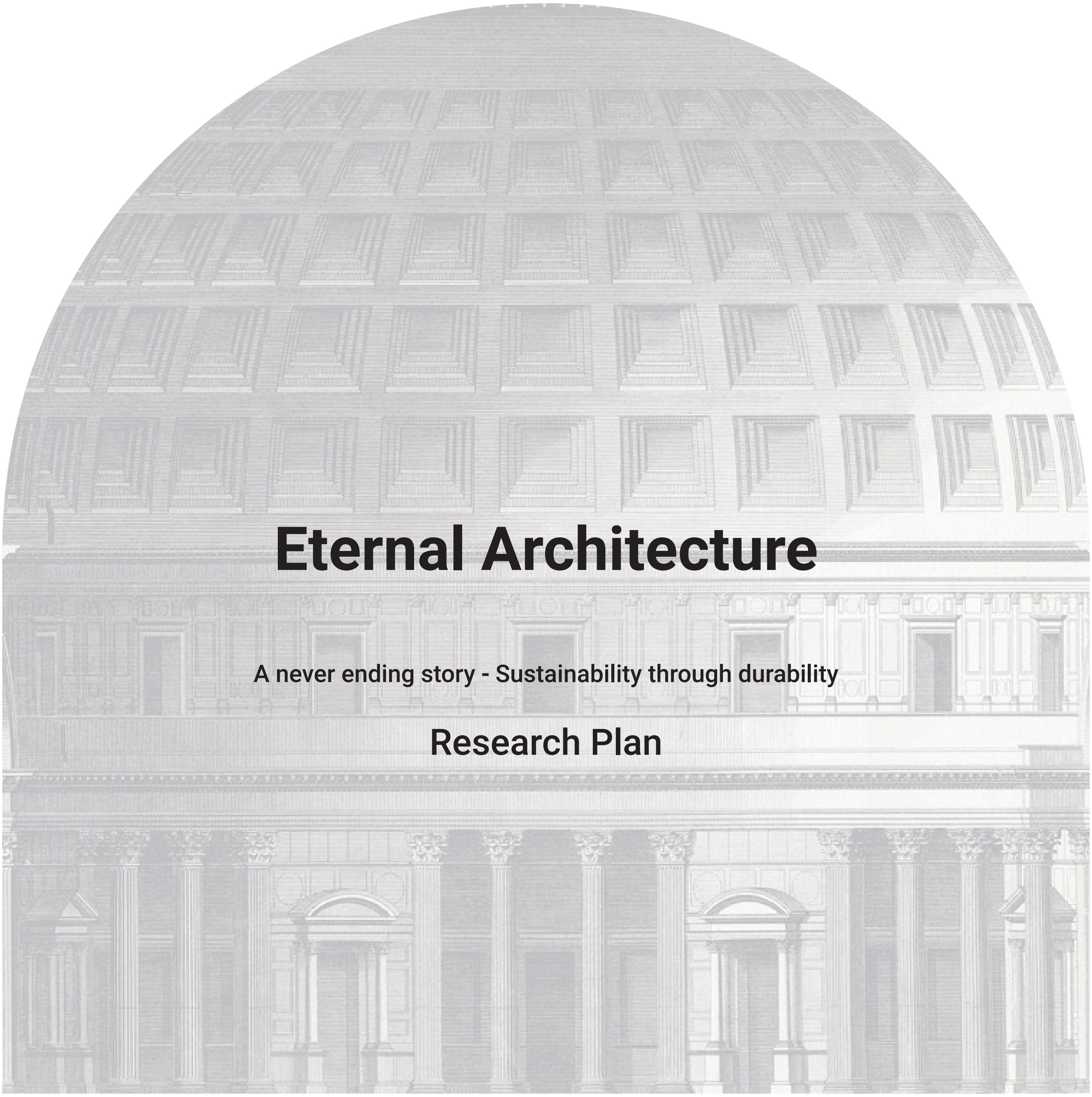

Eternal Architecture

A never ending story - Sustainability through durability

Research Plan

Architectural Engineering
Graduation Studio 2023/24

by Lorenz Eschke

Delft University of Technology
Faculty of Architecture
and the Built Environment

This document is to be read side-by-side with a separate cover page.

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Keywords

Embodied Carbon [EC]

Adaptability

Durability

Eternal elements
+
Temporal elements

Long living
Structures

Future Challenges

Global CO^2 Emissions by Sector

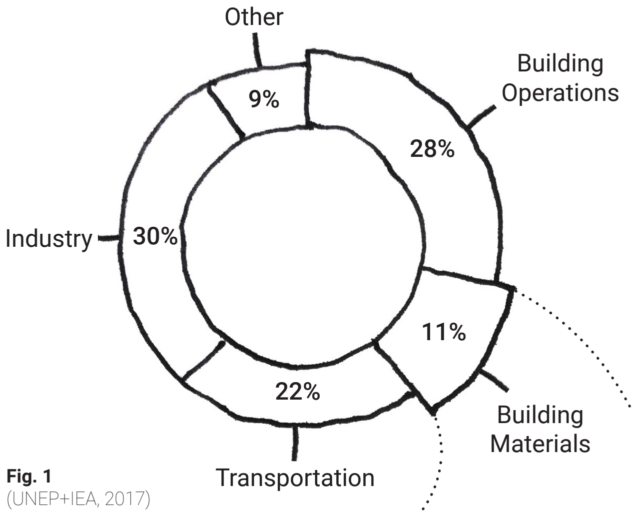


Fig. 1
(UNEP+IEA, 2017)

Embodied Carbon (EC) per Building Element

Case Study 1 - Office Building

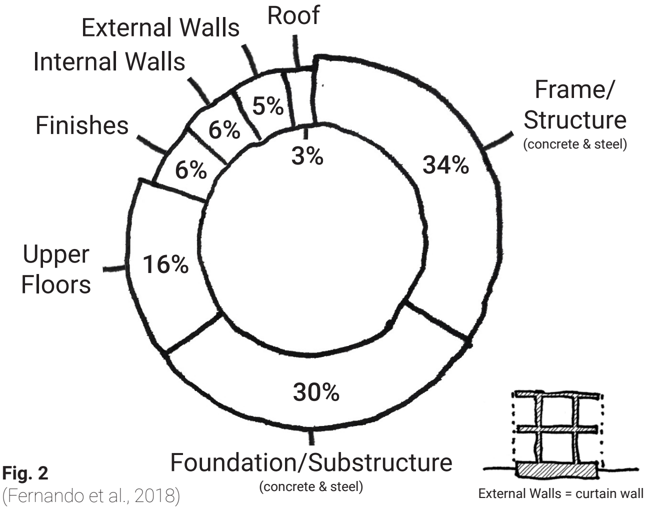


Fig. 2
(Fernando et al., 2018)

Case Study 2 - Apartment Building

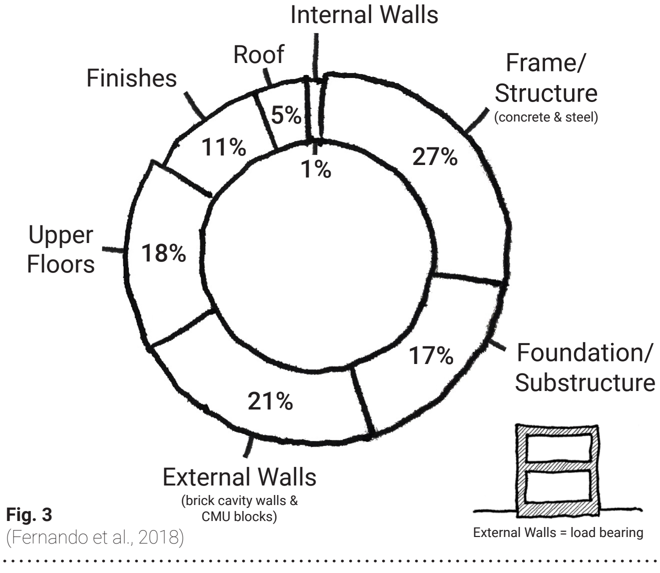


Fig. 3
(Fernando et al., 2018)

Problem Statement

1. Embodied Carbon

The construction industry plays a significant role in causing the climate crisis, accounting for 39% of global CO^2 emissions per sector. Of this, the so-called operational carbon (OC) is the larger part with 28% (Fig. 1). The OC emitted during the service life of buildings through use (e.g. heating, electricity, etc.) or maintenance of the building. With 11%, embodied carbon (EC) is a smaller but no less important share. It describes the carbon footprint of the building materials used. (UNEP & IEA, 2017) “Embodied carbon can be categorised into mainly two types: ‘initial embodied carbon’ and ‘recurring embodied carbon’ (Chen et al. 200). Initial embodied carbon is the emissions associated with raw material extraction, manufacturing, transport and construction, while recurring embodied carbon includes emissions during the use of the building such as repair, maintenance and replacement of building materials and equipment.” (Victoria & Perera, 2018)

Since embodied carbon plays a major role in this project, its composition was investigated with regard to its distribution in the different parts of buildings. In order to obtain comparability, three consecutive studies were consulted. In 2018, a residential building complex in the UK was investigated regarding the embodied carbon distribution (Fig. 3) and compared to an earlier case study (Fig. 2). The author of this reference study from 2015 stated that “according to 80:20 Pareto principle, it can be assumed that 80% of emissions are to be coming from 20% of elements.” (Victoria et al., 2015)

The analysis in the two studies in Fig. 2 and Fig. 3 examined embodied carbon in the cradle-to-gate phase, i.e. the period from the mining of the raw materials (cradle) to the finished building element, which means leaving the ‘industrial hall’ (gate). That means, that the transport to the site was not considered.

The authors used the division into frame, substructure, external walls, upper floors, finishes, roof and internal walls. These categories are based on the RICS definition of building components. (RICS, 2012) A brief definition is to be found in Table 1. It is important to mention that in Case Study 1 and 2 not 100% of all components could be taken into account because data was not available or could not be determined. Especially the building services (sanitary-, electrical-, ventilation-, disposal installations etc.) are excluded.

Case Study 1 from 2015 examined an office building. The three largest CO² emitters were the categories frame, substructure and upper floors. They accounted for 80% of the total embodied carbon. (Fernando et al., 2018)

Case Study 2 of an apartment building looks slightly different. Here, the external walls are added as a carbon hotspot. Frame, substructure, external walls and upper floors contribute to 83% of the EC. (Fernando et al., 2018) The difference in the external walls in both studies can be explained by the fact that Case Study 1 has a curtain wall, while the external walls in Case Study 2 are load-bearing. Table 2 shows the main components of the carbon hotspots in Case Study 2. It is striking that these consist almost exclusively of the building's load-bearing structure (there are a few exceptions: for example, the external walls also include the windows and external doors, and the substructure includes the insulation of the foundation).

Definition of Terms

Frame	To provide a full or partial system of structural support, where this is not provided by other Elements. = part of structure
Substructure	To transfer the load of the building to the ground and to isolate it horizontally from the ground. = foundation + ground insulation layer
External Walls	To provide the vertical component of the external enclosing envelope in conjunction with Windows and External Doors. = external wall construction layers including structure, insulation and outer shell
Upper Floors	To provide floor space on upper levels (i.e. above the lowest floor level). = structural floor slabs, balconies etc.
Roof	To provide the horizontal component of the external enclosing envelope. = all roof elements including roof structure
Internal Walls	To divide the floor space.
Finishes	Wall-, floor- or ceiling finishes

Table 1
(RICS, 2012)

Specifications of Case Study 2

Foundation/Substructure	Pad foundation with Reinforced in-situ concrete Grade C35, 20mm
Frame/ Structure	Steel frame and concrete
Upper floors	In-situ concrete grade C35 with A193 mesh reinforcement, to holorib decking
External walls	Cavity wall brick and blockworks- Engineering brickwork, Class B, mortar (1:4), stretcher bond, half brick thick external face of external wall. Concrete blockwork, 7N/mm2 compressive strength, mortar (1:4), 140mm thick internal face of the external wall

Table 2
(Fernando et al., 2018)

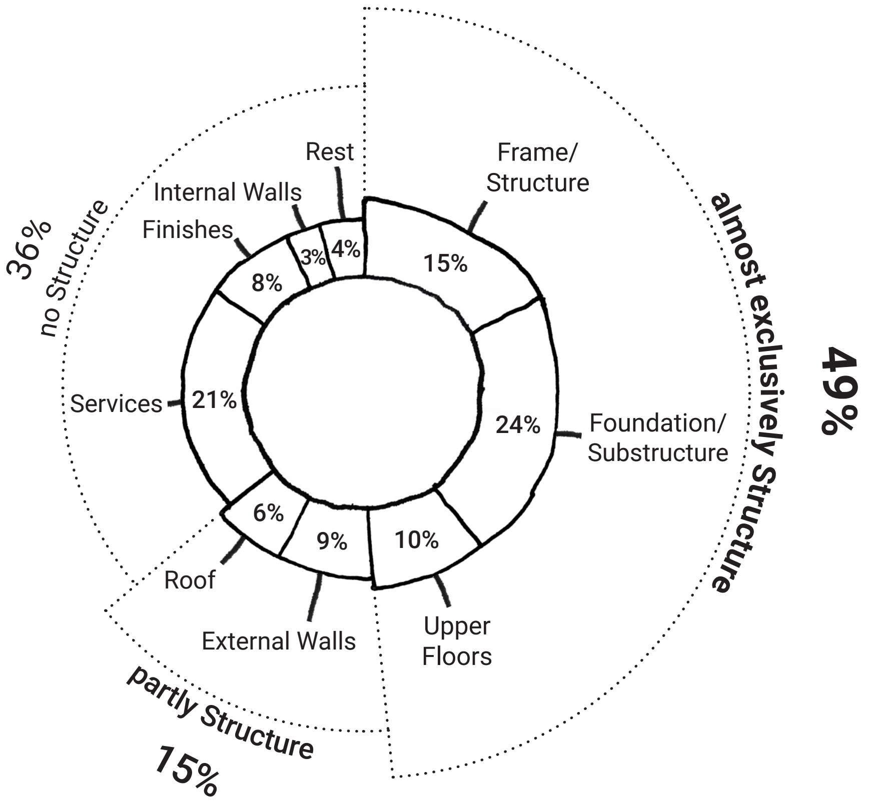


Fig. 4
(Victoria et al., 2018)

The authors M. Victoria and S. Perera conducted a third study in 2018, based on the initial one in 2015. For this, they analysed the EC in 41 office buildings. The number of different buildings makes the study much more representative for office buildings in general. In addition, more data was collected regarding the services. The result is astonishing: the CO² emitters from high too low are as follows: substructure, services, frame, upper floors, external walls, finishes, roof, 'rest' (External Windows and Doors, Stairs, Internal Doors, Fittings and Furnishings), internal walls. (Victoria & Perera, 2018)

This means that services play a much greater role than initially assumed. In the first study, the authors already pointed out the wide range of shares in the services category in various studies, ranging from 1-25%. This is mainly due to the fluctuating availability of data. (Victoria et al., 2015)

In addition, the authors refer to another study that shows that the services category has an even larger carbon footprint when calculated on the basis of the whole service time of a building. In the case of an office building in Canada, after a lifetime of 50 years, the recurring EC of the services due to maintenance etc. was almost as large as the initial EC. (Cole et al., 1996)

The conclusion regarding the Pareto ratio after comparing all 41 case studies is 80:43. 43% of the building elements were therefore responsible for 80% of the EC. (Victoria & Perera, 2018)

The studies show very well which component categories often have a high EC. Nevertheless, the distribution is of course different from case to case and varies greatly. It is striking that the categories that consist almost exclusively of the load-bearing structure (frame, substructure, upper floors) play a very large role with 49% (Fig. 4). External walls and roofs, which at least partially include structure, are responsible for another 15% EC. The largest part that does not contain any structure is, as mentioned, the services, which are also a large factor in the recurring EC.

The biggest potential to save EC in either way lies in these categories.

2. Lifespan of Buildings

The question of how long buildings last until they are deconstructed, demolished or destroyed, i.e. the question of the average length of their life span, is less easy to answer than one might think.

The physical lifespan of buildings can in principle be infinite, since maintenance and replacement can theoretically keep a building alive forever. Even without maintenance, buildings can survive as ruins for millennia. However, the actual lifespan of most buildings is determined by their “fitness of use”, i.e. their ability to perform the function for which they were built. This period is called the (real) service life. (Thomsen & Straub, 2018)

There are different definitions for the causes of the end-of-life of a building. One possible is to distinguish between physical, functional (social) and economic decay. (Grover and Grover, 2015) A more detailed subdivision can be seen on p. 14. In the Netherlands “physical durability turned out to be the least decisive reason for the end-of-life of (...) dwellings.” (Thomsen & Straub, 2018) Consequently, most buildings are demolished due to social or economic inefficiency or disfunctionality.

In 2012 Mooiman and Van Nunen wrote a paper that investigates the relation of the lifespan of buildings to their environmental impact. They refer to a study of the Delft University of Technology which shows that the majority of the buildings studied were between 75 and 125 years old when they were demolished. To show the development of the environmental performance in this timespan, they did a case study of a typical Dutch single family house. For this purpose, they used the calculation tool GPR-Gebouw. The calculated graph shows that building elements that were never repaired or replaced had a 40% lower environmental impact after 125 years than after 75 years. In addition they stated, that “if a material lasts ten times longer than other materials, then the environmental impacts of such material in principle counts, only for one tenth” (Mooiman & Van Nunen, 2012) This quotation underlines the chances of very durable buildings in terms of a low initial EC footprint in relation to the service life.

The authors of both papers emphasize the importance of making reliable lifespan assessments for buildings and their components in order to plan them in a smart, economic and sustainable way. In practice, it is currently most buildings are built without a plan of how long they should and will last. Thomsen and Straub state, that since “the majority of the dwelling stock in most EU countries has been built only recently, the average lifetime of the stock is so young that ex-post based forecasting of their life span is actually impossible.”

In both papers, calculations are made regarding the existing housing stock and the net addition of new buildings. Van Nunen speaks (in 2011) of 7 million dwelling units that would be needed by 2042. This would not be achievable with the current annual net addition of houses and the assumed lifetime reference of 75 years. He recommends a minimum lifetime of 120 years. Thomsens calculation, on the other hand, writes that “it (the annual net addition of dwellings, which is well below 1% in the Netherlands and most EU-countries) indicates that the future real lifespan of the existing EU housing stock may, instead of the often mentioned 50 years, be better measured in centuries.” He raises the figure of 300 years of lifespan for the Netherlands. (Thomsen & Straub, 2018)

Overall, it can be said that intelligently planned long-lasting buildings are in demand both in terms of sustainability, as they make longer use of the initially invested grey energy/embodied carbon, but are also necessary in purely mathematical terms due to the high demand for housing, as the annual net addition of buildings in the Netherlands and many other EU countries is too low.

3. Housing Shortage

In the Netherlands there has been a growing housing crisis for years. Especially in the big cities it is difficult to find affordable housing. That is why there have been more demonstrations against this situation in recent years. As of 2021, there was a shortage of 279,000 units and this number is expected to rise to 316,000 by 2024. One reason for the deficit is the population growth in the Netherlands, which was predicted up to the year 2060 in a forecast (Fig. 5) from 2014. (Statista, 2014) Today, 9 years later, the estimate is astonishingly accurate. To counteract this problem, the government aims to build 100,000 units annually. (Oostveen, 2022)

Delft also has a housing problem. The population has increased from 96,760 to 106,086 between 2010 and 2023 (Allcharts.info, 2023), which is a growth of about 10%. This may be partly due to the strong growth of the student population of the Delft University of Technology. In 2010, it had a student population of 17,039 (TU Delft, 2012), while in December 2022 it was already 27,080 (TU Delft, 2022). This is an increase of 60% in the same period of time.
Since "especially at the start of the academic year, students often end up living on campsites rather than in proper housing" (Van Enk, 2022), the TU Delft advises international students not to start their studies if they have not found accommodation by the time they start. (TU Delft, n.d.) International students are a reason for the housing crisis and also a part of those for whom it can be very difficult to find a accommodation. This is one of the reasons why many students move to surrounding cities such as Rotterdam or The Hague, because they can't find accommodation in Delft. Despite all the problems regarding the housing crisis, the TU Delft has ambitions to increase its student population to 40,000 students. (Bonger, 2022) This is a controversial plan, as there are already complaints from the municipality in Delft because such a large part of the population belongs to the students.

Forecast of the population in the Netherlands

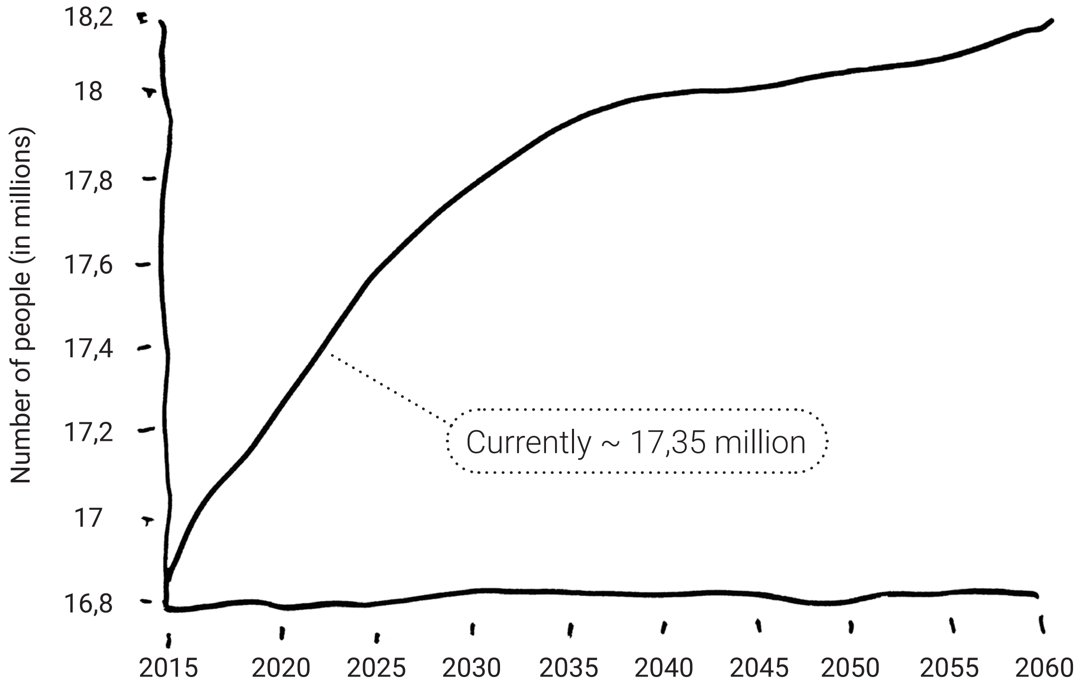
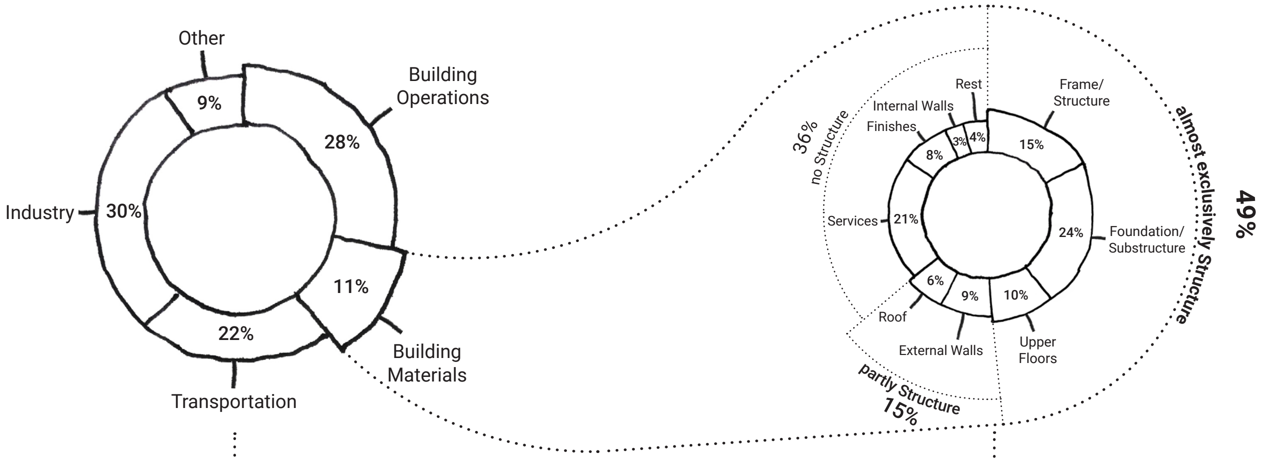


Fig. 5
(Statista, 2014)



Embodied carbon in buildings makes a significant contribution to **climate change**, accounting for 11% of total carbon emissions.

The building elements frame, substructure, upper floors and external walls, which largely consist of the building's **load-bearing structure**, as well as the **technical services** contribute to a **large part of the initial embodied carbon** (in the study by Victoria et al., 2018 it is over 80%).

Pain 1: Embodied Carbon

Most buildings in the Netherlands are demolished even though they are **not yet physically obsolete**, but are socially or economically bad performing. This causes **additional carbon emissions** when a new building is constructed as a substitute. Studies have shown that the **environmental impact of long-lasting buildings is much lower**, as the initial embodied carbon invested is used for longer.

The growing **housing crisis** in the Netherlands makes it difficult to find affordable housing, especially in the big cities and the Randstad. In the city of Delft, with a **rapidly growing student population**, there is **not enough housing** for students. However, this is necessary to meet the ambitions of the TU Delft to grow to the size of 40,000 students.

Experts also recommend a **longer service life** of dwellings in EU countries, as the **annual net addition** of new buildings is **too small** to meet the demand for housing.

Pain 2: Lifespan of Buildings

Pain 3: Housing Shortage

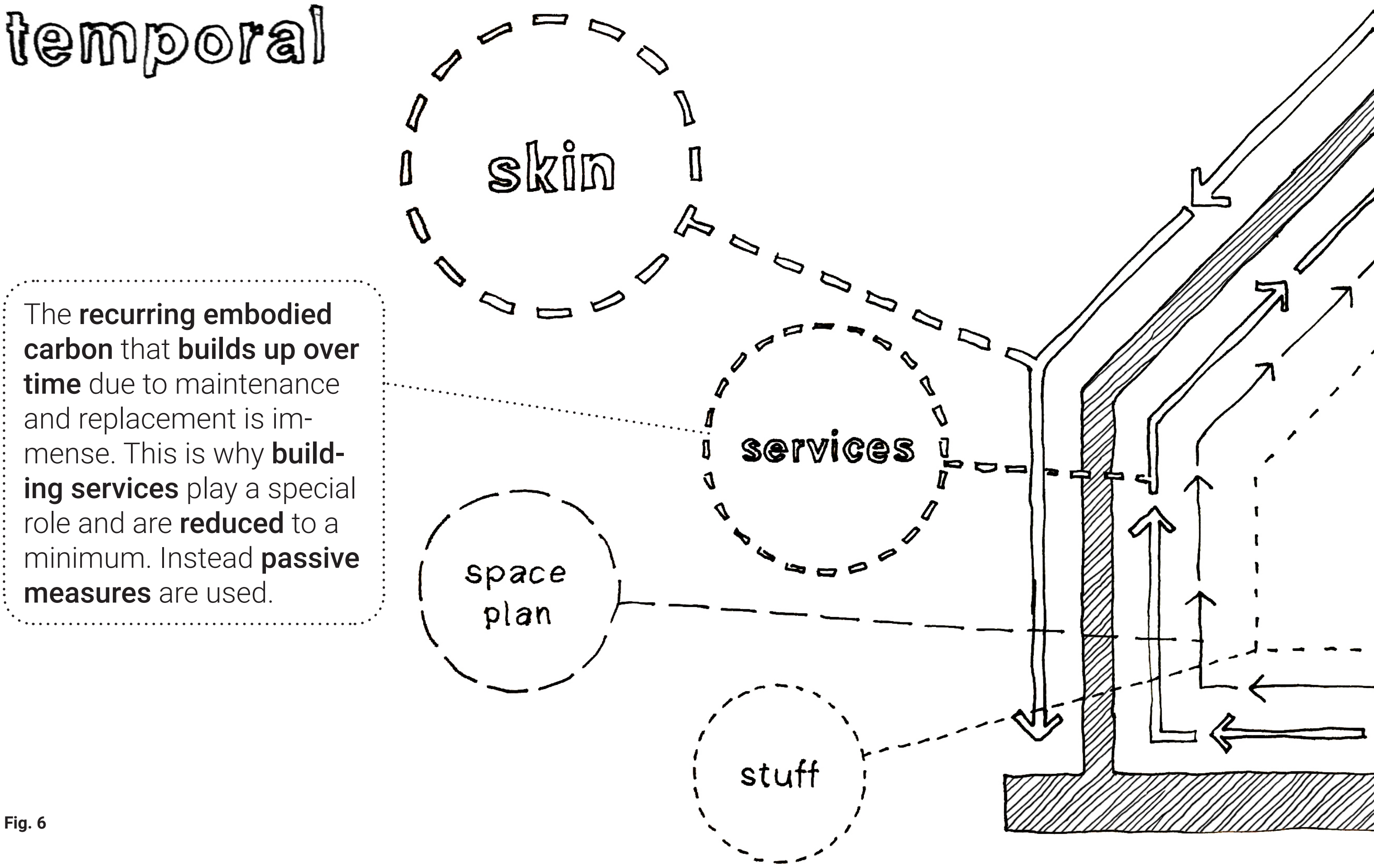
In order to create green and resilient architecture, and in particular housing, longevity should play a major role, as the initial carbon footprint (EC) can be used sustainably. Furthermore, Dutch dwellings need to last longer to counteract the low annual net addition of new buildings and the housing shortage.

Problem Statement

Project Objective

The ambition of this project is to develop a building that responds to the problem statement by ensuring that the building elements that statistically contain the most initial embodied carbon have the longest possible lifespan in order to use this (EC) sustainably and achieve good environmental performance in the long term. The potential service lifespan of the entire building should reach the extreme, i.e. last for centuries. This ambition also requires high adaptability and flexibility in order to be able to react to changes in the function of the building itself on the one hand and external factors such as climate, politics and society, etc. on the other hand.

Since most embodied carbon is contained in the load bearing structure of buildings, that is where the focus lies in terms of longevity. Poetically speaking, the structure merges with the site. The other elements, such as the skin, can only



The **recurring embodied carbon** that **builds up over time** due to maintenance and replacement is immense. This is why **building services** play a special role and are **reduced** to a minimum. Instead **passive measures** are used.

Fig. 6

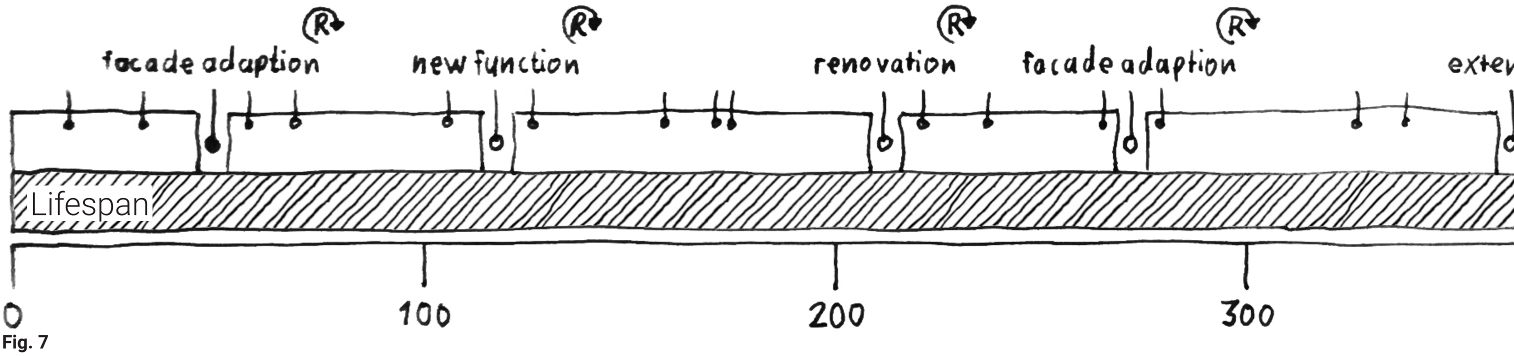
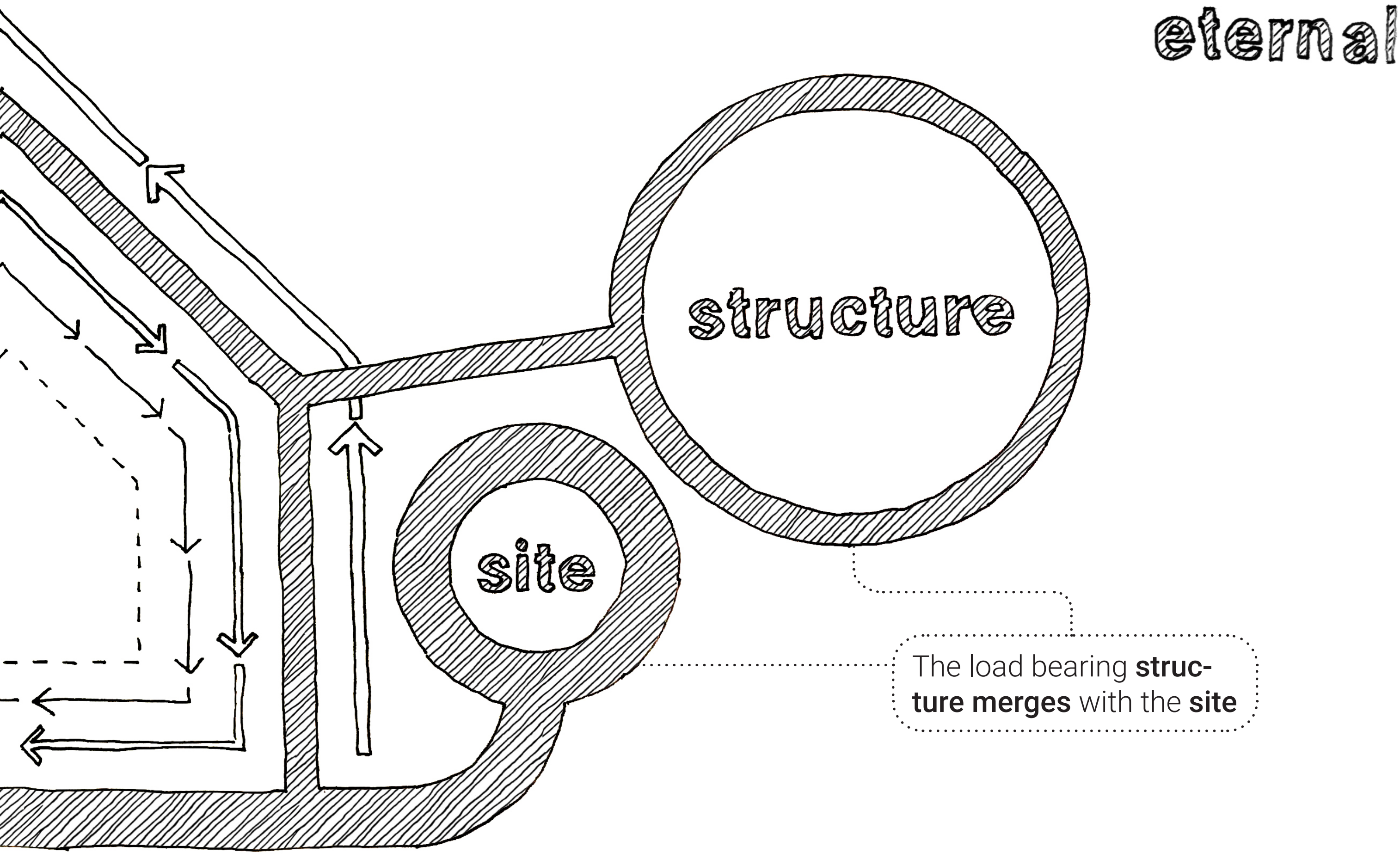


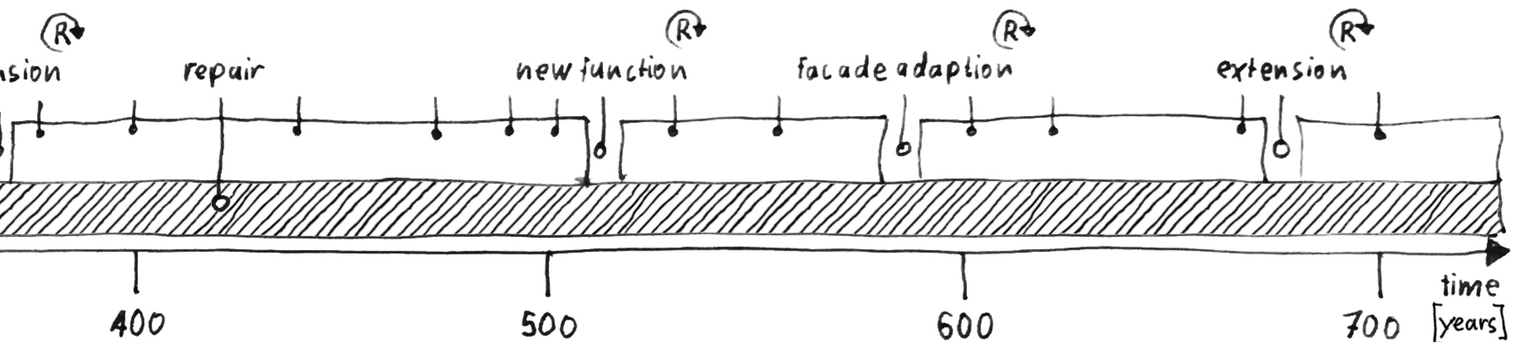
Fig. 7

exist temporarily and are therefore repaired, recycled, etc. whenever necessary according to the r-strategies.

Building services also contribute significantly to the carbon footprint of buildings. In addition to a high initial embodied carbon, they also build up an immense recurring carbon footprint over time which is triggered by maintenances and replacements. Accordingly they play a special role in this project. In order to minimise the continuous growth of this recurring embodied carbon, active measures (e.g. air conditioning systems that require maintenance) are reduced to a minimum, while passive measures (e.g. natural ventilation, thermal storage, etc.) are implemented from the early design stage on. An additional advantage is, that adaptations associated with the constant progress of technical systems are reduced.



The load bearing **structure merges** with the **site**



Overall Design Question

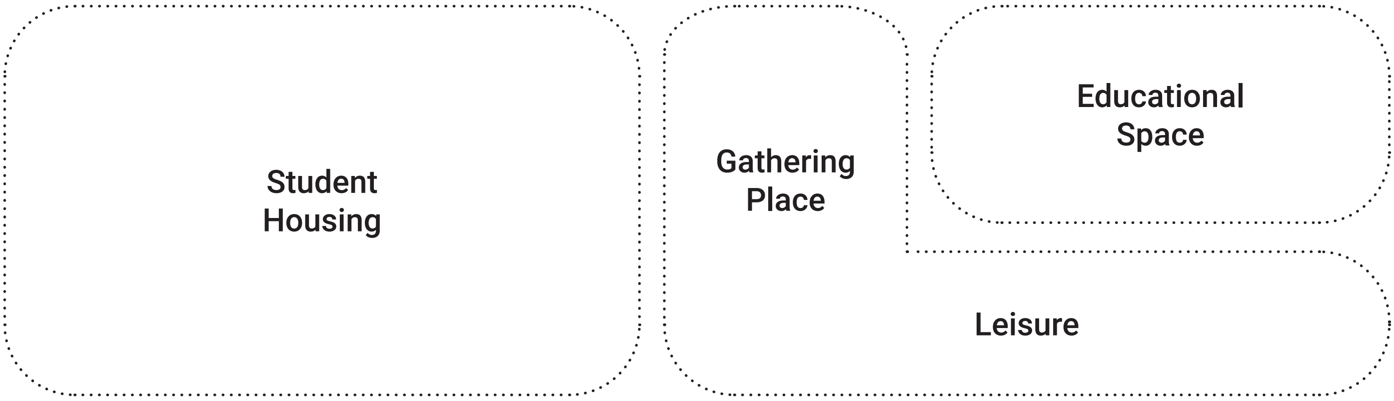
1. Context

This project can be considered a major experiment. Therefore, a university context is ideally suited to monitor and analyze the results that accumulate over time and eventually incorporate them into the teaching of future generations of engineers and architects.

Since the TU Delft in particular has the ambition “to be carbon neutral, climate-adaptive and circular, with contribution to the quality of life and biodiversity, by 2030”, the campus in Delft was chosen as the context for this project. It is also considered as a “Living Lab“ where new innovative ideas can be tested to contribute to this goal.

2. Program

As this project is dedicated to students, it is primarily about meeting their needs. As shown in the problem statement, there is too little accommodation for students in Delft. Therefore, a part of the building will be used for student housing in different unit sizes. Furthermore, with the growing number of students, new educational space is needed. Since the campus is immensely large and there is not really a recreational offer besides the sports facility X, a public leisure function will be integrated into the project, so that students from all faculties can be attracted.



3. Thematic Focus

The focus, as explained in the previous chapters, lies on the design of a very durable building through the combination of long-lasting building elements that form the structure and temporal ones. This should simultaneously achieve a low environmental impact and the greatest possible adaptability for the future.

Design Question

How to design a **multifunctional building** on campus that **rethinks the typical timescales** of architecture and provides a **sustainable alternative** to construction methods with a low initial carbon footprint (such as timber construction) by using a **durable structure** and **passive measures** while remaining **highly adaptable** to future changes in its requirements?

Thematic Research Question

The thematic research question and subsequent research will be used to investigate the challenges associated with longevity and to determine which material and construction method is best suited to pass these. Table 3 shows the "Types of obsolescence" by Grover and Grover in which they explain different reasons for obsolescence. Based on their definition, a strategy was developed on how the project could face them in order not to become obsolete in the future.

Types of Obsolescence

Physical	- Unexpected defects in the building due to the method of construction or materials used so that repair or replacement is not economic - Catastrophic failure due to an external event, such as an earthquake or tsunami, requiring major works that may not be economic - Spare parts, materials, or craftsmen becoming unavailable before planned scrappage so that repairs and maintenance are impossible or uneconomic
Environmental or sustainable	- Acceptable emission levels cannot be met economically - Hazardous components incorporated in construction, e.g. asbestos, which may not be economical to be dealt with - Tenant corporate responsibility expectations cannot be met in a financially tenable manner - Environmental impact does not match up to alternative accommodation
Functional	- Users' requirements for facilities change - Users' requirements for layouts – horizontal or vertical – change - Built to standards that are no longer acceptable and economically incapable of being altered
Social	- Buildings were designed for functions that are no longer socially useful because of a change in behaviour, e.g. decline in religious belief
Legal	Building incapable of being economically modified to meet new legal requirements, e.g. discrimination, health, and safety
Economic or financial	- Impact from changing the economic environment - Changing demand for the goods or services produced by the asset - Excess supply making the production of the goods or services produced by the asset uneconomic - A mismatch between demand and supply results in future rental income not covering property costs - Changing business practices and models affecting space requirements, e.g. e-marketing, just-in-time delivery, mergers, and downsizing
Technological	- Advances in technology providing better user experiences and a lowering of costs are uneconomic to install - Unable to be adapted to meet a continuing demand for new equipment and services as upgrading is uneconomic - Limited maintainability of an existing building
Aesthetic, fashion and cultural	- Demand driven changes in taste or fashion - Building exteriors or interiors have an outdated appearance - Inadequate complementary facilities
Location	- Devaluation of buildings in an area, e.g. planning blight, company failures, crime levels - Issues with infrastructure and local environment - Physical deterioration of an area - Absence of area regeneration - Changing perceptions or interpretations of an area by users - Optimum location for specific users has changed - The location may be unsuitable for new uses - Geophysical changes to an area make it unsuitable

Table 3
(Grover and Grover, 2015)

Research

Durability

Creating a very strong and durable structure which is not likely no need maintenance.

Taking the environmental impact over time into account.

Research Question

Which materials and **construction methods** are most suitable to create a very **durable** and therefore **sustainable load-bearing structure**?

Design

Adaptability + Flexibility

The space plan is adaptable. Horizontal and vertical changes in the requirements can be met by rearranging building elements.

The temporal building elements are low tech and cost to make the needed replacement affordable.

Changes in the climate requirements can be met by changing the hull.

Passive Measures

By reducing active measures and using passive ones instead. Advances in technical systems become unnecessary to some extent.

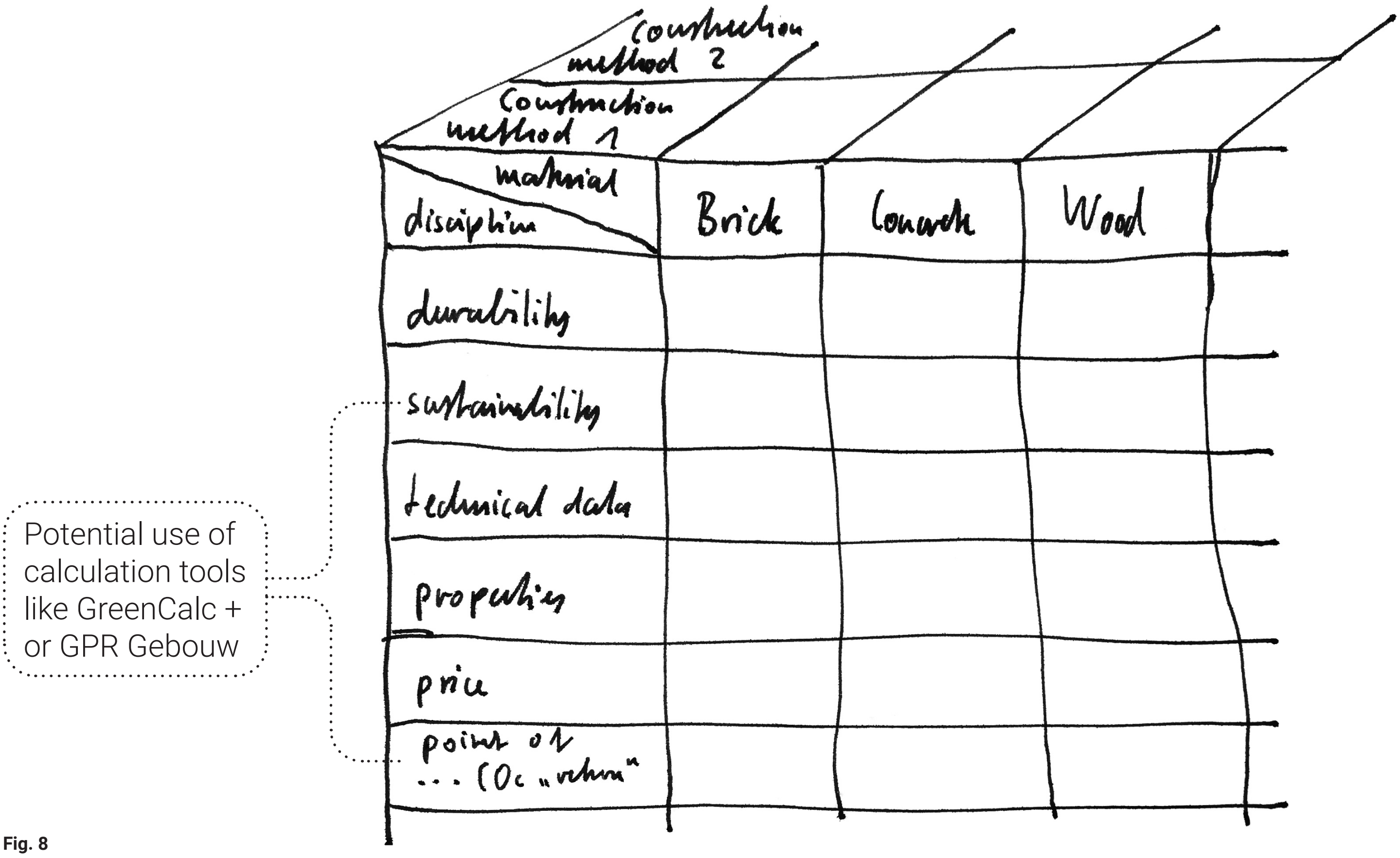
Aesthetic

Creation of a timeless design that can adapt to changes in aesthetic taste.

Besides the careful selection of the initial site, the architect has no influence on changes that affect the whole area.

Thematic Research Methodology

In order to be able to give an answer to the research question, the plan is to compare the classic building materials brick, concrete and wood (possibly also stone). For this purpose, a matrix will be developed that compares not only the materials but also different construction methods. A sketch of how this “3-dimensional” matrix could look like can be seen in Fig. 8. The disciplines are defined in the research process. In order to establish the reference to reality, case studies on certain material-construction combinations are evaluated. The final result should determine one or more possible construction methods for the planned project on which the design can be based.



Potential use of calculation tools like GreenCalc + or GPR Gebouw

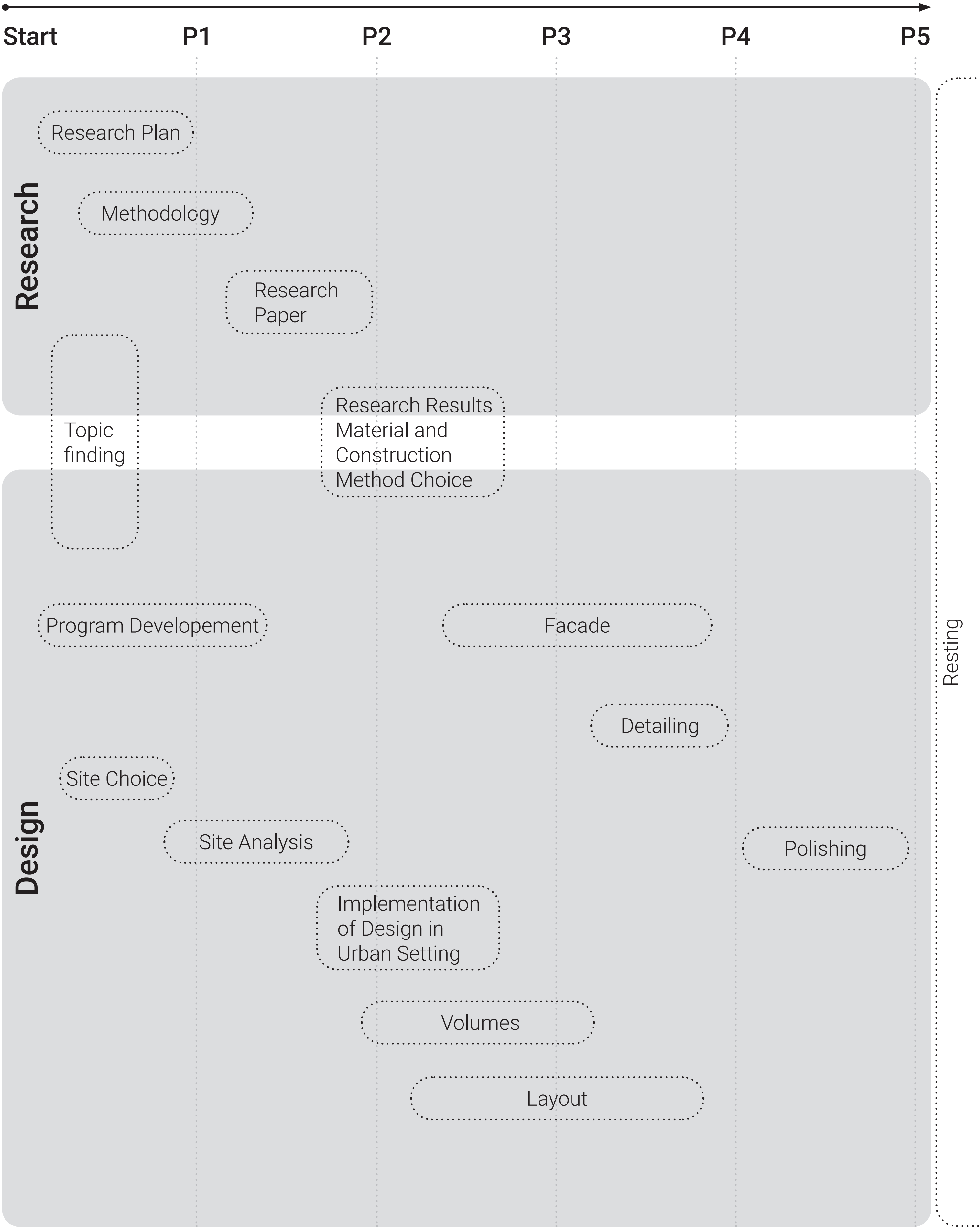
Fig. 8

Literature References

Fig. 9

The sources for the research will be a mixture of literature on materials, construction methods and case studies. “Building Simply” by Florian Nagler compares 3 buildings with the same Layout in difference Materials (Fig 9). The 2226 building by Baumschlager Eberle Architekten uses the passive measure of mass as a heat storage and the projects of BLAF Architects show how the Facade can act as an ever lasting structure. These examples are potential case studies. In addition, as indicated in Fig. 8, environmental performance calculators will be used to obtain comparable figures. Furthermore, it is a possibility to consult material scientists at Tu Delft, although contact with them has not yet been established.

Planning


Start
P1
P2
P3
P4
P5
Research
Research Plan
Methodology
Research Paper
Topic finding
Research Results Material and Construction Method Choice
Design
Program Developement
Facade
Detailing
Site Choice
Site Analysis
Polishing
Implementation of Design in Urban Setting
Volumes
Layout
Resting

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