Rammed Earth

Exploring the material's potential to address residential challenges within Central European suburbs.

research plan
aE Studio

Larissa Götze

Figure 1 [cover page]

The weather-exposed rammed earth facade of Haus Rauch in Schlins, Austria, after two years of erosion.

Keywords

rammed earth, circular building processes, prefabrication, local resources, simplicity, climate control, flexibility

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Studio

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Choice of Studio

My choice for the aE Graduation Studio originated from my interest in the very practical matters of today's building industry. Not only am I excited about the pool of technical knowledge provided by the tutors but also about having company of like-minded students during the graduation year.

Particularly aspects of sustainability and material exploration, and approaches of hands-on research and design enthuse me. During previous experiences at Tu Delft in more technology oriented courses, like the studio Bucky Lab, or the elective Circular Product Design, I noticed that I can find exactly these values within the Department of Architectural Engineering and Technology.

Furthermore, I found a similar understanding of architecture and mindset amongst the tutors, which I see as a great a starting point for the development of my graduation project and the communication. With the hope of also establishing relationships with the building industry for my thesis as well as for the upcoming professional years, I am thankful for the freedom to explore my very own fields of interest.

Contents

With my own roots located in Central Europe, and most of my years spent in its countries, I feel very much at home in this area of the world. Thus, it pains me to see that despite all urgency to contain man-made climate change, we commonly fall short of our goals, with predictions seeing the same for the coming years (Umweltbundesamt 2023, 75). As a citizen of this part of the world, I see my duty in finding out which possible alternatives to the current state are not fully exhausted yet and how we can achieve more, keeping the world a liveable place for all. This research plan is the first step towards exploring exactly one of those for a long time neglected opportunities, rammed earth, trying to identify its potential and unfold it to the best of my ability.

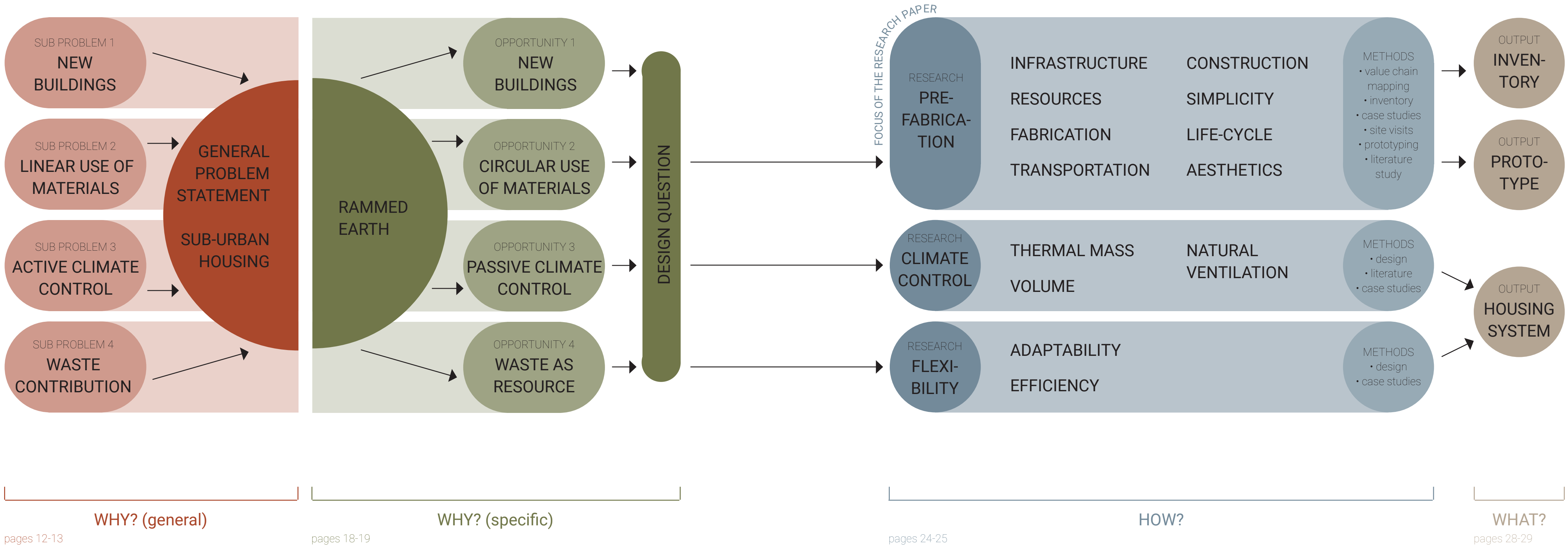

Figure 2
The diagram of the research structure.

General Problem Statement

Environmental Challenges in Sub-urban Housing

By now it is commonly known that the building sector plays a major role in the contribution to global CO_2 emissions. Pleasingly, the industry has witnessed a growing trend towards the adoption and refinement of sustainable and circular building practices. The potential, however, remains still largely untapped, as many fields within the housing development hold environmental problems (see Figure 4).

New buildings continue to emerge: particularly in sub-urban areas of Central Europe, there has been a surge in residential structure development (Dorffmeister 2023, 73), accompanied by an increasing rural flight leading to a heightened demand (BBSR 2016). Paradoxically, new dwellings have not necessarily eased the strain on the housing market. Many residential units remain unoccupied for extended periods, serving as second residences, Airbnb rentals, or requiring significant renovation (OECD Affordable Housing Database 2022). Simultaneously, others are inappropriately occupied, with some residents lacking space whilst others have surplus square meters (Eurostat 2022).

Next to the pressing requirement for greater flexibility in housing solutions to reduce the need for additional construction in general, the choice of resources and materials used in these new buildings must undergo a transformation. The initial costs of sustainable alternatives, coupled with a lack of familiarity with environment-friendly and circular building methods amongst both professionals and clients, have led to the continued application of carbon-intensive and non-circular forms of building (International Energy Agency 2018, 45). A significant portion

of these resources ultimately becomes waste, contributing to a staggering 55,4% building related waste of the total mass (see Figure 3). Whilst there already are certain r-strategies in place to facilitate the recycling of some parts, a substantial 56,3% of the building waste, which consists of non-hazardous soil excavations from building sites, remains largely underutilized (Statistisches Bundesamt 2022, 34).

In addition to the embodied energy contained within building materials' life cycles, operational energy and associated emissions can account for up to 75% of the total consumption and output of a new building, depending on the construction type and efficiency standards (Gebäudeforum Klimaneutral 2022). These multifaceted challenges necessitate a comprehensive examination and transformation of construction practices to move towards a more sustainable and circular built environment.

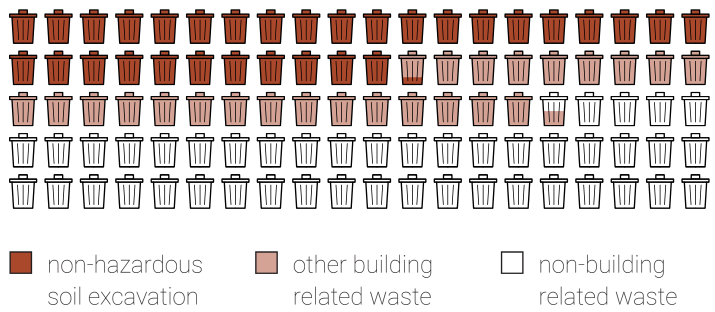

Figure 3
The waste balance of Germany in 2020, compared in weight.

CAUSE 1

significant increase in population in urban and sub-urban areas of around 5,4% between 2001 and 2011
(BBSR 2016)

2

wrong occupancy of existing dwellings, with 17% of the EU population living in overcrowded, and 34% in underoccupied homes
(Eurostat 2022)

3

urban dwelling vacancy rates of 4% and more
(OECD Affordable Housing Database 2022, 3)

SUB PROBLEM 1
NEW BUILDINGS

constant erection of new residential buildings in Europe with around 3,5 dwelling units per year and 1000 inhabitants
(Dorffmeister 2023, 74)

CAUSE 1

higher initial costs of green buildings, with observed differences to conventional methods of 6,5%
(Chegut, Eichholtz, and Kok 2019 ,15)

2

unfamiliarity with sustainable building methods amongst professionals, with only every fifth European respondent of a study previously being involved in a green project
(WBCSD 2007 ,19)

SUB PROBLEM 2
LINEAR USE OF MATERIALS

predominant use of CO_2- and energy intensive, and not circular usable building materials, e.g. concrete for almost 60% of European residential buildings (International Energy Agency 2018, 45)

CAUSE 1

global warming causes more heat waves, which relate to over 85% of human fatalities
(European Environment Agency 2022, 3)

2

mostly active instead of passive climate strategies, air conditioning present in 20% of houses
(European Environment Agency 2022, 5)

3

majority of buildings constructed before thermal standards, nearly 75% is energy inefficient
(European Environment Agency 2022, 4)

SUB PROBLEM 3
ACTIVE CLIMATE CONTROL

much energy used for cooling and heating residential buildings, e.g. the amount for cooling tripled between 2010 and 2019
(European Environment Agency 2022, 5)

CAUSE 1

non-hazardous soil excavations, mostly considered waste, make up for 56,3% of building waste
(Statistisches Bundesamt 2022, 34)

2

other 43,7% of building waste are materials that are not being used in a circular manner
(Statistisches Bundesamt 2022, 34)

SUB PROBLEM 4
WASTE CONTRIBUTION

high waste contribution of the building sector, in Germany with 55,4% of the total
(Statistisches Bundesamt 2022, 34)

GENERAL PROBLEM STATEMENT

SUB-URBAN HOUSING

Figure 4
The different sub-problems within the problem statement and their causes, of which the research focuses are highlighted.

Design

Rammed Earth Housing System

Objective

The design aims to formulate an answer to the challenges outlined in the general problem statement (see Figure 8). In this context, especially rammed earth offers promising opportunities that motivate further in-depth exploration. Empirical data, showing that most newly erected multi-family residential buildings have four stories or less, underscore the material's inherent potential (see Figure 5). Rammed earth readily accommodates the construction of load-bearing walls of this height, seen for instance in the six storey high residential building in Weilburg, Germany. Consequently, the aim of the design extends beyond a region-specific solution, creating an alternative system to the prevailing residential construction methods found in Central Europe, whilst offering an aesthetically adequate response to the already existing surrounding sub-urban context.

Within the broader framework of establishing a housing system, four distinct objectives arise: Firstly, the housing system shall incorporate elements of flexibility and adaptability, improving the irregular building occupancy to eventually lower the need for new construction. Building less already results in a more purposeful utilization of materials. Nevertheless, also a more affordable and practicable use of rammed earth within the housing system shall be achieved by reducing highly specialised labour and the time of construction, as second objective. Thirdly, the material's already inherited beneficial properties of thermal mass and vapour

openness shall contribute to maximize passive climate control, thereby reducing the operational energy. Lastly, an advantage of rammed earth lies in its independence of primary resources. Accordingly, the objective encompasses the utilization of secondary resource soil excavations wherever feasible, extending to ensure that all materials used for the design are used in a way that enables a circular life-cycle.

Design Question

The guiding question for the design will be: How can a housing system out of rammed earth present an aesthetic solution to current challenges of multi-storey residential buildings within the sub-urban environments of Central Europe, whilst allowing for optimum occupancy to lower the future need for new buildings?

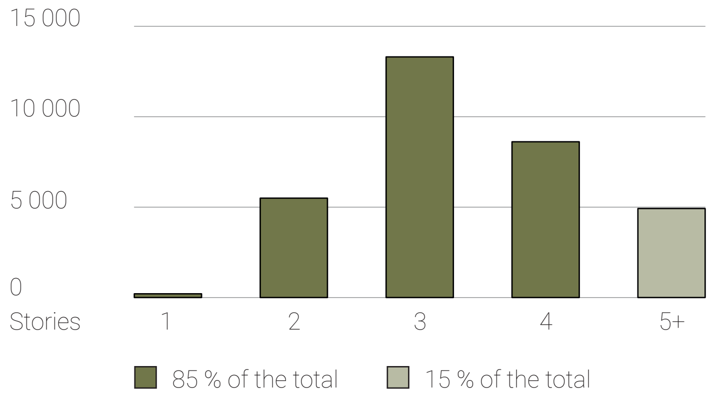

Figure 5
Number of new multi-family residential houses in Switzerland 2022, structured in number of stories.

Reflection on the Relevance

As mentioned earlier, a significant amount of new, low-rise buildings, typically constructed with non-sustainable materials, could potentially be substituted with rammed earth. The numerous advantages of the material are recognized, primarily although only within the communities that already engage a lot with topics of sustainability or earthen materials. Due to the lack of familiarity and the material's niche presence in the built environment, misconceptions and concerns often persist. The design of a versatile housing system aspires to disseminate knowledge widely and raise awareness of the possibilities. Simultaneously, it seeks to address the existing challenges that hinder the widespread adoption of rammed earth.

> *"In our part of the world, where labour is particularly expensive, manually crafted earth building is practically a luxury product. In countries where labour is readily available, for example, in Egypt, my house in Schlins would have been approximately 60 per cent cheaper and could even be a kind of standard dwelling!"*

Martin Rauch
(Sauer and Kapfinger 2015, 10)

On a societal level, the design aims to contribute to a decrease of CO_2 emissions and towards more circular building solutions, especially within sub-urban areas (see Figure 6). Of special interest in these areas are also their usually more urban aesthetics, that housing systems need to fit in. This poses another relevant design task, which rammed earth structures are just in the process of exploring (see Figure 7).

From a user point of view, the investigation of methods and designs that make the material more accessible is very much needed: lower prices could motivate investors and clients to consider rammed earth more often in their selection of materials, and advancements in the practicability make it more attractive to professionals.

Figure 6
The sub-urban city of Dornbirn, Austria, with a density of 412 inhabitants per km² (Statistik Austria 2020).

Figure 7
The Ofentum Ziegelei-Museum in Cham, Switzerland, was constructed out of 91 prefabricated rammed earth elements.

Figure 8
To each sub problem, the material rammed earth reflects an opportunity, whilst still holding challenges.

Thematic Research

Prefabrication of Rammed Earth

Objective

In order to allow for a more common use of rammed earth, particularly the high amount of specialized labour and labour in general needs to decrease. As identified before, those are key factors to lower the costs of rammed earth buildings. Prefabrication offers one economic solution to reduce the amount of necessary labour, ease up the building process, whilst allowing for higher quality (Sauer and Kapfinger 2015, 118). Specific advantages are, for instance, the possibility to work all year around, shorter construction schedules, and better automated processes. Nevertheless, obstacles exist as well: The drying process of rammed earth comprises adverse effects, such as a long duration. This enlarges the required storage area and therefore minimizes the efficiency of the production site. Artificial ventilation systems solve this issue but increase the used energy in the life-cycle (Schroeder 2019, 167). Also the transport of the massive construction, when produced off-site, impairs the CO_2 balance, makes it less local, and adds on to the expenses (Morel and Charef 2019, 5).

Within the opportunities and challenges of prefabricated rammed earth, the right balance between off-site prefabrication, automated processes on site, and local labour has to be found, as it always informs the design. As the main objective of the thematic research paper, the most promising path has to be determined. This involves not only the assessment of existing methods but also the exploration of

innovative approaches that may emerge. As depicted in Figure 11, the investigation will cover many aspects to allow for in-depth research. This will serve as a basis for the design of the housing system and its constituent elements, which will already be touched during this phase.

In addition to the primary objective, the topics of climate control and adaptability hold significant importance in shaping the later design, necessitating additional research. However, most of this will run in parallel with the design phase since it directly informs and guides the design process.

Research Questions

The guiding question for the research paper will be: How can advancements in rammed earth prefabrication improve the efficiency, circularity, and practicability of the material?

Two further research questions relate closely to the design and will only incidentally be covered in the research paper, of which is one: Which elements of passive climate control can be incorporated in rammed earth designs?

The other, primarily design related question is: How can massive structures allow for flexibility within their floorplans and the material?

Reflection on the Relevance

In recent years, notable advancements have been made in the prefabrication of rammed earth using various approaches. For example, Erden erected a factory building, enhancing both quantity and quality in prefabrication (see Figure 9), while Le Pisé, a French company, relies on on-site automated processes (see Figure 10). Nevertheless, an investigation of different methods on a broader, more comprehensive scale is yet to be done. This allows for comparability and paves the way for the optimal method. This, in turn, facilitates a wider and more practical application of the material.

Methodology

To enable a systematic comparison of various production methods, a detailed mapping of them, including the different value chains they involve, is imperative. Additionally, the methodology will encompass the collection of quantitative data, such as distances, required manpower, and more. This will involve a thorough analysis of existing buildings, as well as engagement with studies, research projects, and visits to manufacturing sites. Conversations with industry professionals will contribute to creating a coherent understanding of existing possibilities and future potentials, forming an assumed baseline to inform the later design.

On an element level, a similar approach will involve an investigation of existing designs to provide an overview and better comprehension of the material's requirements. Participation in workshops will facilitate hands-on experience with the material, aiding in understanding its specifications and laying the groundwork for personal experimentation and prototyping of rammed earth elements. This will also inform preliminary concepts for the later housing system.

In both cases, the backbone of the research will be technical literature, serving as a vital resource for gathering knowledge and insights.

Figure 9
The factory building of Erden in Schlins, Austria, for mechanically supported prefabrication of rammed earth elements.

Figure 10
The on-site production line for rammed earth elements, used by Le Pisé.

Figure 11
The thematic research themes, sub themes, and methods.

Expected Results

Output, Planning

Output

The thematic research comprises two consecutive main objectives. In the initial phase, the goal is to establish a comprehensive and comparable inventory of the current state of the art in the realm of rammed earth prefabrication in the form of value chains. To do so, sub-activities of the primary activities will be identified, followed by sub-activities of these secondary activities. Finding links between these individual activities will serve as a basis to evaluate the most efficient and practicable techniques, and to discover opportunities to increase value or decrease cost.

Following this foundational research, the second phase will entail prototyping, aiming to create functional prefabricated elements. This will by carried out by exploring the implementation of the chosen method of prefabrication in an element or elements, which will be part of the housing system. This component too, will aim for maximum practicability and efficiency and already think about ways of construction. The ease of assembly and potential cost savings by the amount of necessary labour will be considered as indicators of success.

In the beginning of the research phase, appropriate parameters will be determined, that allow for a quantitative comparison.

Planning

Within the first two quarters of the graduation year 2023/24, the focus is set on getting as much external input as possible, to allow for the acquisition of fundamental knowledge. In the form of studio visits, a workshop, and an online course, presumably sufficient know-how is gathered to start own tests in prototyping.

The last two quarters will focus on the design, whilst some research is still scheduled in the beginning to cover the mainly design related research themes like climate control and flexibility (see Figure 12).

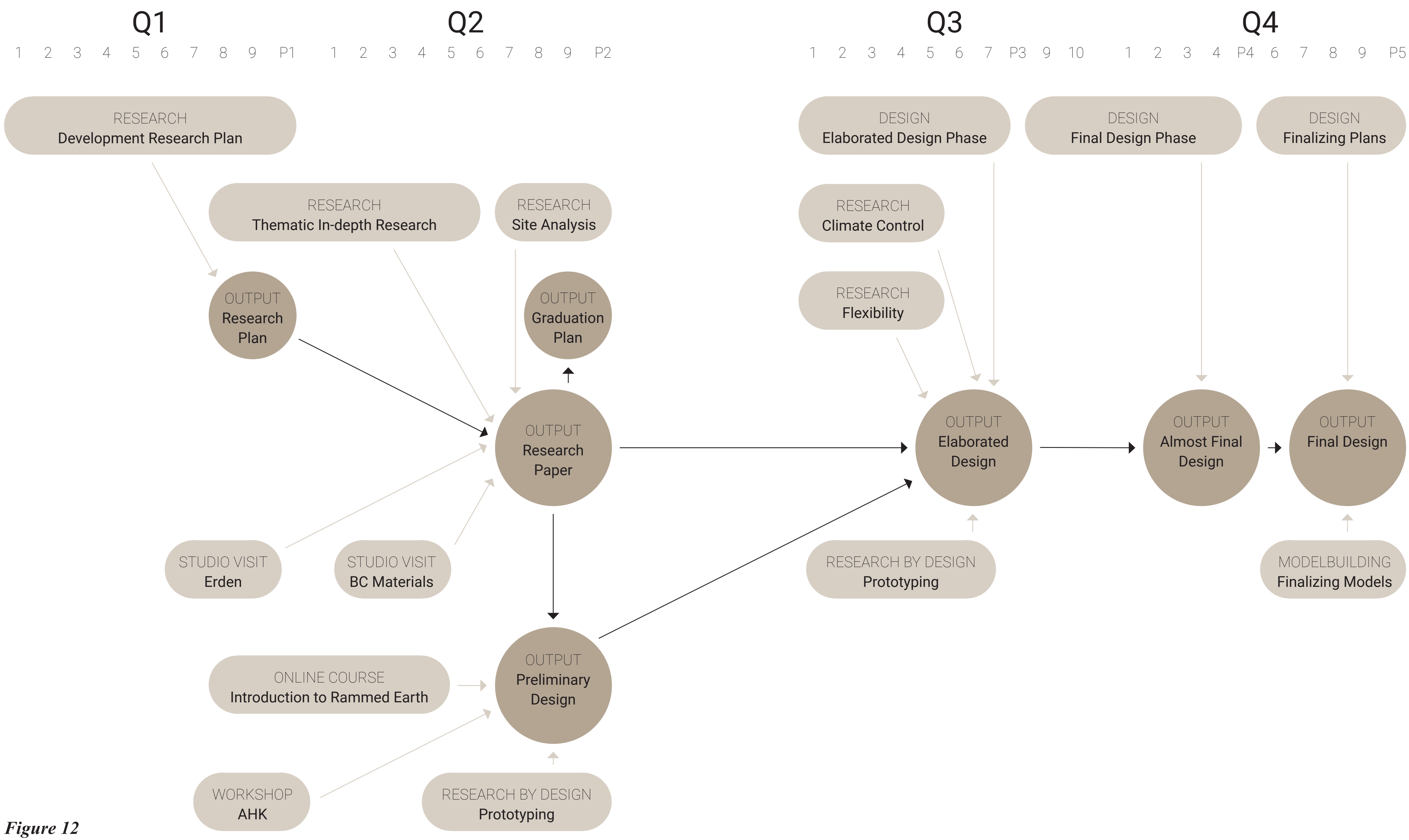

Figure 12

The aspired outputs and the planning of MSc3 and MSc4.

Appendix
Literature References

Books:

Boltshauser, Roger. 2019. *Pisé - Rammed Earth : Tradition and Potential*. Zürich: Triest Verlag für Architektur, Design und Typografie.

Minke, Gernot. 2013. *Building with Earth : Design and Technology of a Sustainable Architecture.* Basel: Birkhäuser. https://doi.org/10.1515/9783034608725.

Sauer, Marko, and Otto Kapfinger, eds. 2015. *Refined Earth: Construction and Design with Rammed Earth.* München: Detail. http://ebookcentral.proquest.com/lib/delft/detail.action?docID=4332914.

Schroeder, Horst. 2019. *Lehmbau : Mit Lehm ökologisch planen und bauen*. Wiesbaden : Springer Vieweg. https://doi.org/10.1007/978-3-658-23121-7.

Databases:

BBSR. 2016. “Wo die Bevölkerung in Europa wächst und wo sie schrumpft.” Accessed October 04, 2023. https://www.bbsr.bund.de/BBSR/DE/themen/_alt/Raumentwicklung/RaumentwicklungEuropa/Projekte/Bevoelkerungsentwicklung/Bevoelkerungsentwicklung.html.

Bundesamt für Statistik. 2023. "Gebäude nach Gebäudekategorie sowie Bauperiode und Geschosszahl." Accessed October 19, 2023. https://www.bfs.admin.ch/bfs/de/home/statistiken/bau-wohnungswesen/gebaeude/groesse.assetdetail.27585128.html

Eurostat. 2022. “Housing in Europe: Quality of Housing.” Accessed October 05, 2023. https://ec.europa.eu/eurostat/cache/digpub/housing/bloc-1c.html?lang=en.

OECD Affordable Housing Database. 2022. "Housing Market: HM1.1 Housing stock and construction." Accessed October 05, 2023. https://www.oecd.org/housing/data/affordable-housing-database/housing-market.htm.

Statistik Austria. 2020. "Fläche und Flächennutzung bzw. Bevölkerungsdichte." Accessed October 22, 2023. https://www.statistik.at/blickgem/G0101/g80301.pdf

Journal Articles:

Chegut, Andrea, Piet Eichholtz, and Nils Kok. 2019. "The Price of Innovation: An Analysis of the Marginal Cost of Green Buildings." *Journal of Environ-*

mental Economics and Management 98 (November): 102248. https://doi.org/10.1016/j.jeem.2019.07.003.

Dorffmeister, Ludwig. 2023. "Europäisches Bauvolumen wird bis 2024 moderat schrumpfen: Ausgewählte Ergebnisse der EUROCONSTRUCT-Sommerkonferenz 2023." *ifo Schnelldienst* 76, no. 7: 72-75. https://www.ifo.de/publikationen/2023/aufsatz-zeitschrift/europaeisches-bauvolumen-wird-bis-2024-moderat-schrumpfen.

Morel, Jean-Claude, and Rabia Charef. 2019. "What are the barriers affecting the use of earth as a modern construction material in the context of circular economy?." *IOP Conference Series: Earth and Environmental Science* 225, no. 012053. 10.1088/1755-1315/225/1/012053.

Norms:

Dachverband Lehm. *Lehmbau Regeln: Begriffe - Baustoffe - Bauteile*. 2008. Wiesbaden: Vieweg+Teubner.

Reports:

European Environment Agency. 2022. *Cooling buildings sustainably in Europe: exploring the links between climate change mitigation and adaptation, and their social impacts.* https://data.europa.eu/doi/10.2800/36810

International Energy Agency. 2018. *2018 Global Status Report: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.* https://wedocs.unep.org/20.500.11822/27140.

Rhomberg, Clarissa, Franziska Möhrle, and Sami Akkach, eds. 2023. *ERDEN Wohnen Forschungsprojekt: Leben in 100% Erde*. https://www.erden.at/ERDEN-Wohnen.

Statistisches Bundesamt. 2022. *Umwelt: Abfallbilanz (Abfallaufkommen/-verbleib, Abfallintensität, Abfallaufkommen nach Wirtschaftszweigen): 2020.* https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/Publikationen/Downloads-Abfallwirtschaft/abfallbilanz-pdf-5321001.pdf?__blob=publicationFile

Umweltbundesamt 2023. *Projektionsbericht 2023 für Deutschland*. https://www.umweltbundesamt.de/publikationen/projektionsbericht-2023-fuer-deutschland.

United Nations Environment Programme. 2022. *2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.* https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction.

WBCSD. 2007. *Energy Efficiency in Buildings: Business realities and opportunities*. http://docs.wbcsd.org/2007/10/EEB_FactsTrends-Summary.pdf.

Websites:

Gebäudeforum Klimaneutral. 2022. "Graue Energie und Emissionen." Accessed October 13, 2023. https://www.gebaeudeforum.de/wissen/ressourcen-und-emissionen/graue-energie-und-emissionen/.

Appendix
List of Figures