LIGHTING THE PATH TO KNOWLEDGE:
ENHANCING COGNITIVE PERFORMANCE AND KNOWLEDGE ACQUISITION IN FUTURE LIBRARIES THROUGH THE LIGHTING LANDSCAPE

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April 17, 2025
Version 3.1

2655 words

ABSTRACT

This research explores how lighting landscapes can be strategically designed in future library environments to stimulate user-driven knowledge acquisition and cognitive performance, with a specific focus on the Royal Library in The Hague as a case study. Throughout history, libraries have evolved from static, exclusive book repositories into dynamic, public learning environments. Central to this transformation is the role of light, which is not just a source of illumination, but also a spatial and neurological stimulant influencing cognition, engagement and user experience.

While the cognitive benefits of natural and artificial light have been widely studied in workplaces and educational contexts, their application in library environments—particularly heritage buildings—remains underexplored. This study aims to address this gap by examining how lighting strategies can be optimally integrated into future library design to enhance cognitive performance and support user-driven knowledge acquisition.

The main research question that guides this investigation is: *How can the lighting landscape be designed to stimulate user-driven knowledge acquisition and cognitive performance in the 'Future Library'?*

Adopting a hybrid theoretical framework grounded in neuroscience, architecture, and lighting design, this research investigates how light affects neurological processes such as attention, memory, and alertness, and how spatial lighting can shape orientation and engagement. The study employs a mixed-method approach, combining literature review, case studies, empirical observation, and design-oriented research.

By analysing successful lighting strategies and their cognitive effects, the study aims to develop an evidence-based spatial lighting framework that repositions light as an active agent in learning environments. The findings will inform the design of future libraries, including the revitalisation of the Royal Library, by offering lighting strategies that enhance cognitive performance, support knowledge acquisition and ensure user well-being and an optimal spatial experience.

INTRODUCTION

Throughout history, libraries have played a vital role in preserving and disseminating knowledge. Initially, they served as exclusive repositories for manuscripts and books, accessible only to an elite group of scholars, rulers, and religious figures. Early libraries, such as those in Mesopotamia, Egypt, and Greece were closely tied to centers of governance and learning, emphasising control over knowledge. As libraries evolved, their role expanded beyond mere storage. During the medieval period, libraries were often integrated into monasteries and cathedrals, where ornate architecture and intricate detailing reflected both religious devotion and intellectual prestige. The grand and monumental libraries of later centuries further reinforced the notion of knowledge as a symbol of power and enlightenment (Lushington et al., 2016; Kececi, 2024).

The architectural design of early libraries played a crucial role in shaping the user experience. Limited access to daylight was a defining feature, influenced by both practical and symbolic considerations. As early libraries were primarily designed to preserve rare and valuable collections of books, scrolls and manuscripts, their enclosed nature helped to protect these collections from physical deterioration and unauthorised access. At the same time, this exclusivity reinforced their perception as institutions reserved for the elite. However, medieval libraries were not entirely dark; they often incorporated controlled natural light that allowed scribes to work effectively. Since artificial lighting did not yet exist, library interiors were often dimly lit, resulting in a somewhat somber atmosphere (Malman, 2009).

The transition of libraries from exclusive archives to dynamic learning spaces was a gradual process, accelerating with the invention of the printing press in 1439. The mass production of books led to increased accessibility and democratisation of knowledge. This evolution continued into the 18th and 19th centuries, with the establishment of public libraries that prioritised accessibility and enlightenment for all. Modern libraries have continued this trend, shifting from static book repositories into dynamic learning environments, characterised by open, flexible spaces that emphasise user-friendliness, accessibility, engagement, and comfort. A key aspect of this transformation is the growing integration of both natural and artificial light to shape the spatial experience[1] while enhancing cognitive engagement[2] and overall well-being (Lushington et al., 2016).

This shift underscores a pivotal challenge in library design: the creation of environments that simultaneously support cognitive performance[3] and knowledge acquisition[4] while ensuring an optimal spatial experience. Lighting plays a crucial role in achieving this balance. Natural light has been shown to enhance the spatial experience, improve concentration and learning, and support cognitive engagement by regulating circadian rhythms[5] and increasing alertness (Çelik et al., 2024). However, the benefits of natural light must be carefully managed to avoid glare, visual discomfort and potential distractions. Conversely, artificial lighting provides greater control over environmental conditions; however, if not designed effectively, it can disrupt the ambiance and hinder cognitive performance (Baeza Moyano et al., 2020). The challenge lies in developing an optimal lighting strategy that balances the interaction between light, the built environment, and the neurological processes involved in user-driven knowledge acquisition and cognitive performance.

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1 Spatial experience refers to the way individuals perceive and interact with a physical space, influenced by various factors such as layout, lighting, and acoustics. Lighting, in particular, can enhance the spatial experience by creating a comfortable and engaging atmosphere, or it can disrupt it through issues like glare, visual discomfort and potential distractions.

2 Cognitive engagement refers to the mental effort and focus a person applies when processing information, involving activities like concentration, analysis, and problem-solving to enhance learning and knowledge retention.

3 Cognitive performance refers to an individual's ability to process information, retain knowledge, focus attention, and solve problems within a specific environment. In this study, it refers to the user's mental functioning within a library setting.

4 Knowledge acquisition refers to the process of obtaining, understanding, and internalizing information or skills through learning, experience, or instruction.

5 Circadian rhythms are internal processes that regulate the sleep-wake cycle and other physiological functions, typically on a 24-hour cycle. They are influenced by external factors, especially light, which helps synchronize these processes and promote alertness and well-being.

This study will investigate how the lighting landscape in the ‘Future Library’ can be designed to optimise user-driven knowledge acquisition and cognitive performance. By analysing the neurological effects of light on cognitive processes and knowledge acquisition, exploring spatial lighting strategies, and identifying effective lighting solutions for the Royal Library’s existing structure, this research aims to bridge the gap between architectural lighting design and cognitive optimisation. Furthermore, the study will explore how varying lighting conditions influence different learning acquisitions, ensuring that the Future Library, including the Royal Library as a key case study, actively supports diverse modes of learning and cognitive engagement through a well-designed lighting landscape[6].

6 Lighting landscape refers to the integrated system of natural and artificial lighting within a spatial environment, designed to support cognitive, emotional, and spatial experiences. It includes dynamic modulation, seasonal variability, and interaction with architectural elements.

PROBLEM STATEMENT

Libraries have evolved from being exclusive book repositories to becoming interactive and dynamic learning spaces, with a focus on accessibility, engagement and adaptability. However, the challenge of creating an environment that optimises cognitive performance and knowledge acquisition remains underexplored in contemporary library design. A key factor in creating such an environment is lighting. The role of lighting extends beyond mere illumination; it is a crucial factor in cognitive performance, user-driven knowledge acquisition, and overall well-being (Çelik et al., 2024).

The static and monotonous nature of current library environments often fails to support the diverse cognitive needs of users. As Matthijs van der Meulen (intermediary at the Royal Library of the Netherlands) notes: 'Every day is the same here' and 'One doesn't notice the seasons here,' highlighting the lack of adaptive and dynamic lighting approaches in existing library environments.

Despite extensive research on the impact of lighting on cognition in the workplace and educational contexts, and several guidelines for energy-efficient and functional lighting in buildings being written, its application within libraries—particularly heritage buildings such as the Royal Library in The Hague—remains underexplored. In this context, the Royal Library serves as an ideal case study for exploring how lighting strategies can be integrated into an existing heritage building, with the aim of optimising both the cognitive and spatial needs of users while respecting its historical significance.

A clear research gap exists in linking the neurological effects of the overall lighting landscape to its spatial role in library design and its impact on user-driven knowledge acquisition and cognitive performance. This research aims to address this gap by exploring how lighting strategies can be optimised to enhance cognitive performance and support user-driven knowledge acquisition in future libraries. Drawing on insights from neuroscience[7], architecture, and case studies, the goal of this study is to develop an evidence-based spatial lighting framework that positions (day)light as a neurological stimulant[8]. The outcome will contribute to the discourse on neuroarchitecture and guide future library design in aligning spatial lighting with cognitive needs.

7 Neuroarchitecture is the field that explores the relationship between the brain and the built environment, focusing on how architectural elements like light, space, and design influence cognitive processes, emotional well-being, and behavior. It aims to design environments that support neurological functions, enhancing mental health, productivity, and overall human performance.

8 Neurological stimulant refers to an environmental factor that influences brain functions like attention, memory, alertness, and emotional regulation. In this study, light—especially the interaction of natural and artificial lighting—is seen as a neurological stimulant due to its impact on circadian rhythms and hormonal processes, enhancing cognitive performance and supporting knowledge acquisition in libraries.

RESEARCH QUESTIONS AND THEORETICAL FRAMEWORK

Building on the problem of underexplored lighting strategies, this research examines how lighting can enhance cognitive performance and knowledge acquisition in the 'Future Library.' The main question focuses on designing an effective lighting landscape, with sub-questions addressing its neurological effects, spatial strategies, and integration in the Royal Library.

MAIN QUESTION

How can the lighting landscape be designed to stimulate user-driven knowledge acquisition and cognitive performance in the 'Future Library'?

SUB-QUESTIONS

What is the role of the lighting landscape in influencing the neurological processes that drive knowledge acquisition and cognitive performance in a library environment?

What spatial lighting strategies enhance user-driven knowledge acquisition and cognitive performance within libraries?

What are effective lighting strategies to integrate into the existing structure of the Royal Library to optimise knowledge acquisition and cognitive performance?

THEORETICAL FRAMEWORK

This research adopts a hybrid theoretical approach, combining insights from neuroscience, architecture and lighting design principles. The central hypothesis underpinning the project is that an integrated lighting landscape, specifically one that leverages both natural and artificial light, can function as both a spatial and neurological stimulant. This, in turn, will enhance cognitive performance and user-driven knowledge acquisition in future library environments.

At the core of the theoretical foundation lies the understanding that light directly influences the brain's cognitive functioning—including attention, memory, emotional regulations and alertness—through its regulation of circadian rhythms and hormonal processes (Çelik et al., 2024; Yang & Jeon, 2020). Simultaneously, architectural theory positions light as a spatial tool that can shape user orientation, engagement and the atmosphere of learning environments (Lushington et al., 2016; Baker & Steemers, 2002).

In synthesising these fields, this research proposes a neuroarchitectural framework in which light is conceived not just as a passive element but as an active component in shaping the knowledge environment. This framework aims to go beyond functional or energy-efficient lighting design, proposing an evidence-based strategy for future library lighting landscapes, with the Royal Library in The Hague as a case study.

In order to operationalise this theoretical framework and test the central hypothesis, the research employs a mixed-method approach[9]. The details of which will be explained step by step in the next chapter.

9 A mixed-method approach is a research strategy that combines both qualitative and quantitative methods to gain a more comprehensive understanding of a complex topic. Integrating data from various sources, such as literature reviews, observations, statistical analyses and case studies, it allows for cross-verification of findings, bridging theoretical insights with empirical evidence and enhancing the depth, validity and applicability of research findings.

METHODOLOGY

In order to ensure a comprehensive exploration of the research questions, this study integrates four complementary methodological strategies (mixed-method approach): literature review, case study analysis, empirical research, and design-oriented research. The combination of these methods offers both theoretical insight and practical contributions, ensuring a comprehensive approach to the research questions. The next chapter explains how each method will be applied and its role in the overall research.

LITERATURE REVIEW

To establish a solid theoretical foundation, the study's literature review is structured around key themes that align with the main and sub-research questions. The selection of relevant academic and scientific sources is guided by carefully chosen keywords reflecting the core themes of this study. The primary keyword and main search term is "Library lighting design," which helps identify research related to lighting strategies in libraries. However, as this term alone does not cover all relevant aspects, additional search terms will be used, including "Lighting and cognitive performance," "Lighting design for study spaces," "Daylight strategies for academic environments," "Library lighting design and user engagement," "Lighting design in academic and heritage buildings," "Lighting impact on learning performances," and "Lighting effect on books."

the literature review is organised around two interconnected domains to provide a comprehensive understanding of the topic. First, literature on the impact of (day)light on neurological processes that drive knowledge acquisition and cognitive performance will be examined in order to integrate insights from neuroscience and environmental psychology regarding the effects of (day)light on knowledge acquisition and cognitive performance. Secondly, research on (day)light architectural design and concepts will be explored, focusing on how lighting strategies in educational and cultural environments, including libraries, can enhance knowledge acquisition and cognitive performance. These are often explained through the investigation of usefull case studies, investigating real-world applications.

To maintain focus and feasibility, the literature study has been based on a carefully selected pool of approximately 20 to 30 sources. These sources were selected based on their direct relevance to the research questions, as determined by an evaluation of abstracts, methodologies, and conclusions. The integration of insights from diverse disciplines is intended to provide a comprehensive understanding of the relationship between daylighting, knowledge acquisition, cognitive performance, and their architectural context. Figure 1 presents a matrix of the selected sources that inform this literature review, highlighting the associated themes and keywords identified within each source.

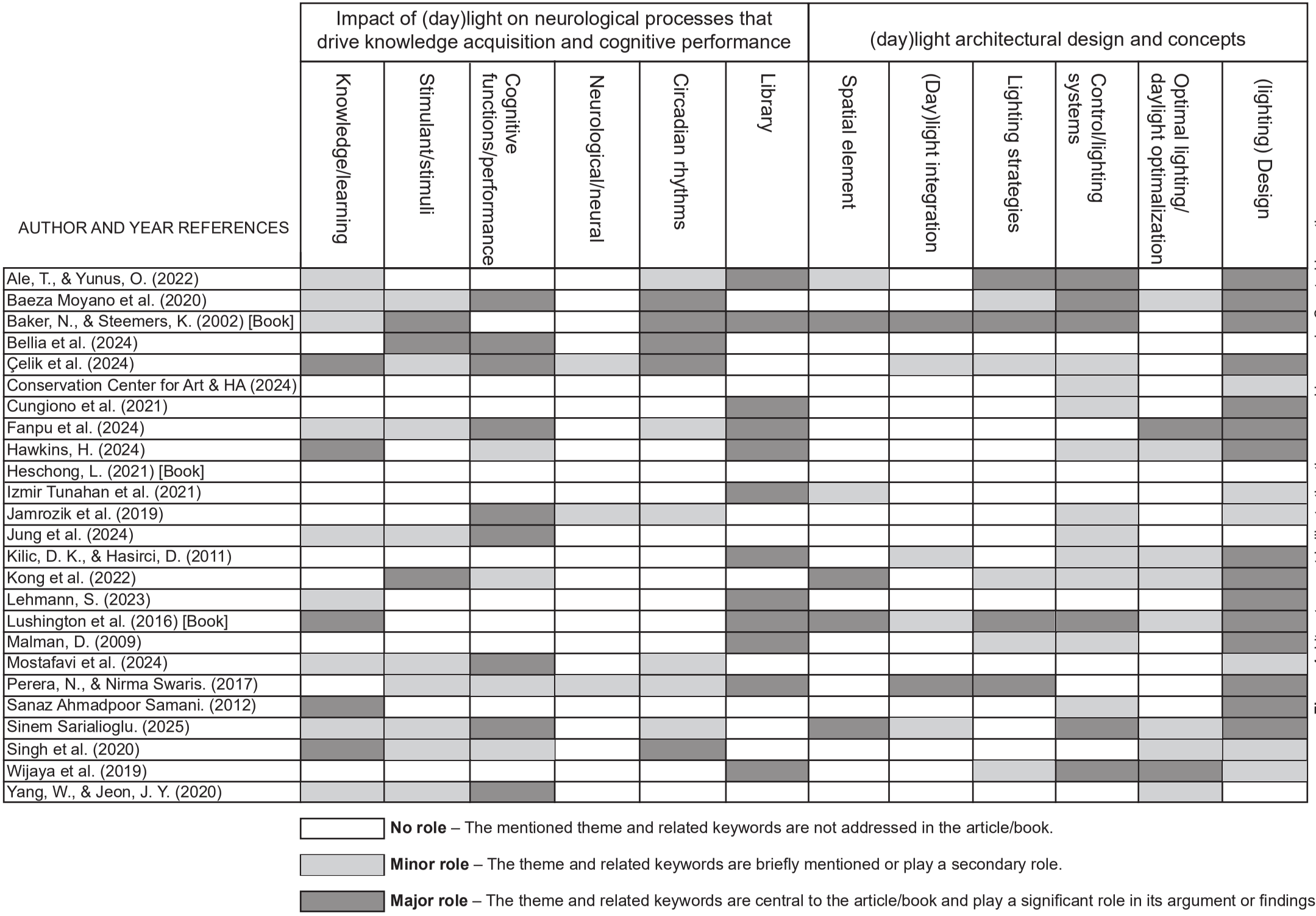

Figure 1. Literature matrix illustrating themes and keywords. Created by author.

Case studies are an essential method for analysing existing strategies of integrating daylight and/or artificial light in buildings that focus on enhancing user-driven knowledge acquisition and cognitive performance. The selected case studies align with the research questions and focus on buildings where lighting significantly contributes to user interaction and spatial organisation.

The case studies will be categorised based on two main criteria: (1) on-site visits for empirical analysis and (2) secondary research through literature. Site visits will be selected based on proximity to the researcher's location (Breda) and educational institution (Delft), ensuring feasibility within the project's time frame and budget. The study also differentiates between new libraries and those that have been revitalised, offering a comprehensive perspective on the role of lighting in a variety of architectural settings.

The case study method employs a primarily qualitative approach to understand how lighting is integrated and how it supports knowledge acquisition and cognitive performance in different spatial settings. This includes site visits, photographic documentation, and, if appropriate, short interviews with users. The analysis aims to identify lighting strategies that leverage (day)light as a neurological stimulant, focusing on how lighting can optimize spatial organisation and cognitive engagement in future libraries. Ultimately, this will contribute to an evidence-based spatial lighting framework that enhances user-driven knowledge acquisition and cognitive performance.

To provide insight into the different types of case studies, a diagram (Figure 2) has been created, categorised based on the aforementioned criteria.

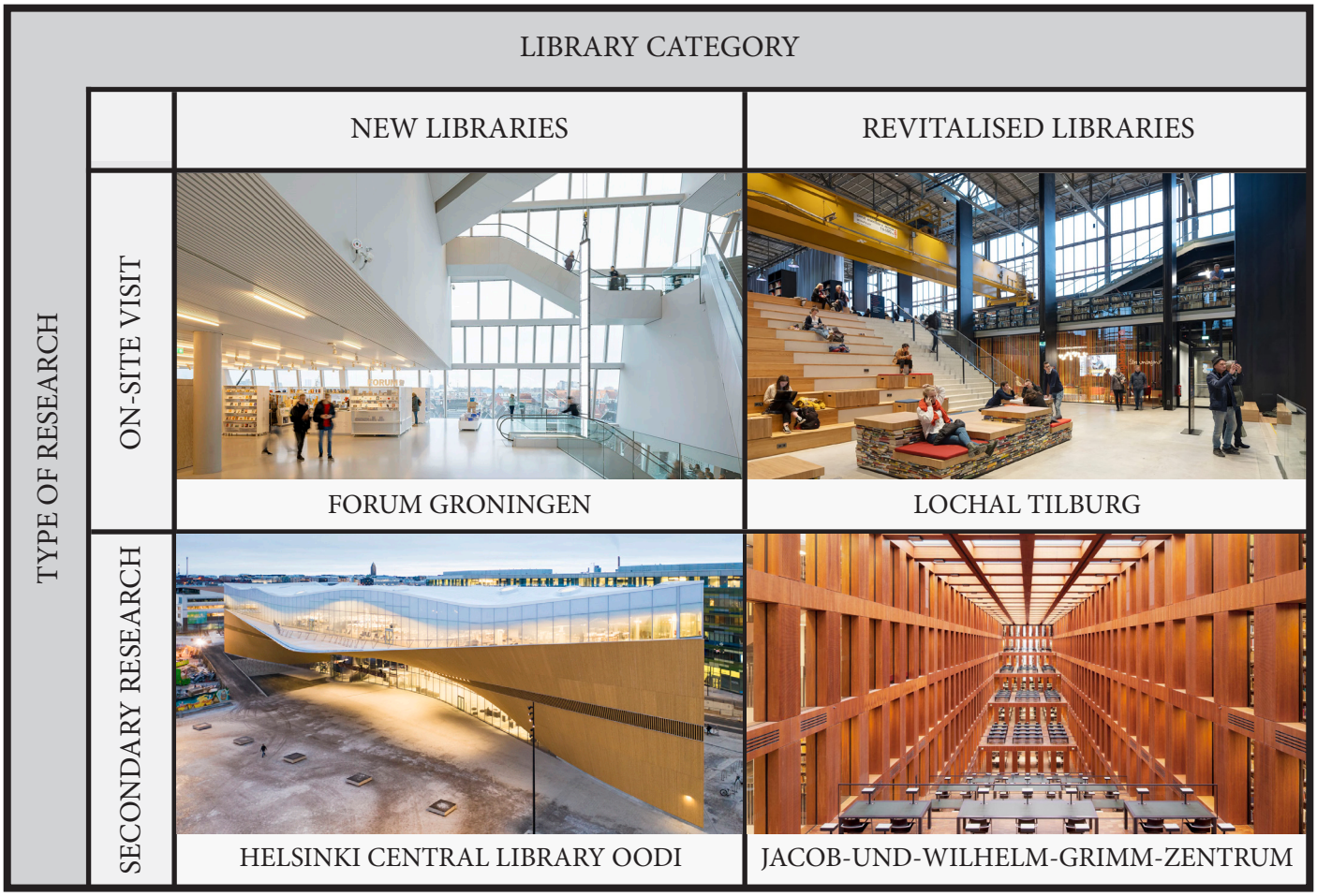

Figure 2. Categorisation of selected case studies based on type and research method. Created by author.

To ensure feasibility within the available timeframe, the case studies will be analysed through the lens of a single architectural element: the building's openings (such as windows, skylights, and façade perforations). This focused approach will allow for a more in-depth and manageable investigation of how openings contribute to daylight integration and, consequently, support user-driven knowledge acquisition, cognitive performance, and spatial organisation within library environments. A set of research questions, visualised in Figure 3, provides a focused and systematic approach to analysing the openings in each case study.

CASE STUDY ANALYSIS	ARCHITECTURAL & SPATIAL ANALYSIS OF OPENINGS	-What types of openings are used in the building? (e.g. vertical windows, skylights, clerestories, façade perforations) -What is the spatial distribution of these openings throughout the building? (e.g. concentrated around reading areas, evenly distributed, only on façades, etc.) -What is the visual connection between inside and outside through these openings? (e.g. views to nature, urban context, internal courtyards) -What is the orientation of the openings in relation to sun path and site context? -How does the depth of the rooms influence daylight penetration and distribution? -What kind of shading devices or light-regulating systems are applied? (e.g. louvers, dynamic shading, deep reveals) -In what ways do the openings shape the spatial experience and cognitive engagement of users? (e.g. sense of openness, focus, calm, stimulation) -Are there specific architectural elements or materials around the openings that enhance light diffusion or control glare? -How does the placement of openings relate to different functional zones (e.g. reading, circulation, group work)? -Do the openings allow for direct sunlight, diffuse daylight, or both? (And how is this managed to prevent discomfort?)

Figure 3. Analytical framework: research questions for evaluating daylight openings. Created by author.

EMPIRICAL RESEARCH

To complement the theoretical foundation and case studies, empirical research will be conducted at the Royal Library (KB) in The Hague. This location is chosen because it is the subject of the design project and provides a real-world context to test and develop lighting strategies. The objective of this component of the research is to assess the current integration of daylight and artificial lighting within the building, and to evaluate their impact on cognitive performance, engagement and spatial organisation.

This analysis aims to address key aspects of the research questions, especially the final sub-question, by directly measuring and evaluating the existing lighting conditions, identifying potential challenges, and uncovering opportunities for improvement. The ´raw data´ willl be compared with the subjective elements/aspects of the lighting conditions in the Royal Library. These subjective insights, such as users' feelings about the current atmosphere and the spatial usage in relation to lighting, will be gathered through on-site observations, surveys and interviews. The objective is to compare the measurable lighting data with its perceived effects on user experience and cognitive performance.

This empirical insight will serve as a practical foundation for refining lighting strategies at the KB, with the aim of enhancing user-driven knowledge acquisition and cognitive performance. Key aspects are illustrated in Figure 4, which outlines the main themes and guiding questions for data collection. The framework focuses on daylight, artificial lighting and user experience.

EMPERICAL RESEARCH – LIGHTING CONDITIONS AT THE ROYAL LIBRARY (KB)	DAYLIGHT INTEGRATION	-What percentage of the library surface receives direct sunlight? -What is the distribution of daylight across the library's different floors or levels? -Are there specific architectural design choices that enhance daylight penetration and distribution? Or shading/light-diffusing techniques to manage daylight exposure? -How does daylight vary throughout the day and across different seasons? -What are the UV levels/intensity and quality of daylight in different areas of the library? -How does the building's orientation and façade design influence natural light entry? -How do weather conditions (e.g., cloudy, sunny, rainy) affect the lighting experience inside the library? And are there any dynamic lighting systems that respond to changing daylight conditions? -What areas of the library are most exposed to glare from direct sunlight? -Are there spaces in the library that would benefit from additional daylight exposure? -How do seasonal daylight changes (e.g., longer daylight hours in summer vs. shorter days in winter) influence user behavior, comfort, and activity in the library?
	ARTIFICIAL LIGHTING	-What types of artificial lighting (LED, fluorescent, halogen) are used? -What are the LUX levels within different rooms? -Is the artificial lighting adapted for different areas (e.g., quiet study areas, collaborative spaces)? -Are there variations in lighting intensity, color temperature, and directionality to support different cognitive tasks (e.g., deep focus vs. casual reading)? -To what extent does the lighting strategy support different study behaviors (e.g., solitary deep work, group collaboration, informal reading)? -What role does artificial lighting play in compensating for seasonal or daily variations in daylight availability?
	USER ECPERIENCE	-How do users interact with and respond to the lighting environment in the library? -Are there any know problems with the current (day)lighting systems, such as too much or to little light, glare or uneven distribution? -How do visitors and staff experience this, and are there any complaints or suggestions? -What is the average length of stay of visitors in different lit areas? -What role do materials (e.g., glass, reflective surfaces, absorptive materials) play in shaping the lighting landscape? -Are there personalized or adaptive lighting strategies that respond to user needs throughout the day?

Figure 4. Empirical research framework for the Royal Library (KB): main themes and guiding questions. Created by author.

In addition to the empirical research, design-oriented research will be carried out to explore how lighting strategies can be integrated into the existing structure of the Royal Library (KB) to enhance cognitive performance and knowledge acquisition.

Using DIALux software[10], simulations can be created to model the interaction between natural daylight and artificial lighting across different times of day, seasons, and weather conditions within the space. This can provide insights into how these factors affect both spatial organisation and cognitive engagement. If full-scale simulations prove too complex, a selected portion of the building will be analysed instead. Should simulation efforts prove unfeasible, the research will rely on material-based analysis and simplified design experiments using tools such as SketchUp.

The results will inform evidence-based lighting design and contribute to a spatial lighting framework for future library spaces that enhance knowledge acquisition and cognitive performance. A diagram illustrating the design oriented research is shown in Figure 5.

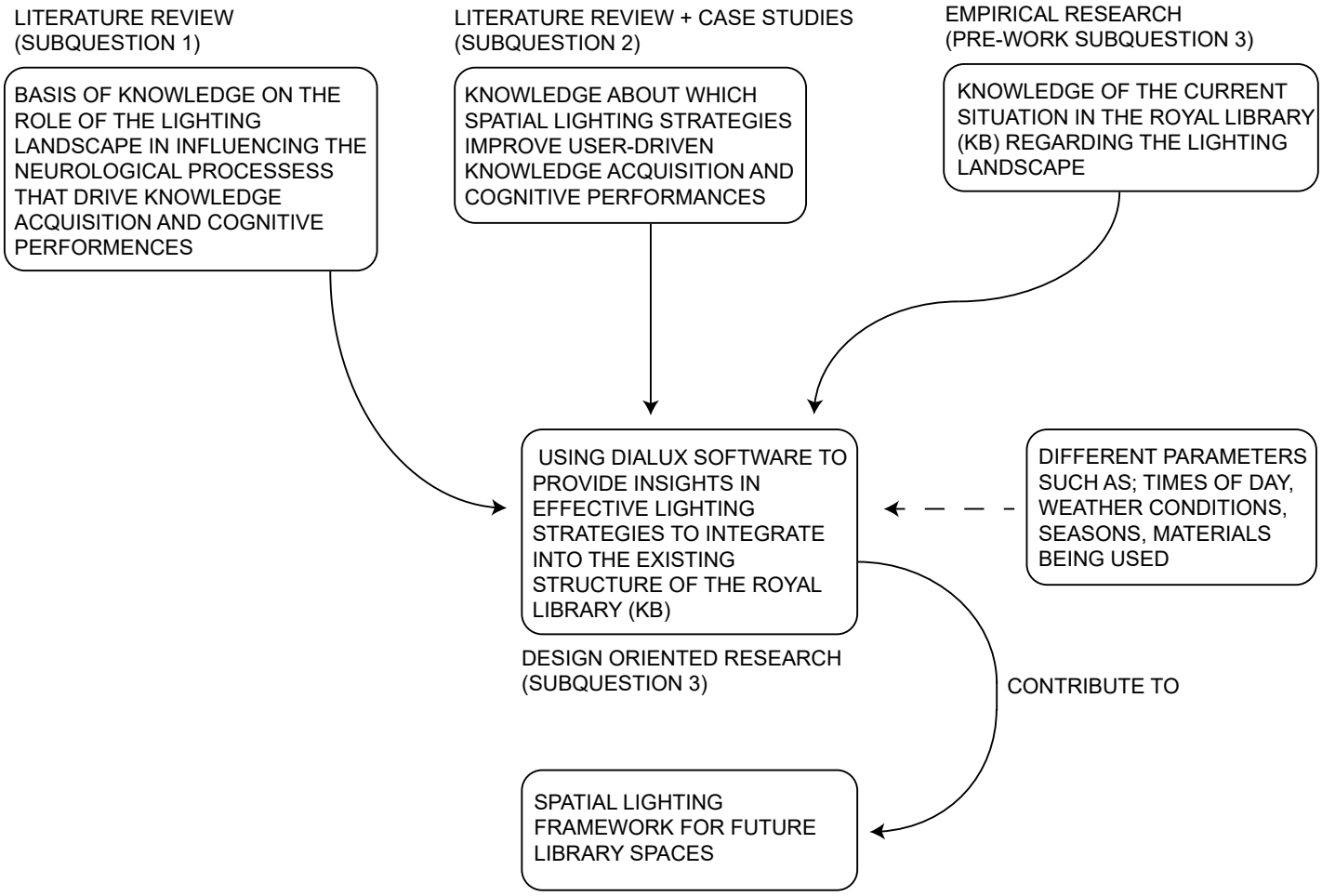

Figure 5. Design-oriented research process for lighting strategy integration in the Royal Library (KB). Created by author.

10 DIALux software is a professional lighting design tool that is used to simulate natural and artificial light in architectural spaces. In this study, it supports design-oriented research by modelling how lighting strategies affect cognitive performance and knowledge acquisition in the Royal Library.

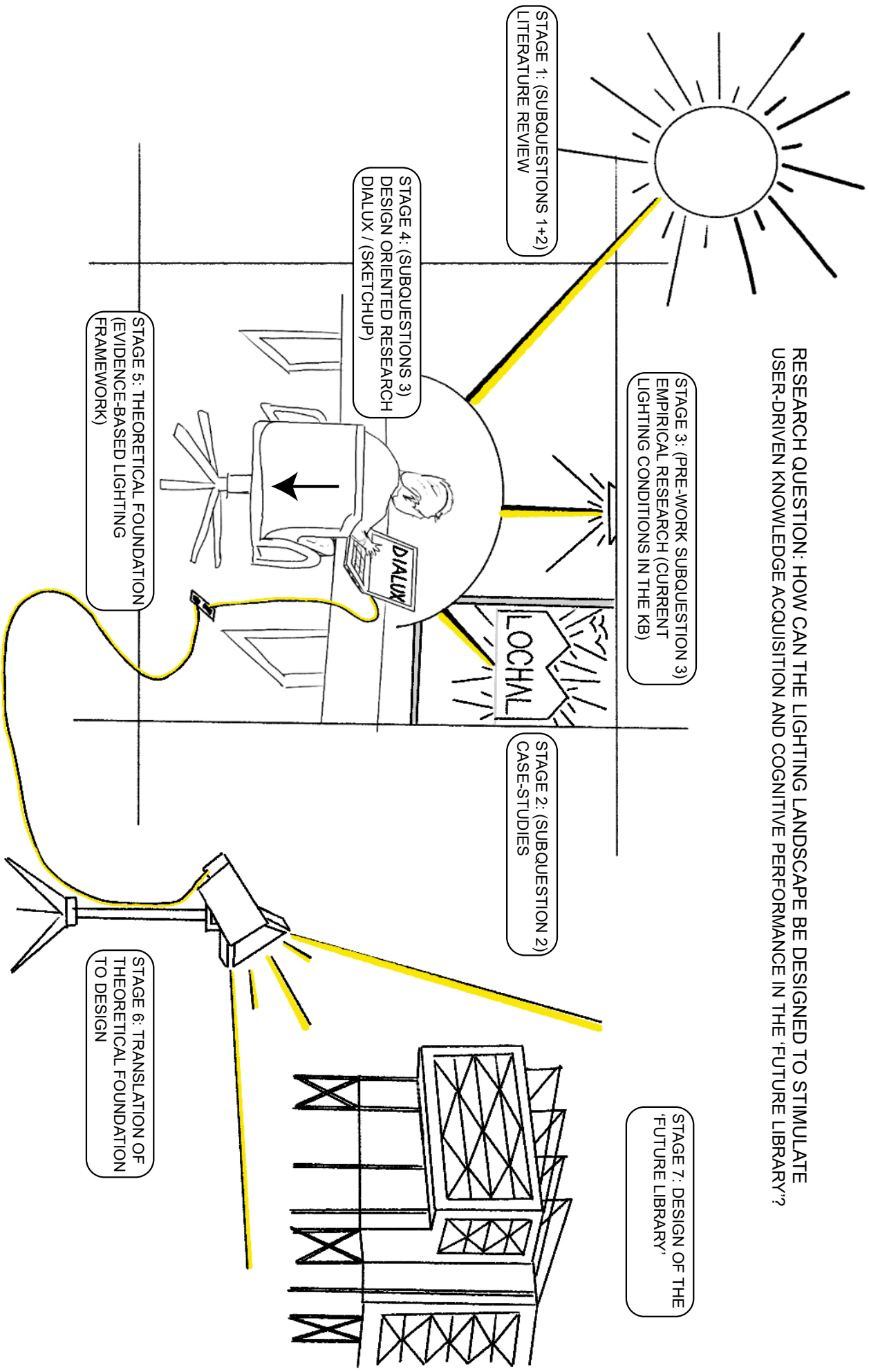

Figure 6. Comprehensive workflow research-plan and translation to design (for KB). Created by author.

RESULTS, OUTCOME AND RELEVANCE

This research is expected to yield a comprehensive, evidence-based framework for the design of lighting landscapes in future libraries. Through the integration of findings from neuroscience, architecture, and empirical case studies, the study will identify spatial lighting strategies that actively enhance user-driven knowledge acquisition and cognitive performance.

The outcome will contribute to the discourse on neuroarchitecture by positioning light not merely as a technical requirement but as a spatial and cognitive stimulant. The proposed design framework aims to inform architects and lighting designers, offering practical strategies for transforming libraries into environments that foster intellectual engagement, knowledge acquisition and cognitive performance through lighting design.

The relevance of this study lies in addressing a critical gap in contemporary library design by establishing a link between lighting and neurological stimulation, as well as spatial experience. As libraries continue to evolve from static repositories into dynamic learning environments, the findings will offer guidance for designing cognitively supportive and user-oriented lighting strategies, particularly in heritage contexts such as the Royal Library in The Hague. This case study will demonstrate how adaptive lighting design can be integrated into an existing architectural framework.

RESEARCH PLANNING

ACTIVITY
PRE-WORK (PREPARATION)
Implement Feedback within Research Plan
Hand in the P1 Research Plan
GROUP RESEARCH (LIBRARIAN USERS)
Workshop
Prepare interviews and needed attributes for site visit
Visit to Royal Library (KB) (Photo recording, sketches, mapping, interviews)
Reflecting on the information
Value Matrix
Extra Group work if necessary
SUB-QUESTION 1
Reading literature on impact of (day)light on neurological processes...
Write down important aspects to take into account simultaneously
Conclude important aspects and write structured story
SUB-QUESTION 2
Reading literature on (day)light architectural design and concepts
Write down important aspects to take into account simultaneously
Conclude important aspects and write structured story and sketches
Case-study analysis through secondary sources
Case-study reflection and writing/sketching
Case-study visit
Conclude case-studies and write structured story and sketches
SUB-QUESTION 3
Empirical-Research regarding the existing lighting conditions in the Royal Library
Document the Royal Library (or part of it) in 3D program (Sketchup/Dialux)
Design-Oriented research using DiaLux with different parameters
Reflect on the design oriented research and write down important aspects
Draft design evidence-based spatial lighting framework
Design of evidence-based spatial lighting framework
Develop conceptual ideas from research to design (SoR (PvE), Mass studies, spot plan)
Powerpoint presentation P2
P2 Presentation
Implement Feedback and revision of research + conceptual design
START DESIGN PHASE
Work out conceptual ideas to more concrete design ideas
DRAFT DESIGN (IMPORTANT TEST PHASE)
Test the evidence-based spatial lighting framework with the start of the project
Implementing feedback and improvements
FINAL DESIGN
TECHNICAL DESIGN
Details based on design principles from research
Refining/writing

Figure 7. Research planning: Research activity overview. Created by author.

DAYLIGHT AND ARTIFICIAL LIGHTING STRATEGIES FOR 'FUTURE LIBRARIES'

A GUIDE FOR THE LIGHTING LANDSCAPE TO ENHANCE

USER-DRIVEN KNOWLEDGE ACQUISITION AND COGNITIVE PERFORMANCE

Bart Mooren 5644747

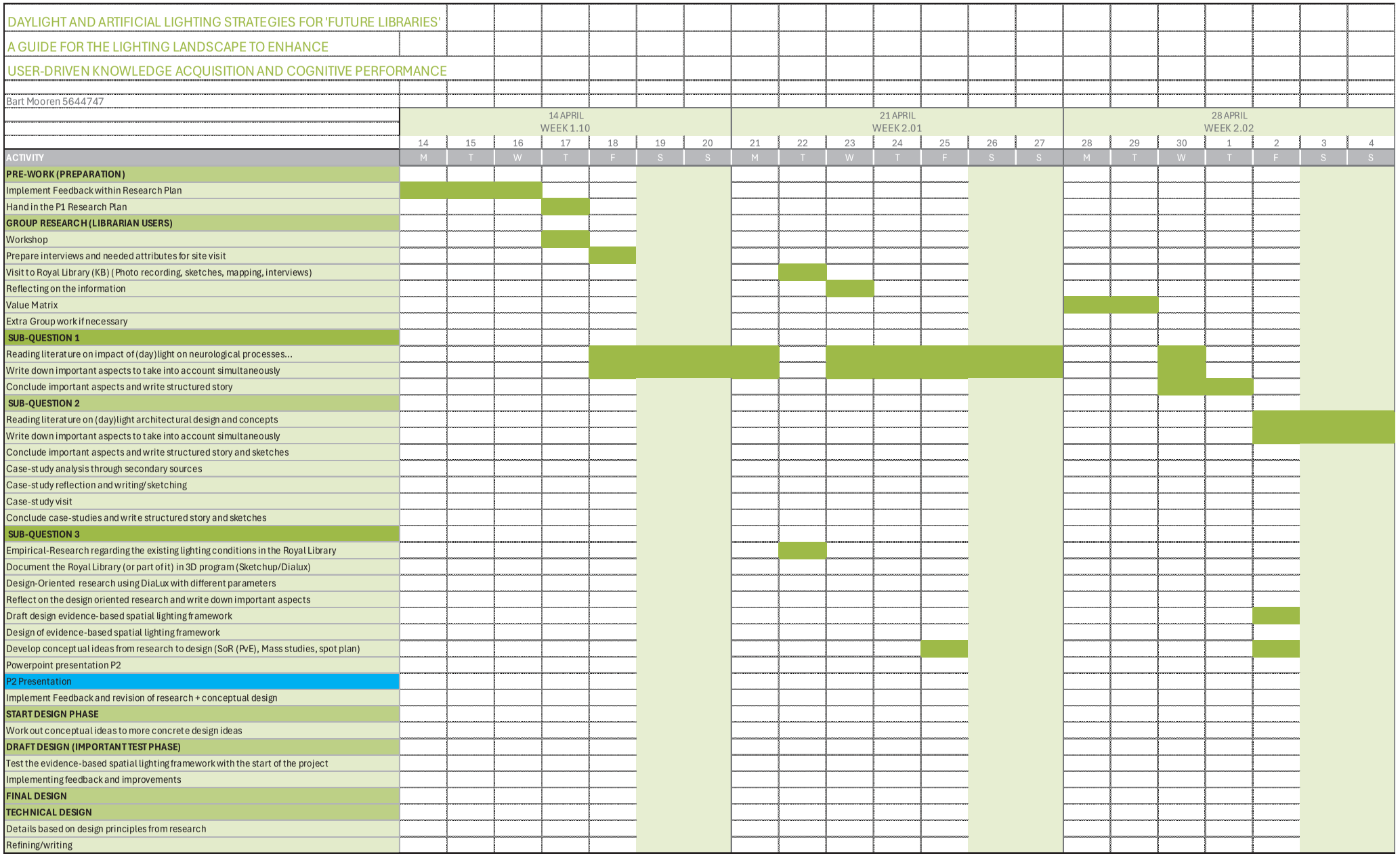

Figure 8. Research planning: week 1.10 to week 2.02. Created by author.

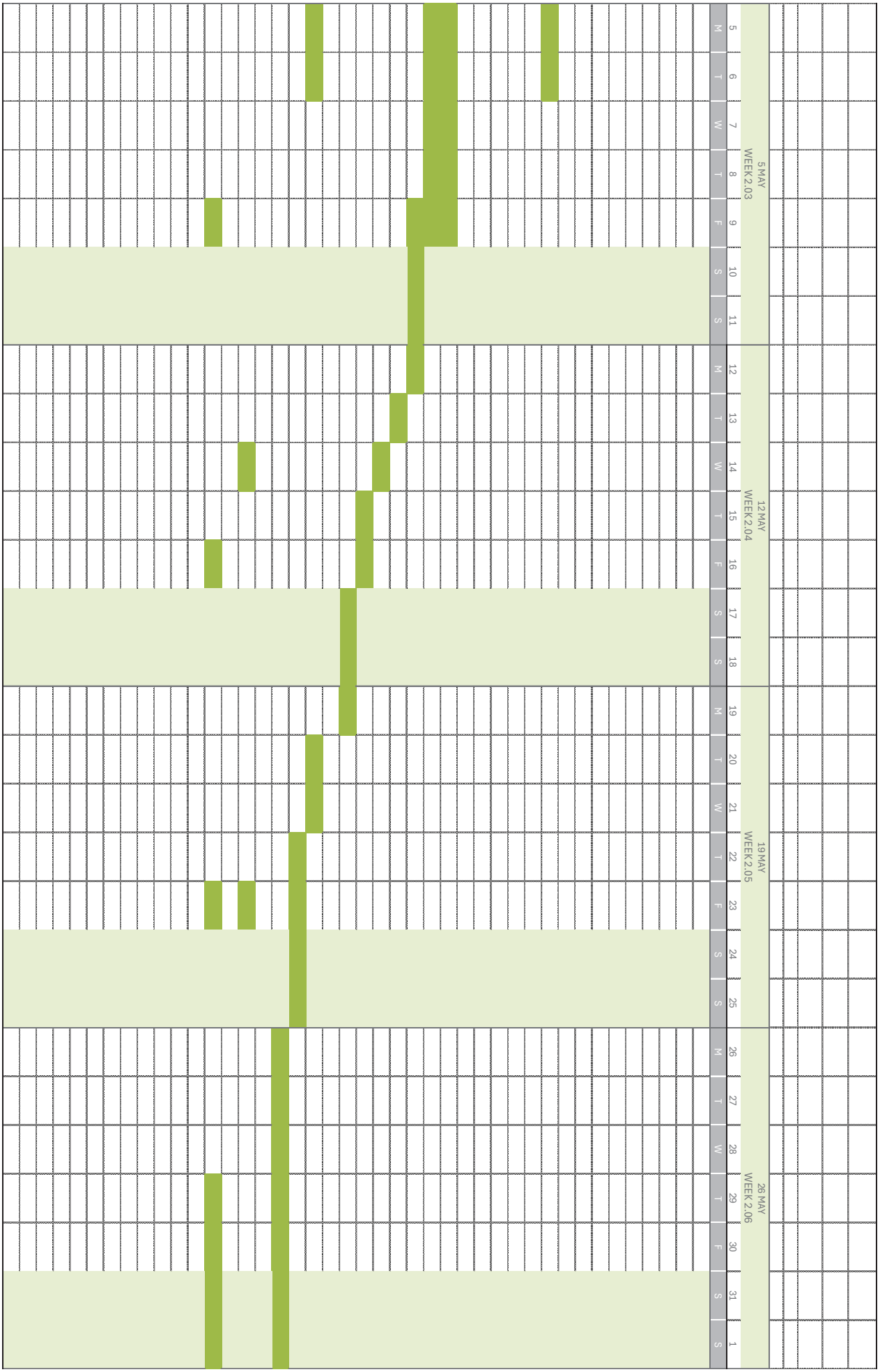

Figure 9. Research planning: week 2.03 to week 2.06. Created by author.

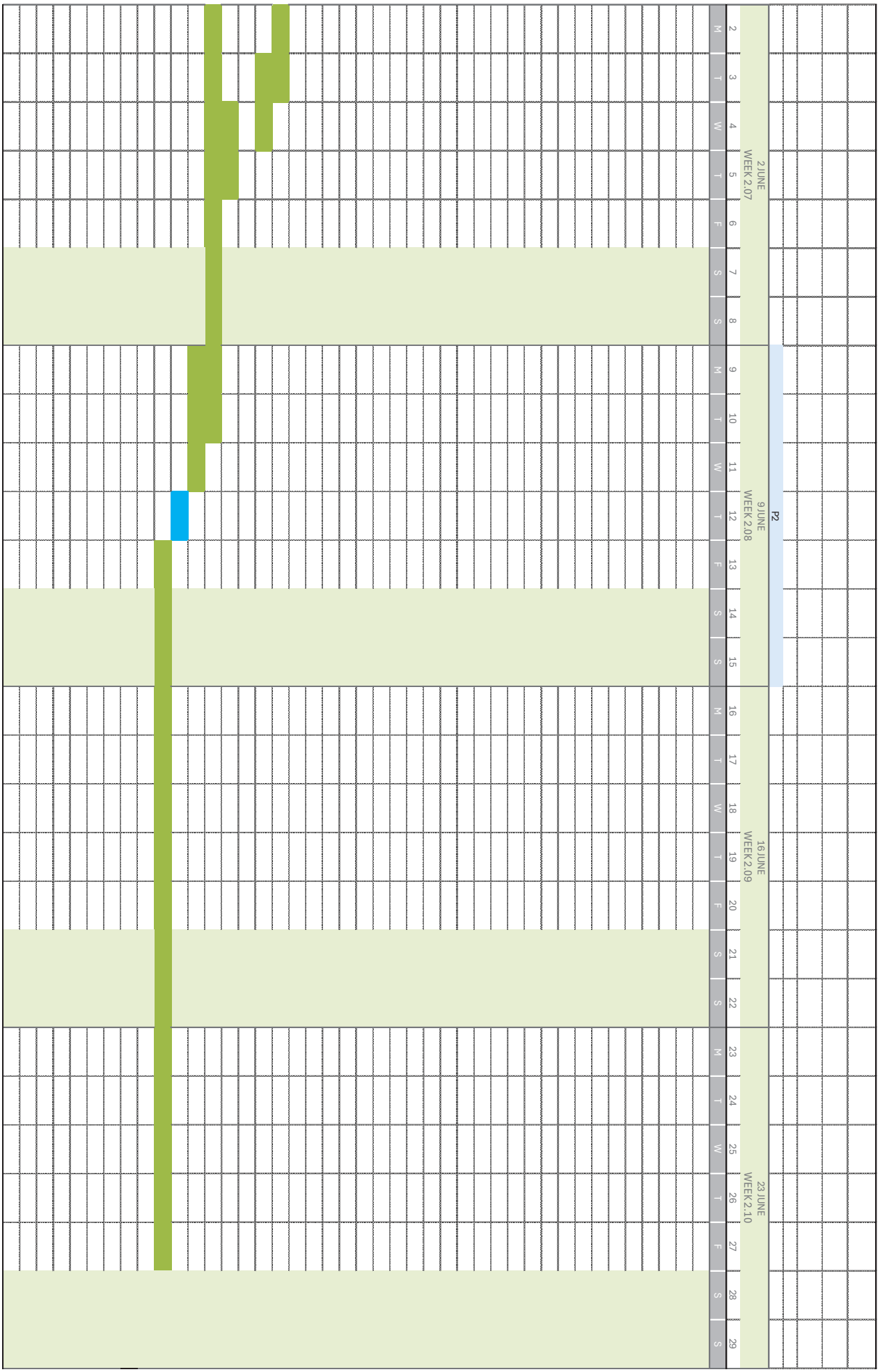

Figure 10. Research planning: week 2.07 to week 2.10. Created by author.

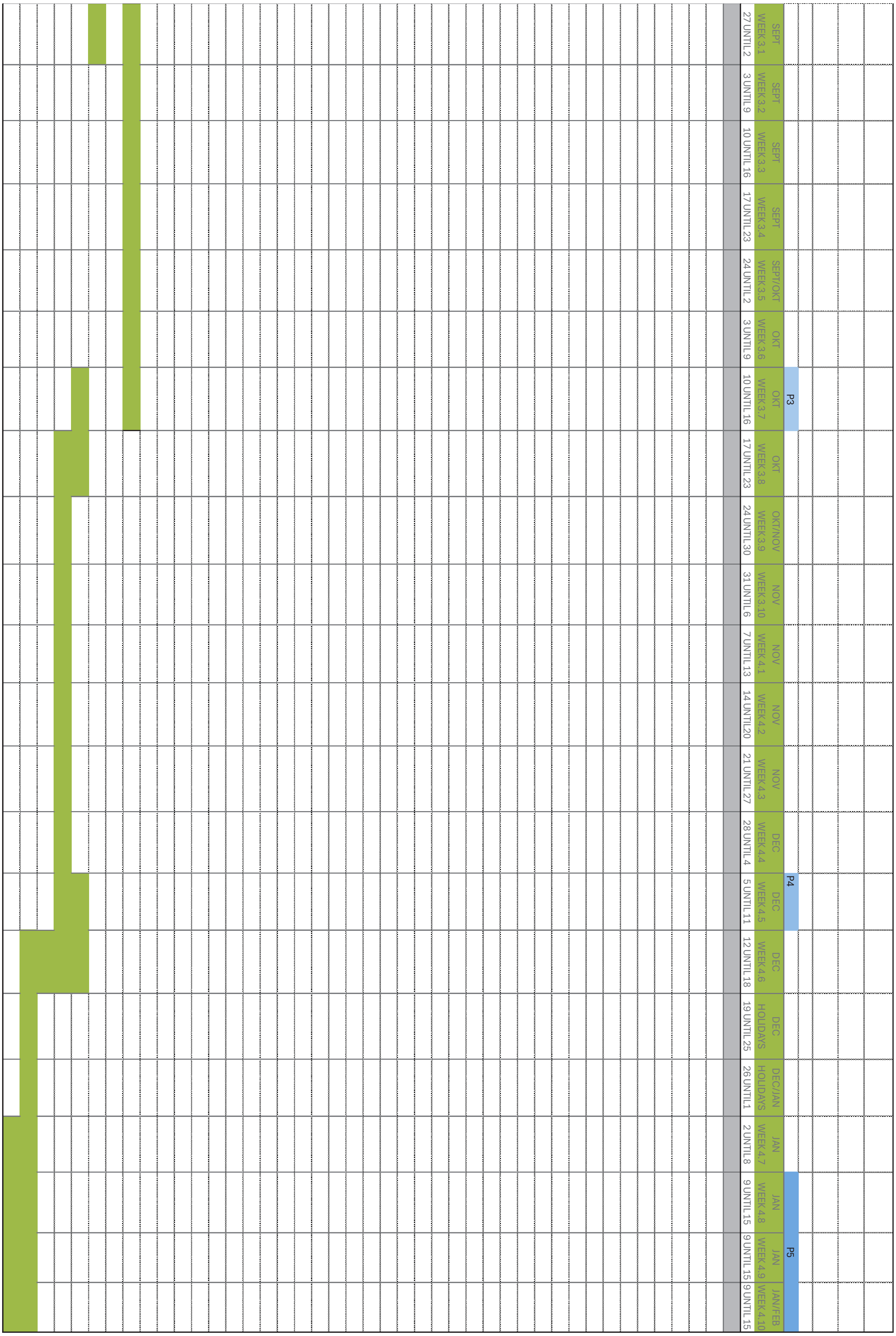

Figure 11. Research planning: week 3.1 to week 4.10. Created by author.

PRELIMINARY PROGRAMME & DESIGN IDEAS ROYAL LIBRARY (KB)

Before the research phase officially began, a preliminary spatial programme was developed to outline initial assumptions about the future functions of the Royal Library (KB). This preliminary programme will form the basis of the design process and reflects intuitive expectations based on the site's current conditions and potential. It should be noted that this programme is provisional and is expected to evolve as the research progresses and new insights are gained through literature, case studies, empirical analysis and design-oriented research. An overview of these initial assumptions is presented in Figure 12 and an early set of spatial design explorations for the future Royal Library is illustrated in Figure 13, showcasing conceptual ideas regarding the site and a visualisation of its possible transformation.

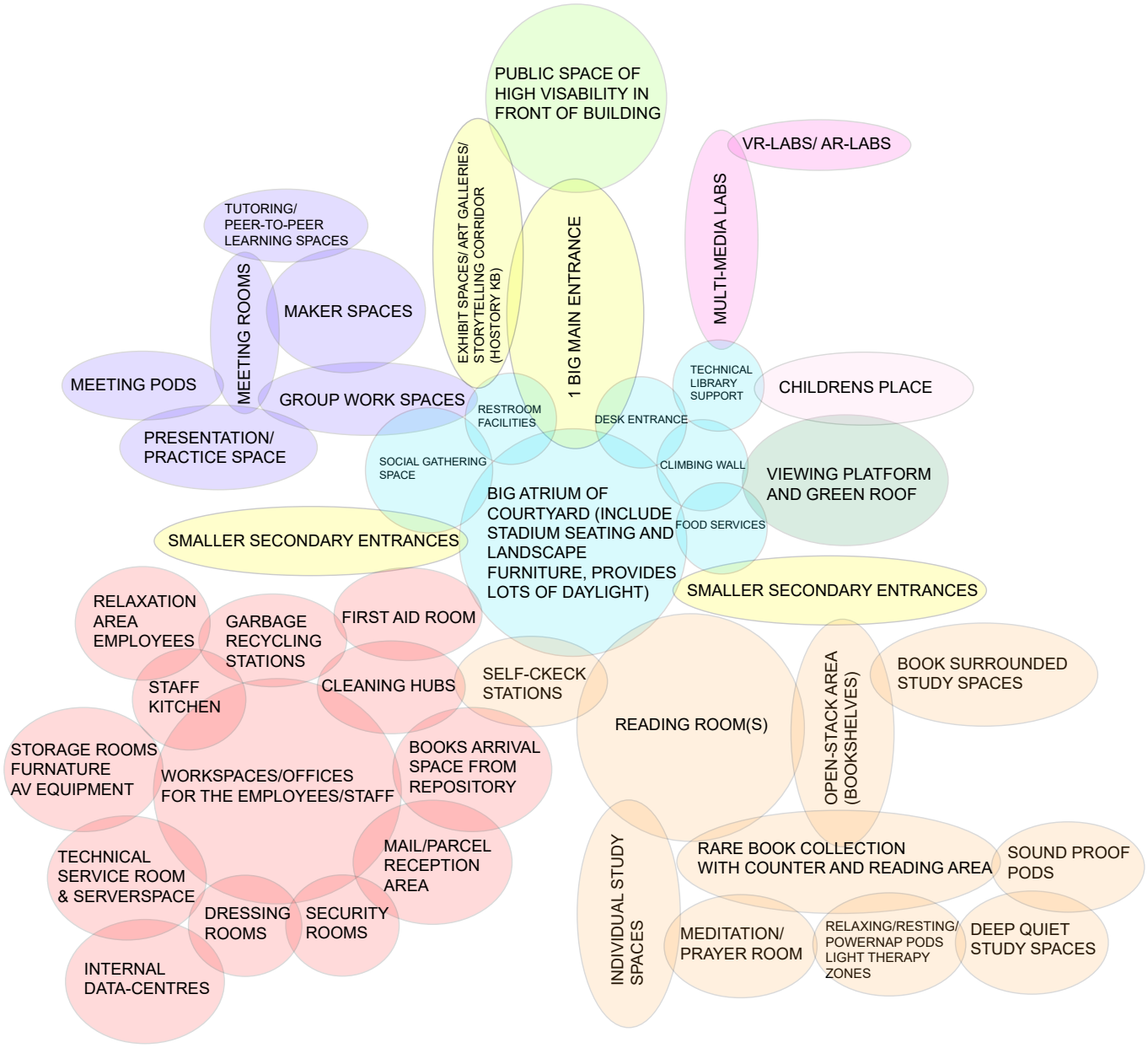

Figure 12. Preliminary programme assumptions for the KB before research phase. Created by author.

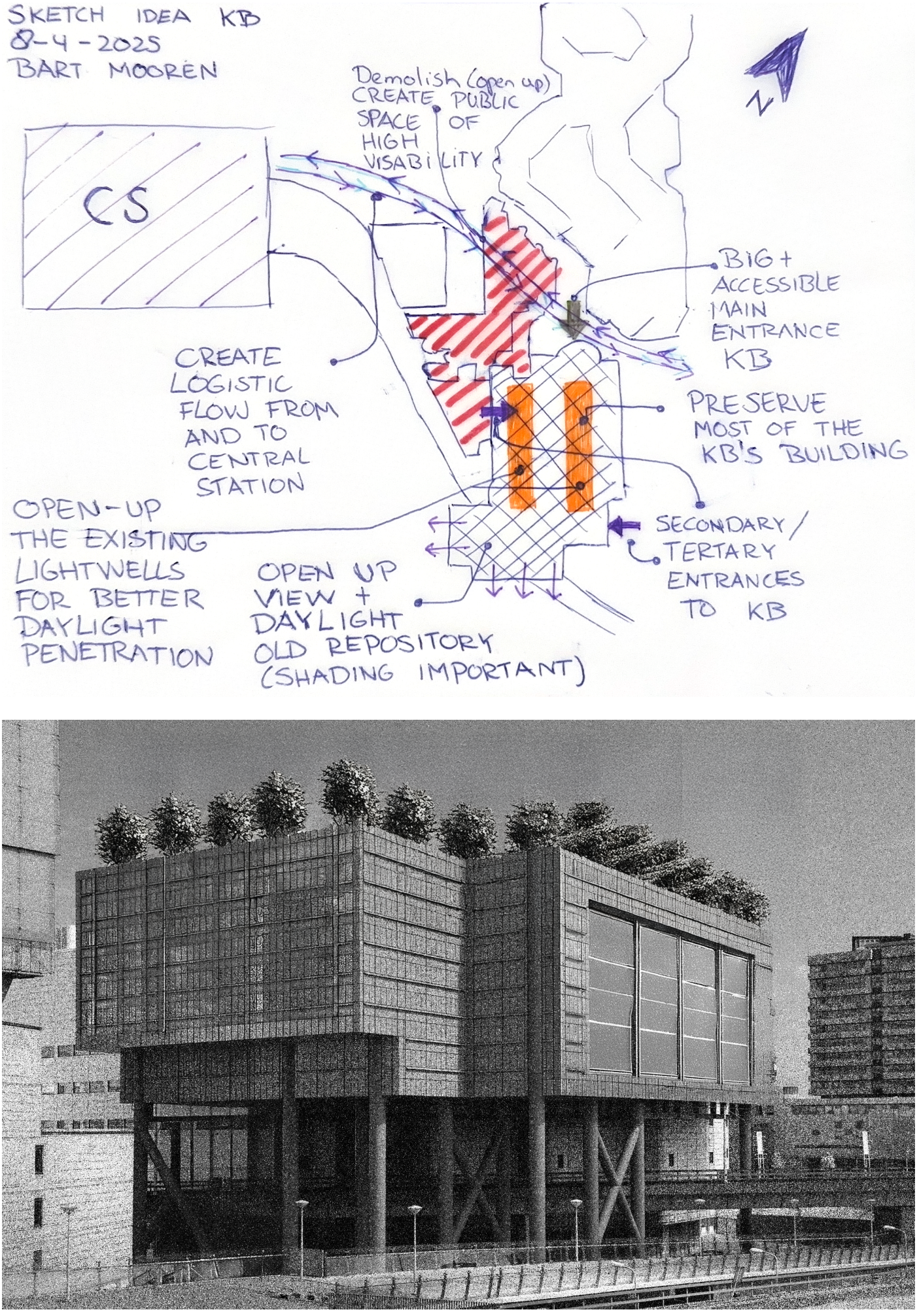

Figure 13. Design explorations for the future Royal Library (KB). Created by author.

APPLIED AND FUTURE BIBLIOGRAPHICAL SOURCES

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