Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Anurag Sonar
Student number	5201756

Studio		
Name / Theme	Building Technology Sustainable Design Graduation Studio	
Main mentor	Dr. Ir. Faidra Oikonomopoulou	Assistant Professor, TuDelft Transparent structures/glass design
Second mentor	Dr. Ing. Marcel Bilow	Associate Professor, TuDelft Façade & Products
Argumentation of choice of the studio	N/A	

Graduation project	
Title of the graduation project	Product development of Hybrid Glass Blocks: Rethinking shape, manufacturing process and assembly system
Goal	
Location:	Maastricht, The Netherlands
The posed problem	The use of glass in the building industry over the last few decades has rapidly increased due to its innate optical, thermal, and acoustical properties. Glass possesses such varied properties and has a great potential to be sustainable and energy-efficient material in the contemporary era. The technical advancements in Glass technology have completely changed the perception of its innovative application. The application of glass in the building industry has evolved from a flat facade panel to a 3D block which is prominently seen in some recent projects such as Maison de Hermes, Tokyo, and Crystal House, Amsterdam. Currently, there are two approaches in glass blocks: load-bearing solid glass blocks with poor thermal properties and hollow glass blocks with optimal thermal properties but no structural performance. Can we combine these approaches and develop a glass block with good load-bearing and thermal properties? Research on Hybrid glass

	blocks is one such topic that investigates the potential of this unique concept. A hybrid glass block is the combination of solid and hollow glass blocks designed as a single product with good thermal performance and load-bearing capacity. The existing research on this topic is promising and noteworthy for further development as it conceptualizes the rudimentary guidelines for the system. The output of the existing research is oriented towards the design of the novel hybrid glass blocks, ideation of the production methodologies, and validation of their thermal performance. Thus the scope for further research and development can be actual prototyping of the design concepts, validation of the structural performance, and qualitative analysis. It is observed that the shape of the hybrid glass blocks impacts the structural-thermal performance, production methodology, and desirability of standardization. Thus, to develop this product a thorough investigation and exploration are necessary. The research will first focus on developing design guidelines for the innovative hybrid glass system. It will then explore various design concepts and attempt to establish their relationship with the production methodology, thermal-structural performance, and assembly system. The explored options will further establish assessment criteria and categorization of design concepts for various applications. The design concepts will be manufactured and then validated through various real-life experiments.
Research questions	The focus of this research is to contribute towards the innovation of glass structures by developing Hybrid glass blocks. The main goal is to explore various design concepts, develop (prototype), and experimentally validate the structural & thermal performance of these hybrid glass block designs, from the components, form to an overall structural system. It can lead to partial or fully transparent, self-supporting building envelopes made from a combination of cast glass and float glass components. The main research question formulated is: What are the main design considerations and challenges in designing and manufacturing a hybrid glass block system that exhibits good thermal and structural performance?

	The research can be divided further into the following sub-questions: 1. What design characteristics influence the load-bearing capacity and thermal performance of glass blocks? What strategies can improve the load-bearing capacity and thermal performance? What are the advantages and limitations of these strategies? 2. What are the structural and thermal properties associated with the performance of hybrid glass blocks? 3. What is the connection between the shape of glass blocks and their structural performance? What are the optimum cross-section thickness and cavity width of glass blocks to improve structural and thermal performance? 4. What are the main design standards that affect the production and assembly process? What are the advantages and limitations of these criteria? 5. What are the engineering standards and challenges involved in fabricating the Hybrid glass blocks? 6. What are the design strategies to develop a sustainable (recyclable) hybrid glass block?
Design assignment in which these result	The research will lead to designing, experimenting and validating different hybrid blocks and engineering its fabrication and assembly in accordance with the design criteria.

Process

Method description

The product development of Hybrid glass block is categorized into five phases;

Phase 1: Literature Review and Theoretical framework

The focus lies in extracting necessary information through existing research and available literature related to the chosen topic. This forms the basis for the development of the research framework. A case study of the Academy of Arts, Maastricht (1993) is selected and analyzed to provide a realistic scenario in defining structural, thermal, and assembly criteria. The European building codes are studied to define the design guidelines. The in-depth research on glass block technology, its manufacturing and installation process will assist in the formation of design guidelines for the product development of Hybrid glass blocks.

Phase 2: Design Development

The design guidelines formulated in Phase 1 are the basis of the design process. The focus of phase 2 is firstly to formulate a design development methodology. Initially, design aspects are identified and various alternatives are explored. These alternatives will be evaluated based on the specific boundary conditions such as structural and thermal performance along with ease in manufacturing, design for disassembly, aesthetics, sustainability, and problem-specific design criteria set before alternatives exploration. The shortlisted alternatives are combined to form a final design concept. For the evaluation of various cross-sections, basic hand calculations are carried out to identify the structural performance under loading.

Phase 3: Design Refinement

In terms of manufacturing and constructability, the final design concept will be developed. To improve the design, the production standards and problems associated with mold fabrication via CNC milling, glass casting and annealing, tolerances, and movements will be considered. Few predetermined risk scenarios, such as structural damage, accidental impact, vandalism, lack of maintenance, vehicle impact, fire, and natural disasters, will be examined, and design solutions to mitigate their impact will be applied for the final design. The final design will be detailed and evolved based on these factors. The final design will be detailed and evolved based on these factors. A manufacturing and assembly sequence will be detailed step by step. This will help with the hybrid glass block prototyping in the studio. This will be a concurrent procedure with the design's details. The study will investigate the prototyping of hybrid glass blocks within the context of an automated, industrial process; however, glass block prototypes will be produced in the glass lab facilities of TuDelft using either the kiln-casting method or/and water-jetting and bonding float glass elements (based on final design) to understand mold limitations, glass flow, and so on.

Phase 4: Design Evaluation

The focus of this phase is to evaluate the final design based on various parameters by numerical and (if permitted) experimental methods.

Structural: Hand calculations for the compression load, buckling load, deflection, cross-section thickness & stiffness.

Qualitative analysis of strain concentration by polarisation test (Suggested)

Thermal: Hand calculations for U-Value on unit and system level

Hard-body impact and vandalism test (not conducted but considered during risk scenario analysis)

Design for disassembly: Number of steps involved

Ease in Manufacturing: Number of processes and their complexities.

Phase 5: Design Application & Conclusion

The last phase focuses on summarizing details of the prototyped hybrid glass block and its application to the case study. Detailed facade drawings, installation methodology, and risk scenario analysis will be portrayed. The aim is to evaluate the applied design followed by the set of recommendations for future development of Hybrid glass blocks.

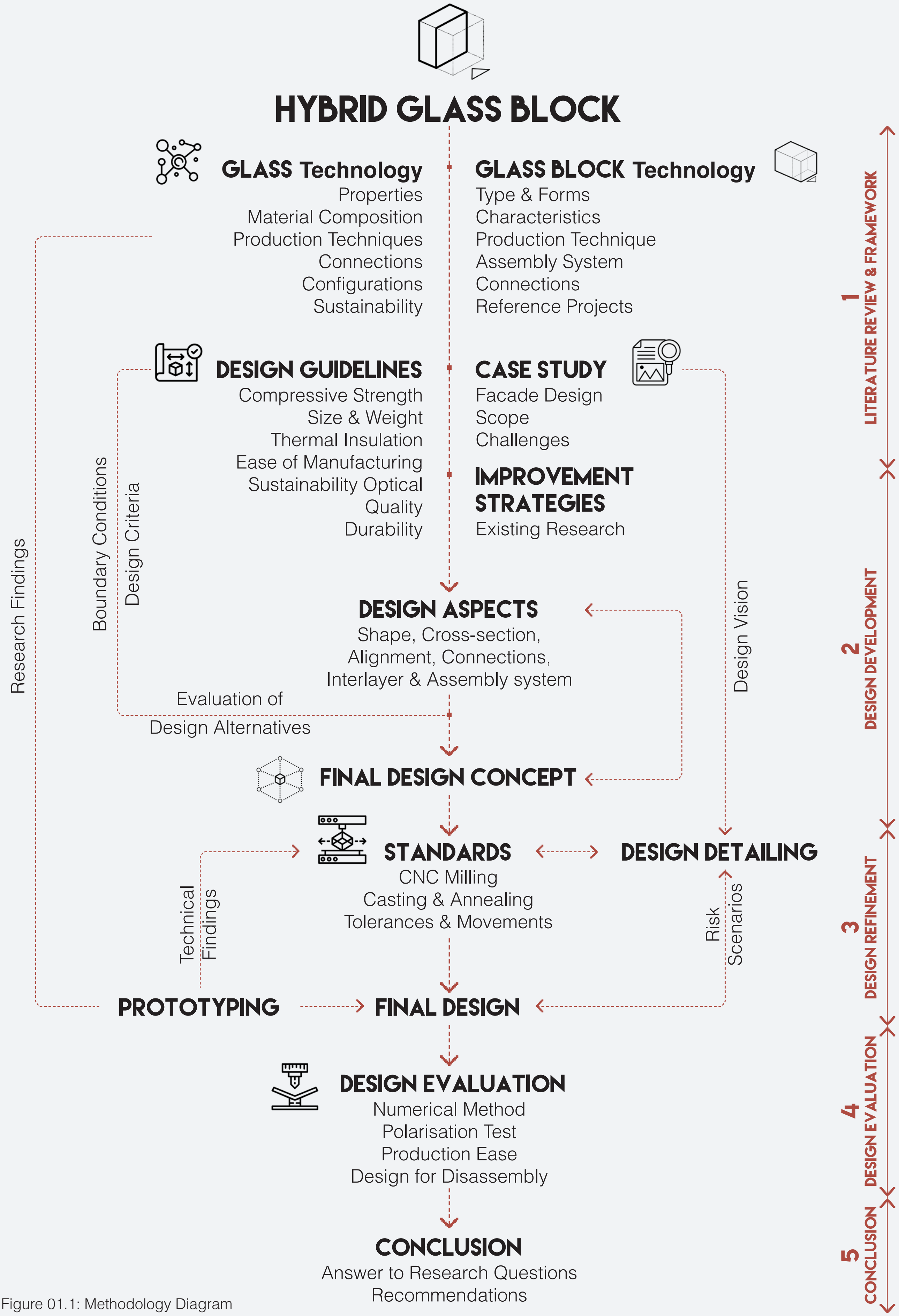

Figure 01.1: Methodology Diagram

Literature and general practical preference

Literature & webpages referred:

Flashback: Academy of Art & Architecture, Wiel Arets Architects. (2011, September 24). Retrieved November 19, 2021, from Archdaily: https://www.archdaily.com/171315/flashback-academy-of-art-architecture-wiel-arets-architects

Crystal Houses / MVRDV. (2016, April 20). Retrieved November 9, 2021, from Archdaily: https://www.archdaily.com/785923/crystal-houses-mvrdv?ad_medium=gallery

Optical Glass House / Hiroshi Nakamura & NAP. (2020, September 13). Retrieved December 2, 2021, from Archdaily: https://www.archdaily.com/885674/optical-glass-house-hiroshi-nakamura-and-nap?ad_medium=gallery

Agustinus Djoko Istiadji, P. T. (2012). *Raising High Energy Performance Glass Block from Waste Glasses with Cavity and Interlayer.*

Akerboom, R. (2016). *Glass Columns: Exploring the potential of free standing glass columns assembled from stacked glass elements.*

Another Chicago Tribune Tower. (n.d.). Retrieved December 18, 2021, from MOS NYC: https://www.mos.nyc/project/another-chicago-tribune-tower

Barou, L. (2016). *Transparent Restoration.* TuDelft Repository.

Briques en Verre. (n.d.). Retrieved November 10, 2021, from https://www.glassian.org/Prism/BlanpainMassonet/Briques_en_Verre.pdf

Cao, L. (2020, June 16). *Glamorous Glass Bricks Are Booming – Again*. Retrieved November 23, 2021, from Archdaily: https://www.archdaily.com/941686/glamorous-glass-bricks-are-booming-nil-again

Chiou, A. (2019). *The Cast glass travelling pavilion.* TuDelft Repository.

Dimas, M. (2020). *In Between: An Interlayer material study for interlocking cast glass blocks.* TuDelft Repository.

Fagan, E. (2015). *Building walls of Light: The development of glass block and its influence on American Architecture in the 1930s.*

John Klein, M. S. (2015). Additive Manufacturing of Optically Transparent Glass. *3D Printing and Additive Manufacturing, 2*(3), 92-105.

Marco Beccali, C. G. (2021). *Improving the thermal performance of the transparent building envelope: Finite element analysis of possible techniques to reduce the U- value of the glassblocks.*

Nathani, T. (2021). *Hybrid Glass Block: Load bearing and thermally sound glass block.* TuDelft Repository.

Oikonomopoulou, F. (2019). *Unveiling the third dimension of glass: Solid cast glass components and assemblies for structural applications.* A+BE (Architecture and the Built Environment), TU Delft BK.

Solid Glass: Vistabrik & Vetropieno. (n.d.). Retrieved December 16, 2021, from Seves Glass Block: https://www.sevesglassblock.com/vistabrik-and-vetropieno/

Velden, M. v. (2020). *The increased thermal performance of a structural cast glass brick wall.* TuDelft Repository.

Reflection/Relevance

Relevance between Graduation topic and Master Studio

The Sustainable design graduation studio focuses on the development of innovative design technologies within the built environment. The material 'Glass' is widely used in the building industry due to its distinctive optical, thermal, and structural properties in various forms, for example, partitions, glazing panels, glass blocks, etc. The existing glass block systems offer either optimal thermal performance or structural stability but neither a combination of both. 'Hybrid glass block' is an innovative concept that endeavours to bridge the gap between the solid glass blocks' thermal performance and hollow glass blocks' load-bearing capacity. Since this is a recently emerged concept, the research will focus on defining design guidelines, manufacturing methodology, and evaluation through design and experimentation along with the freedom of exploration of various design concepts in a realistic case study.

This research will result in an energy-compliant sustainable glass product for application in the building industry. On a broader level, the focus is on structural design and climate design, which are two branches of the Building Technology track. The research topic is also related to the ongoing research on Sustainable structures in TU Delft.

Scientific and Social Relevance

In the last two decades, the building industry is slowly evolving and transitioning towards designing and creating sustainable environments to meet the global challenges of climate change and scarcity of natural resources. The focus is aligned towards adaptable building systems that are energy efficient and have a low carbon footprint. This simply means that every product that goes into the making of the building environment should be energy-efficient, sustainable, and have less carbon footprint. The focus is not only limited to a system-level but also on a unit level. Another important aspect is the circularity and reusability of building products after their end of function or life-cycle.

"The use of glass in architecture has never been more popular, but the global drive to increase the energy efficiency and sustainability of buildings is posing a challenge to architects, engineers, and manufacturers alike" (James O' Callaghan, 2020)

To ensure the future of architectural glass it is important to push the boundaries of products that provide innovative solutions to meet these global challenges. A lot of architectural projects are increasingly using glass in many innovative ways and this will significantly increase in the future since it is circular and recyclable.

The research aims at developing a glass block that adheres to the energy efficiency and sustainability goals by unveiling its true potential. The newly developed glass product and the system will focus on sustainability and achieve maximum recyclable components (e.g. by having a pure glass part, dry-assembly method, etc). The research also focuses on design for disassembly so as to reuse the building components at the end of their function or life cycle. This will completely change the way how glass is perceived in society. The methodology in which the potential of the glass has been explored relates to the scientific curiosity of developing innovative glass structures that are energy giants and sustainable.

Planning

The time planning for the research has been tactically spread between the five presentations.
The first phase lies between P1 and P2 focuses on literature study and data collection. A case study will also be selected for a more realistic approach and this will end in the development of final design criteria. The second phase lies between P2 and P3 in the design and analysis phase. This will be directed towards developing the block and testing it computationally on software for thermal verification. The third phase between P3 and P4 will focus on the fabrication and assembly of the design in real-world conditions. The fourth and final phase between P4 and P5 is marked for refinement of the research and the final report will be produced at the end.

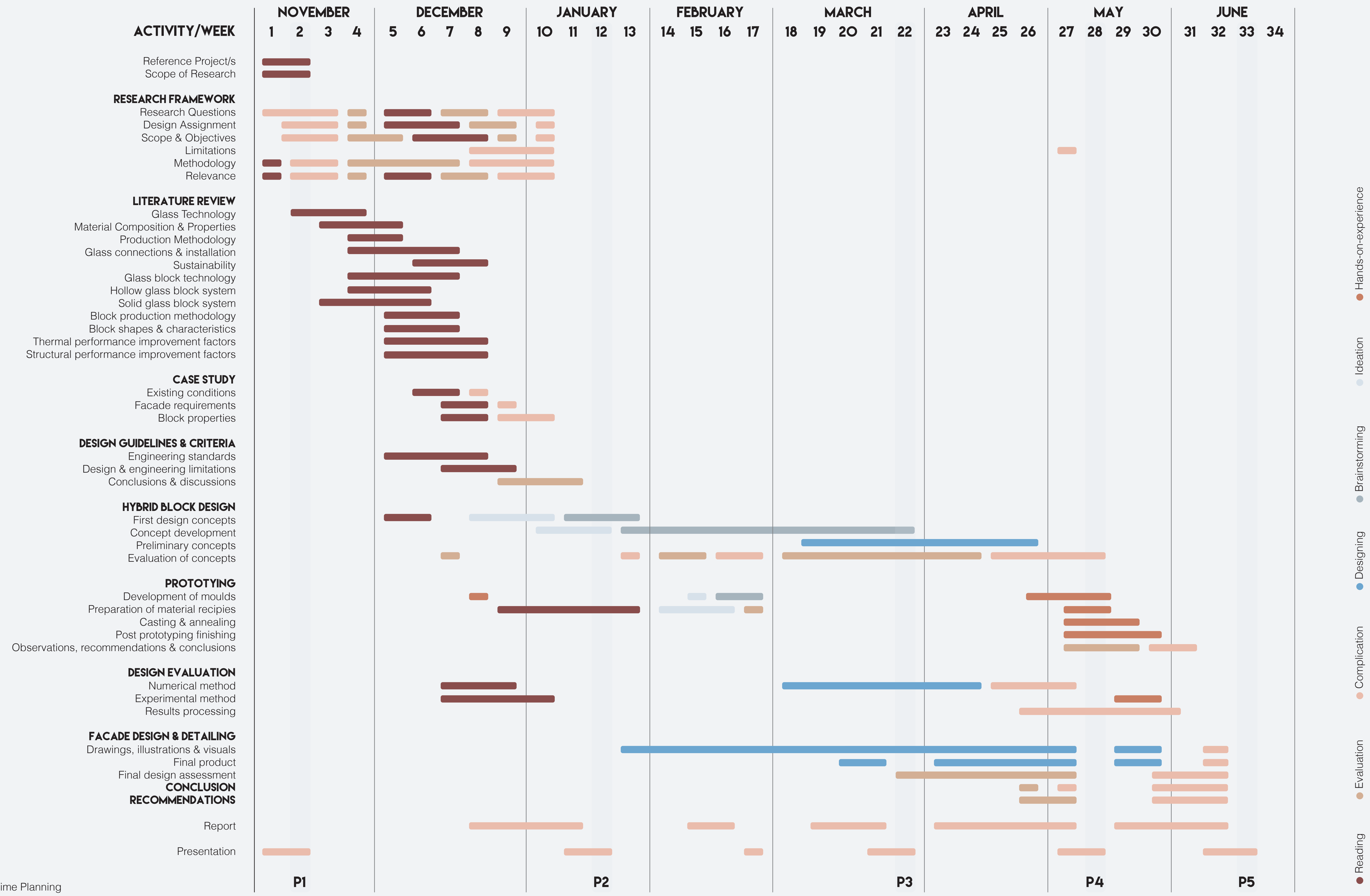

Figure 01.2: Time Planning