39.22	3.14	732	2,296.63	2,296.63	gypsum-based
MFH	1981-90	F6	13th	walls	prefab. concrete	1	8.33	2.60	0.080	20.51	1.64	2500	4,101.63	4,101.63	concrete-based
MFH	1981-90	F6	13th	ceiling covering - plaster	lime-sand plaster	1	n/a	n/a	0.020	198.37	3.97	1800	7,141.32	7,141.32	plaster-based
MFH	1981-90	F6	13th	slab	reinf. concrete	1	n/a	n/a	0.165	212.80	35.11	2500	87,780.00	87,780.00	concrete-based
MFH	1981-90	F6	Roof 2	roof covering - concrete	concrete	1	n/a	n/a	0.030	212.80	6.38	2400	15,321.60	15,321.60	concrete-based
MFH	1981-90	F6	Roof 2	roof covering - vapour barrier	tar paper	1	n/a	n/a	0.00008	212.80	0.02	929	15.82	15.82	bitumen-based
MFH	1981-90	F6	Roof 2	roof covering - thermal insulation	eps panels	1	n/a	n/a	0.06	212.80	12.77	53	676.70	676.70	polystyrene-based

Type of building	Period of construction	National typology coding	Building element location	Building element function	Material type	Quantity (pcs.)	Dim. 1 (m)	Dim. 2 (m)	Dim. 3 (m)	Area (m^2)	Volume (m^3)	Vol. mass density (kg/m^3)	Mass per piece (kg)	Total mass (kg)	Material category
MFH	1981-90	F6	Roof 2	roof covering - water-proofing	bitumen	1	n/a	n/a	0.01	212.80	2.13	1500	3,192.00	3,192.00	bitumen-based
MFH	1981-90	F6	Roof 2	roof covering - gravel	gravel	1	n/a	n/a	0.04	212.80	8.51	1850	15,747.20	15,747.20	stone-based
MFH	1981-90	F6	Roof1-Roof2	gutters	sheet metal	1	162.00	0.2	0.001	32.40	0.02	7860	165.53	165.53	metal-based
MFH	1981-90	F6	1st - 13th	fire escape	steel	26	0.06	n/a	2.600	0.01	0.03	7860	208.49	5,420.62	metal-based
MFH	1981-90	F6	1st - 13th	fire escape	steel	338	0.33	0.85	0.010	0.14	0.0014	7860	11.02	3,725.99	metal-based
MFH	1981-90	F6	1st - 13th	fire escape - railings	steel	26	0.02	0.02	0.840	0.0003	0.0002	7860	1.69	43.95	metal-based
MFH	1981-90	F6	1st - 13th	fire escape - railings	steel	26	5.20	0.16	0.160	0.8320	0.13	7860	1,046.32	27,204.40	metal-based

Curriculum Vitae

Ana Nadaždi (née Nikolić) was born in Kruševac on December 1st, 1984. She completed elementary education in Aleksandrovac, followed by the Architectural Technical High School in Belgrade. She obtained her Diploma in the Construction Project Management programme at the Faculty of Civil Engineering Belgrade in 2010 with an average grade of 8.56 out of 10. In the same year, she began doctoral studies at the Faculty of Civil Engineering in Belgrade. During her doctoral studies in 2016, via the Erasmus+ student exchange programme, she spent four months at the University of the Aegean in Greece. By 2018 she passed all the exams from the doctoral programme with an average grade of 9.75.

Since March 2011, Ana has worked as a Contract Management Consultant for the Faculty of Civil Engineering in Belgrade on large and complex investment projects, including residential, non-residential, mixed-use, highways and industrial projects. She worked both for the Employer/Client and the Contractor and has gained hands-on experience with contracts, claims and variations preparation, evaluation, and negotiation.

Since September 2014, Ana has worked as a Teaching and Research Assistant at the Construction Project Management Department at the Civil Engineering Faculty in Belgrade. She teaches courses in Construction Management and Technology, Maintenance of Structures, Investment Project Management and Human Resource Management in the Construction Industry.

Her research interests involve ex-ante and ex-post analyses in the construction project management and the waste management domain. She particularly focuses on public-private partnerships in transport and cost-benefit analyses in the waste management sector. She authored and co-authored six manuscripts in journals listed in JCR and five conference proceedings related to this topic. Ana has also participated in one scientific project that analysed business models and funding schemes in transport infrastructure.

She speaks Serbian and English.

Statements

образац изјаве о ауторству

Изјава о ауторству

Име и презиме аутора Ана Надажди

Број индекса 910/10

Изјављујем

да је докторска дисертација под насловом

Модел за процену одрживости управљања отпадом од грађења и рушења засновани на принципима циркуларне економије

- резултат сопственог истраживачког рада;
- да дисертација у целини ни у деловима није била предложена за стицање друге дипломе према студијским програмима других високошколских установа;
- да су резултати коректно наведени и
- да нисам кршио/ла ауторска права и користио/ла интелектуалну својину других лица.

Потпис аутора

У Београду, 20.05.2022

образац изјаве о истоветности штампане и електронске верзије докторског рада

Изјава о истоветности штампане и електронске верзије докторског рада

Име и презиме аутора Ана Надажди

Број индекса 910/10

Студијски програм Докторске студије - грађевинарство

Наслов рада Модел за процену одрживости управљања отпадом од грађења и рушења засновам на принципима циркуларне економије

Ментор проф. др Ненад Иванишевић, дипл. инж. грађ., дипл. правник

Изјављујем да је штампана верзија мог докторског рада истоветна електронској верзији коју сам предао/ла ради похрањивања у **Дигиталном репозиторијуму Универзитета у Београду.**

Дозвољавам да се објаве моји лични подаци везани за добијање академског назива доктора наука, као што су име и презиме, година и место рођења и датум одбране рада.

Ови лични подаци могу се објавити на мрежним страницама дигиталне библиотеке, у електронском каталогу и у публикацијама Универзитета у Београду.

Потпис аутора

У Београду, 20.05.2022

образац изјаве о коришћењу

Изјава о коришћењу

Овлашћујем Универзитетску библиотеку „Светозар Марковић“ да у Дигитални репозиторијум Универзитета у Београду унесе моју докторску дисертацију под насловом:

Модел за процену одрживости управљања отпадом од грађења и рушења засновани на принципима циркуларне економије

која је моје ауторско дело.

Дисертацију са свим прилозима предао/ла сам у електронском формату погодном за трајно архивирање.

Моју докторску дисертацију похрањену у Дигиталном репозиторијуму Универзитета у Београду и доступну у отвореном приступу могу да користе сви који поштују одредбе садржане у одабраном типу лиценце Креативне заједнице (Creative Commons) за коју сам се одлучио/ла.

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(Молимо да заокружите само једну од шест понуђених лиценци.
Кратак опис лиценци је саставни део ове изјаве).

Потпис аутора

У Београду, 20.05.2022

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