Preserving the past, building the future: analyzing design issues in monumental building transformations

Master Thesis Civil Engineering and Management

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Abstract - The adaptive reuse of monumental buildings presents a complex challenge that balances historical preservation with modern functionality. This study explores the design issues and solutions associated with repurposing historically significant structures, aiming to bridge gaps between theoretical frameworks and practical applications. Through a dual-method approach, the research integrates a systematic literature review and detailed case studies to develop a comprehensive framework for managing design challenges. The analysis reveals that design issues can occur in all parts of the monument, including for example the installations or the skin of the building. In addition, this study highlights the inadequacy of one-size-fits-all solutions, emphasizing the need for tailored strategies. Retaining a building's original function and layout often reduces design issues, demonstrating the value of aligning new uses with historical designs. The study also contrasts literature with practical findings, identifying a gap where Brand's "site" and "stuff" layers are less explored in existing research. The discussion extends to the sustainability impacts of adaptive reuse, addressing social, environmental, and economic dimensions. The research highlights limitations such as the underexplored regulatory frameworks and calls for further investigation into the "site" and "stuff" layers and the need for broader, more diverse case studies to enhance the understanding of adaptive reuse in various contexts.

Keywords: Adaptive reuse, heritage, design issues, monumental buildings, transformation.

1. Introduction

The built environment embodies a kind of duality, encapsulating a so-called internal conflict within its architectural essence. The remarkable endurance of the built heritage, persisting for decades, shows a unique continuity rarely seen in other fields (Mort & Drennan, 2002). This comes from the careful selection of materials and construction methods used in building design (Soronis, 1992). Moreover, the built environment has the potential for creating monumental, emotional and societal value (Vîlcea et al., 2023). It can become symbols of culture, history and identity, fostering a sense of connection and emotional resonance within a community. Therefore contributing uniquely to the society they are anchored in and offering more than just physical shelter and utility (Saul & Marsh, 2018).

On the other hand, the longevity of buildings can create a situation where design criteria from the past may not align with the present. In such instances, various alternatives emerge for the extant edifice. The most apparent alternative involves the demolition of the construction (Thomsen & Van Der Flier, 2011), followed by the erection of a new building on the vacant land. Nevertheless, in consideration of sustainability imperatives, a growing shift towards the repurposing of existing constructions can be observed, entailing the reassignment of the building to a function divergent from its initial design, so-called “adaptive reuse” processes (Armstrong et al., 2023). The approach is especially applicable to monumental buildings, which often have protected status due to their historical significance and cannot be easily demolished (Draye, 2008). Monuments are defined as structures of historical or cultural significance, typically featuring distinctive design elements, intricate craftsmanship and materials that reflect the era of their construction (Lourenço, 2022).

The convergence of incorporating modern materials and technologies to meet present-day demands, alongside the preservation of intrinsic historical elements of the monument, presents significant challenges in both design and execution of the adaptive reuse process (Beltran Rodriguez & Simon, 2016; Hein & Houck, 2008).

1.1. Adaptive reuse in literature

Although the concept of adaptive reuse in itself is not new in the construction industry, there is limited knowledge available focusing on the repurposing of cultural heritage. The challenges that arise when designing new functions into the monument while simultaneously safeguarding the historical significance. These are further referred to as “design issues”.

Within the existing body of knowledge, many articles focus on broad topics. This includes studies with a focus on mapping factors that influence decision-making processes of monumental building transformation (Bullen & Love, 2011; Chen et al., 2018). While other studies focus on personal, local and regional perspectives with respect to heritage transformations (Pranskūnienė & Zabulionienė, 2023).

The absence of dedicated research becomes even more apparent in the comprehensive review of Kahvecioğlu and Selçuk (2023), which reveals that the main focus within the domain is on the concept of sustainability. Therefore, the challenges related to balancing modern functionality and preservation, are often overshadowed by these broader topics. This includes papers focusing on specific topics of sustainability, such as conservation of the embodied energy (Assefa & Ambler, 2017; Baker et al., 2017; Munarim & Ghisi, 2016), but also on the general term of sustainability (Doshi & Sudha Devi, 2023; Faiz Büyükçam & Eyüboğlu, 2023). Controversially, Kristl et al. (2020), conducting a comprehensive literature review of 120 selected papers, concluded that sustainability is not well addressed in recent literature on heritage buildings reuse. However, also they acknowledge the gap in design issues is remarkable, while the building geometry in combination with specific heritage requirements can prevent designers to implement certain solutions. Further acknowledged by Bianchi et al. (2023).

While there is a growing trend towards preserving global architectural heritage through adaptive reuse, the connection between the academic and practical exploration of design issues and solutions remains scarce. The need for compatible, appropriate, and scientific means to evaluate and address design issues in the adaptive reuse of monumental buildings is highlighted as an area requiring further attention and research in the field (Hegazi et al., 2021).

By acknowledging the existing gap, this research aims to uncover and understand the practical complications that may arise in adaptive reuse projects of heritage buildings and provide applicable solutions to it. The specific objectives include developing a practical framework for classifying these design issues and examining real-world approaches employed in the adaptive reuse process. By synthesizing the data, communication within the industry will be improved and trial-and-error processes will be reduced (Kahvecioğlu & Arslan Selçuk, 2023; Plevoets & Van Cleempoel, 2011).

In this research, an answer is sought to the following research question: “How are design issues solved in the process of monumental building transformations and what lessons can be learned from that?”.

The outline of the research paper is as follows. The paper begins with covering the background of the study. Subsequently, the methodology consisting of two phases will be discussed. Followed by the results of the research and a thorough discussion including the key findings, limitations and recommendations.

2. Theoretical background

This section serves as a basis for the consecutive phases of the research and is divided in three parts. Firstly, the drivers for implementing adaptive reuse are discussed. While the primary objective of this research is not to identify motivations for implementing adaptive reuse approaches, this does provide the reader with a better context of the decision-making framework. Secondly, the theoretical background delves into the unique challenges and complexity within the field of monumental transformations.

2.1. Drivers of adaptive reuse

There are multiple drivers for the implementation of adaptive reuse in the current construction industry which might not be (or be less) present in the common practice of constructing new buildings (Sev, 2009). These drivers can be recognized as parts of the three pillars of sustainability, incorporating economic, social and environmental issues in the planning, construction and demolition stages (Kibert, 1994; Purvis et al., 2019).

2.1.1. Environmental sustainability

The *Global Status Report for Buildings and Construction,* published in 2019, highlights the criticality of environmental sustainability within the construction industry for achieving the Paris Agreement of 2015 (Morel & Dorpalen, 2023). With the construction industry being the largest emitter, the growing trend of adaptive reuse can contribute significantly to achieving the goal of 45% reduction in 2030 (Ahmed et al., 2021; Saier, 2022). It helps in preserving the embodied energy of (heritage) buildings, making projects more environmentally sustainable compared to new constructions (Hegazi et al., 2021). Adaptive reuse promotes in fact a shift from the (common) linear supply chains to a circular economy, requiring a minimum overall natural resource extraction and environmental impact by extending the use of materials and reducing the consumption and waste of materials and energy (Foster, 2020). Finally, by reusing buildings also lands are saved, leaving more habitats for different flora and fauna (Karakuş, 2022; Virtudes, 2016).

2.1.2. Economic sustainability

Secondly, adaptive reuse of monumental buildings pursues economic sustainability. It must be recognized that characteristic buildings inherent in the urban environment for decades, assume a pronounced significance, encapsulating the historical narrative and cultural identity of the locality (Lahoud, 2008). These buildings in fact offer the community a unique and aesthetically distinctive character. On the one hand, this unique character can draw the attention of companies that are seeking permanent (unique) locations for their offices or operations, such as architects or cultural institutions. While, on the other hand, attraction of short term interested parties, such as tourists, is also well possible and creates opportunities for the community to capitalize on the tourism industry (Bianchi & De Medici, 2023). Both opportunities create a higher level of employment and financial income for the community (Adil Abdulameer & Sati’ Abbas, 2020).

Although there is a widespread belief that repurposing old constructions is more cost-effective than demolishing and constructing new buildings (Ball, 1999; Douglas, 2006), there remains contention regarding whether the expenses associated with building reuse are genuinely lower than those of demolition and rebuilding (Kohler & Yang, 2007).

2.1.3. Social sustainability

Thirdly, the conservation of buildings with historical significance is a manifestation of social sustainability as well. It fosters positive cultural impacts on local communities and the enhancement of urban and territorial contexts (Bianchi & De Medici, 2023; Lundgren, 2023). Additionally, repurposing heritage buildings, especially religious ones, can address broader sustainable development goals by promoting equity and well-being. Such constructions frequently serve as a home for vulnerable individuals, including those who may be experiencing homelessness or require (extensive) support and shelter (Faro & Miceli, 2019). Both functions require high spatial requirements, especially for individuals with physical or mental health challenges, necessitating round-the-clock assistance, since both clients and service providers need to be housed (Elrod & Fortenberry, 2017). The need for large spaces in combination with the high construction costs associated with new developments often pose budgetary constraints, rendering the execution of such initiatives unfeasible for the targeted groups. While in the case of adaptive reuse, the construct is already (partially) established for the proposed function (Davari et al., 2016).

Overall, opting for the adaptive reuse of older buildings embraces historical preservation and aligns with sustainable development practices of all three pillars. In this research, the drivers provide only one side of the story, while the issues of the adaptive reuse process are discussed in the following sections.

2.2. Challenges of reusing built heritage

Although adaptive reuse of heritage has advantages, the complexity within the field inhibits widespread implementation. The complexity stems both from the functional change of the monument, as well as from the conservation of its authenticity. The commitment is articulated in international guidelines, such as the United Kingdom Guidance for Practice (United Kingdom Institute for Conservation of Historic and Artistic Works, 1983). Conservation is defined in this as the means by which the true nature of an object is preserved, including evidence of its origins, original construction, materials and the technologies used (Harun, 2011).

The awareness of contributors to this true nature of a historic buildings is not always clear to construction workers and designers that execute the transformation process (Cramer & Breitling, 2007; Wong, 2016). This lack of awareness can lead to operational issues, which encompass organizational, regulatory and financial challenges (Zainal Abidin & Harun, 2023).

Firstly, the lack of specific knowledge within project teams may cause organizational challenges to arise. The specialized nature of heritage conservation means that the required expertise is not always readily available, causing suboptimal decision-making (Keitsch, 2020; Otero, 2022). Improving the expertise may require significant resources: external knowledge can be bought in or specialized labor can be trained, both requiring costs and time.

Secondly, heritage transformations incorporate many diverse interests and roles in decision-making processes, as highlighted in various research papers. Bansal and Chhabra (2022) note that stakeholders, including locational and social entities, significantly impact the adaptive reuse of heritage buildings. Additionally, research by Popescu and Staicu (2022) underscores that challenges in cultural heritage reuse mainly revolve around civic engagement domains, necessitating a multi-stakeholder approach for successful outcomes. Therefore, the complexity of stakeholder involvement, differing priorities, and decision-making processes contribute to the challenges faced in the adaptive reuse of heritage buildings (Katrakazis et al., 2018).

Thirdly, transforming the building is restricted by permits. Permits ensure that changes to cultural heritage buildings are controlled, preserving their historical and architectural significance (Stokin & Ifko, 2014). However, the lack of legal security can lead to risk reversion of investors, delays and therefore potential destruction of heritage sites (Faridi & El-Sayegh, 2006). In some countries, permit systems can also be used as barriers to entry, allowing monopolization of industries by a single entrant through the acquisition of all permits (Živković et al., 2019). The challenges regulations exert on heritage buildings, can also be seen on a broader scale: zoning plans (Amayu, 2014). Finding financial attractive new functions, may clash with zoning requirements, necessitating adjustments to ensure regulatory compliance without compromising the design vision.

Financial attractiveness forms the fourth issue. The primary challenge revolves around the high costs inherent in the complete renovation of historic buildings, often leading to demotivation among end users and real estate owners. The combination of being limited in construction activities for preserving the authenticity and the uncertainty of having underlying surprises that become apparent during the construction phase make preparing a balanced budget difficult (Soleymani et al., 2023).

Moreover, including the estimation of economic returns in the context of adaptive reuse intensifies the complexities within the category of design issues. Two primary factors contribute to this challenge. Firstly, cost overruns, a pervasive concern in the construction industry, can threaten budget calculations for each project, potentially diminishing the return, which is the income-to-cost ratio (Vaardini, 2016). Secondly, heritage buildings often exhibit low insulation values, necessitating substantial investments for upgrading insulation. This dual challenge involves the considerable costs of improving insulation on one hand, while on the other, predicting the precise financial benefits derived from these measures proves to be a difficult task (Cluver & Randall, 2010).

The complexity of this field is caused by both social and economic considerations, as well as technical considerations which will be elaborated on in the next section. This makes it rather the combined result of socio-technical issues (Herrera-Avellanosa et al., 2020).

2.2.1. Design issues

In addition to the operational issues, this section provides a concise explanation of the more technical (design) issues that can be encountered during the adaptive reuse of heritage buildings. Including technical integration, the availability of original materials and craftmanship, and aesthetic issues. These design issues can occur in several layers of the building's structure, each interacting in ways that may be recognized as

Brand's *Shearing Layers of Change* (Brand, 1995). Further discussed in section 2.3.

Technical integration

One important contribution to design issues in monumental building transformations is the technical integration of new materials and technologies in the old structure. The compatibility issue is particularly evident when introducing contemporary materials, such as reinforced concrete or steel, into structures built with traditional materials like stone or wood (Rodrigues & Grossi, 2007). Disparities in characteristics of the materials such as thermal (e.g. thermal expansion coefficients), visual (color differences) and mechanical properties (bending strengths) can lead to challenges in achieving an overall safe and coherent structure (Roca, 2011).

The incompatibility of different materials can be even more critical on the long term. Different aging and deterioration rates emerge as prominent concerns. Traditional building materials, having demonstrated resilience over the years, may age differently compared to newer counterparts. The varied reactions to environmental conditions and wear between these materials can result in imbalances that compromise both the structural integrity and the aesthetic cohesion of the building over time (Sanchez-Silva et al., 2011). Therefore, implementation of materials and technologies in the design, should be considered carefully.

Original materials

Finding suitable materials is another key issue in design. This holds for the more or less “standard” materials that are globally used in construction projects and encountering scarcity (Sparenberg & Heymann, 2020), but also for the traditional materials that often have a higher degree of compatibility to the monumental structure (Haas, 2002). These traditional materials include for example specific types of stone, rare woods or ornamental metals, which might have been integral to the monument's original composition and which are now increasingly scarce or entirely absent in today's contemporary market. Therefore, the scarcity adds an additional layer of challenge to maintaining the historical authenticity of the structure.

Craftsmanship

Additionally, the scarcity of materials poses a significant challenge in finding qualified craftsmen capable of working with them, the third design issue category (Holvoet, 2021). Specialized skills required for crafting and restoring historical structures are often not mainstream, limiting the pool of individuals with the necessary expertise. The tradition of passing down these skills through generations faces challenges as societal structures evolve and younger generations may not perceive traditional craftsmanship as viable career paths. Additionally, formal training opportunities for these specialized skills may be limited or not easily accessible, contributing to the shortage of craftsmen in the field and adding a layer of complexity to the preservation efforts (Okaka, 2004).

Aesthetics

Another major design issue – mainly located in the space plan and skin layer of Brand’s model - stems from the balance between restoration on the one hand and modernization on the other hand. For the preservation of historical authenticity, historical research and documentation can be searched that provide a comprehensive understanding of the monument's unique characteristics. However, documentation is often very limited of the historical buildings and having research reports drawn up costs a lot of time and money and may not provide insight into all (hidden) aspects (Reyers & Mansfield, 2001).

In addition, the principle of "minimum intervention" should be emphasized to preserving as much of the original material as possible, minimizing unnecessary alterations and maintaining authenticity (Zhang & Dong, 2021). Matching materials to closely resemble the originals is crucial for visual and tactile continuity, but have inherent challenges as previously described. Whether repairing masonry, replacing roofing or restoring decorative elements a specific attention to the details contributes significantly to preserving the building's authenticity, but increases costs as well.

While modernization is often necessary for contemporary use, within the context of preserving historical authenticity, it should be approached with sensitivity. Integrating modern elements, such as lighting, climate control or accessibility features, should be done thoughtfully to minimize visual impact and respect the original design.

Cascade effect

Design issues within a project may initially appear distinct, but they can intertwine. Take, for instance, the scenario of replacing deteriorated wooden materials in a century-old church. This specific type of wood may be scarce, and even when found, specialized workers are required to replace the severely damaged sections and integrate the new pieces into the structure. While seemingly straightforward, the act of replacing deteriorated elements, due to aging or wear, can have extensive repercussions. The introduction of new materials may not seamlessly align with existing structural components, leading to the need for adjustments in adjacent elements. This sets off a chain reaction, demanding additional replacements and potentially impacting the entire technical integrity of the monument.

The connection between materials and their structural counterparts implies that alterations in one area may require modifications to interconnected components. In addition, the complex nature of historic buildings means that unforeseen challenges may arise during the replacement process. This could include both hidden structural issues or unexpected material interactions, as well as the discovery of hidden historical features that require specialized conservation techniques (Glavaš et al., 2019).

The domino effect can extend beyond the initial point of replacement, necessitating a broader range of adjustments throughout the structure. These adjustments can - on their turn – cause one of the other design issue categories such as skilled construction workers and scarce materials. The challenge lies in anticipating and addressing these consequences to maintain the authenticity and structural safety of the monument.

2.3. Application of Brand model

The "*Shearing Layers of Change*" model, introduced by architect Frank Duffy and later elaborated by Stewart Brand, provides a valuable framework for understanding the dynamics of change within a building. Duffy argues: “Our basic argument is that there isn't any such thing as a building. A building properly conceived is several layers of longevity of built components" (Brand, 1995, p. 12).

The concept of shearing layers implies that the disparate rates of change among these layers can lead to a metaphorical tearing apart of the building. This misalignment in the tempo of change creates a dynamic within the building, which reflects the expression “shearing layers of change” and leads to an internal struggle or tearing, as these layers pull and push against each other. The profound implication of buildings tearing themselves apart lies in the recognition that architectural structures are not static entities but are, instead, in a constant state of adaptation.

Originally applied to architecture and buildings, this model can be effectively implemented in the realm of design issues. Guidetti & Robiglio (2021) have incorporated Brand's shearing layers of change by utilizing a methodology that combines morphological analysis and decay-stage evaluation. By linking decay stages to either "incremental" or "decremental" design approaches based on variations in buildings' shearing layers, the article provides insights into the transformation process and its effects on building integrity.

According to Brandt Wassink (2023), another option is to apply the Brand model not on the building structure as a whole, but rather on the building components that can be reused. In their study, they concluded that the potential for reuse of materials varies across the different layers. Building products in the structure layer show for example a relatively high possibility for reuse, while the space plan is limited due to limited size modification and low adaptability potential.

In this research, the frequency of change of the corresponding layer will be connected with the impact the intervention has. Moreover, considering the inclusion of frequency provides valuable perspectives on the maintenance's periodic nature. This contribution goes beyond its initial implementation, influencing not just the present but also the long-term outcomes. It ensures sustained high performance of implemented components, thereby enhancing their durability (Ferreira et al., 2021).

In summary, the "*Shearing Layers of Change*" model, originally used to analyze architectural dynamics, highlights the impact of varying change rates among a building's layers. This concept can be adapted to understand design issues in building transformations, focusing on how different layers' change frequencies affect maintenance and long-term performance. Therefore, providing valuable insights into the durability and adaptation of building components over time.

3. Methodology

In this research, both a literature review and case study are conducted. By integrating the data from the literature review and the case study, the reliability of the findings will be increased. Additionally, it allows for a comparison between practice and literature, thereby enriching and adding knowledge to the existing literature.

3.1. Literature review

In this study, a systematic literature review complying with the Preferred Reporting Items for Systematic Reviews or shortly stated “PRISMA” was performed to identify relevant articles on the topic of design issues in monumental building transformations (Moher et al., 2009). By analysing relevant articles within this domain, an answer was sought to the main purpose of the literature review: providing a conceptual framework that can be used for the case studies. The chosen method was complemented by the snowball method in the selected literature (Wohlin, 2014).

The (complete) literature review followed three stages:

(1) Screening of the available publications and selection and evaluation of the relevant studies

For collecting available publications on design issues the Scopus database was used. Limited restrictions were included in the search process in order to achieve a higher quantity of publications to analyze in the next step of the literature review. However, the document type “conference paper” and “conference review” were not included in the selection.

A critical component of performing a systematic literature review entails carefully pinpointing and choosing suitable keywords or terms for querying databases. The area of search is defined as design issues in monumental building transformations. However, there is a wide variety of synonyms that are used to define adaptation or transformation processes (Lanz & Pendlebury, 2022). The decision to select synonyms of adaptive reuse and heritage was made based on previous scanning of the literature both in the Scopus database as in Google Scholar.

The following search terms were used: “adaptive AND reuse AND design AND issues OR challenges AND monumental OR heritage AND building’”, which resulted in 58 documents. In addition, for achieving a higher reliability of searched papers, additionally the following search terms were used: “adaptive AND reuse AND monumental AND building”, “monumental OR heritage AND building OR structure AND adaptive AND design”, “design AND issue* AND monument* AND building” and “transformation* AND monumental OR heritage AND building AND design AND issue*”. These search terms resulted in 5, 193, 102 and 32 papers respectively.

After a preliminary screening of the 390 studies, 288 were removed since they were in duplicate (58), could not be accessed (11) or because these papers had focused on other fields (219), based on the title and abstract of the publication. Some publication focused on the fields of tourism (Kołaczek, 2000; Melkert & Munsters, 2013), psychology (Karlygash et al., 2021) or education (Cimadomo & Varagnoli, 2023). In addition, some articles focused on issues presented by natural events (Boni & Royer-Carfagni, 2023), or focused on non-buildings such as parks (Cromley, 1984; Sinha, 2004) and were therefore excluded. Similarly, papers which focused on specific political or legal issues and the consequent difficulties for adaptive reuse of monuments were disregarded (Conejos et al., 2016; P. Yin, 2021). Furthermore, papers that were purely focused on conservation of monuments instead of design issues corresponding to adaptive reuse were excluded (Marchewka, 2021). Finally, also papers that focus on historical development, such as evolution of industrial landscape (Hrdina, 2010; Nilsson, 1992) were excluded.

(2) Analysis of publications

As a result, 102 articles were thoroughly examined, with only 15 papers centering specifically on design issues. The majority of the papers encompassed a global analysis of multiple case studies. Then, by applying the snowball method, an additional 11 papers could be included. Therefore, in total 26 relevant articles were derived from the literature study.

(3) Data organization and development of conceptual framework

The literature articles underwent a thorough analysis targeting the identification of design issues inherent in the adaptive reuse of monumental buildings. This process aimed to uncover issues commonly encountered in repurposing such constructions and sought to propose viable solutions to address these issues. Additionally, the analysis delved into understanding the impact these solutions could have on the adaptive reuse process.

Following data collection, the identified design issues, proposed solutions, and their potential impacts were systematically categorized within a framework. This framework served as a structured approach to organizing the findings, allowing for a clear visualization of patterns and trends across the literature. By categorizing these elements, recurring themes within the literature can be highlighted, which could then inform the case study analysis.

3.2. Case study

The second research method for this study is case study analysis, a robust approach highlighted by Zainal (2007) for its effectiveness in conducting thorough, holistic investigations. This method proves invaluable in delving into emerging processes or established knowledge within society, making significant contributions to the existing theoretical framework on the subject (Meyer, 2001).

Moreover, the chosen method is well-suited for addressing "how" or "why" questions, facilitating a comprehensive understanding of real-world events and phenomena (Cresswell & Cresswell, 2023; Yin, 2018). Consequently, this method is often adapted by researchers to achieve detailed and in-depth analysis of cases in the world of adaptive reuse projects (Conejos et al., 2012; Langston, 2012).

In this research an in-depth study on design issues occurring in the transformation of monumental buildings is researched in three cases. These cases are all part of Roelofs and Haase’s portfolio.

3.2.1. Roelofs and Haase

Roelofs & Haase, a contracting and development firm headquartered in Rijssen, the Netherlands, is one of the (few) companies dealing with the design issues occurring in the repurposing of heritage buildings. Originating as a contracting entity in 1921, the company has now expanded its purview to encompass project development and, in recent decades, has distinguished itself as a contractor and developer working in the realm of adaptive reuse projects, with a pronounced focus on religious heritage.

Going beyond conventional contracting roles, the firm assumes ownership of the buildings it revitalizes, thus circumventing reliance on external investment entities. The firm's portfolio consists of various heritage buildings throughout the Netherlands. From former factory complexes to monasteries, churches, educational institutions, and residential properties.

3.2.2. Selection criteria

Selecting suitable case studies is a critical process that demands careful consideration to ensure the reliability and validity of the insights gathered (Neitzel et al., 2022). To achieve this, the following selection criteria should be diligently applied through purposive sampling:

(1) Relevance

The selection of case studies should prioritize examples where the adaptive reuse process of monumental buildings has led to notable design issues. These issues could encompass various aspects such as architectural preservation, structural modifications, integration of modern amenities, sustainability considerations, and compliance with regulatory requirements.

(2) Variety of building characteristics

The second selection criteria is the (non-)variety of building typologies of the cases selected. Different historical functions of the building can cause other types of (design) issues to occur (Bento, 2022). For instance, a historical church may involve stained glass while an industrial building requires more structural modifications. On the other hand, there might also be overlap between building's historical functions, to provide transferable knowledge for the adaptive reuse of historical buildings.

(3) Possession of monumental value

The third selection criteria, possession of monumental value, mandates all chosen cases possess significant historical, cultural, or architectural importance. This value could be designated through various channels, including municipal or national recognition as a monument, or identification within zoning plans as having characteristic value.

(4) Varied function requirements

The monuments should serve diverse functions in their new roles, such as museums, cultural centers, offices or residential spaces. Each function imposes specific requirements on the building's design. Studying a variety of function requirements allows the analysis of how different functional needs influence the adaptive reuse process and design outcomes (Añibarro et al., 2023).

For the present thesis, three select properties from Roelofs & Haase's portfolio have been designated as case studies. This includes the Hazemeijer factory complex in Hengelo, the monastery of the Order of Capuchin Friars Minor in Tilburg and the vicarage of the Gereformeerde Kerk in Rijssen.

3.3. Data collection

Data collection of the case studies is mainly performed based on two methodologies: archival research and interviewing. In addition, the author has visited all case studies to conduct observations and to get to know the buildings firsthand.

(1) Archival research

The analysis of design issues occurred in these projects is partially performed based on an examination of existing and available documents. This involves the analysis of documents which included a few notes of meetings, two construction agreements with specifications, approximately 25 quotations, 2 full specifications with drawings, multiple advisory reports and hundreds of e-mail conversations.

The extraction of information contributes in twofold to the research: for identifying key aspects which can be used in interviews and as a validation tool, to check whether information gathered from interviews is in-line with the documentation.

It is important to note that the focus (i.e. the incorporation into the framework) is only on the effects of the final implemented decision and therefore potential solutions that are made during the process to resolve design issues are not included. The decision is made considering that the effectiveness of the mitigation strategy can only be assessed based on implemented solutions. Additionally, the entire process from identification to final solution, including intermediate steps, may no longer be accessible.

(2) Interviewing

Following the archival research, interviews are conducted. The selection of interviews as one of the primary methods for data collection is based on their effectiveness in acquiring insights into aspects that may not be directly observable from available documentation, as suggested by Taylor and Bogdan (1984).

This study employed purposive sampling, a method where participants are selected deliberately based on their expertise in the relevant area. In total, ten interviewees were selected for the cases. Factors such as knowledge, experience, willingness to participate, and availability were considered when selecting participants (Etikan et al., 2015). This entails conducting interviews with essential stakeholders, including representatives from Roelofs & Haase, as well as external parties.

After selection of interviewees, key questions and topics were established, ensuring that the interview process was streamlined and efficient. The interview started with an introduction to inform the participant about the goal and scope of the research. Consequently, in the key part of the interview, open questions were asked that are in close relationship with the results from the literature review. The question were stated (systematically) in 3 categories, answering if the topic was a design issue, how it was solved and if something could be said about the impact of the implemented solution. Then, in the third part of the interview more space was given to the participants to describe important aspect of the transformations not mentioned earlier. By not over structuring the whole interviews, participants were encouraged to show their own experiences, challenges and insights via open-ended questions. In this way not only a comparison with the existing literature can be made based on what is known, but also what is missing.

In addition, there was a risk that the interviews conducted to unravel the motivations behind the implemented strategies, may prove to be time-consuming. Therefore, prioritizing key questions and topics in combination with a balanced mix of in-person and virtual interviews was employed to maximize time utilization.

Table 3 (Appendix) provides an overview of the interviewees, detailing their roles, experience, and involvement in the case studies. The ten interviewees represent a range of professions, including directors, architects, development managers and sustainability advisors. Their experience in the field varies widely, from 2 to over 20 years, and they have collectively managed numerous historic transformation projects, with involvement in up to 50 projects by some. Two interviewees were interviewed about multiple cases, other were only involved in one of the cases. The interviews lasted from 27 min to 1 hour and 3 minutes. All interviews were carefully documented on paper, based on the information given.

3.4. Selected cases

The following cases were selected based on the selection criteria of the previous section.

Hazemeijer factory complex, Hengelo

The Hazemeijer complex lies in the city of Hengelo within the province of Overijssel. Comprising eight former factory halls sprawled across a plot exceeding 30,000 square meters, it sits precisely between the Hengelo-Deventer and Hengelo-Zutphen railway lines, just a short distance from the city center of Hengelo.

Hazemeijer Hengelo owes its name to founder Floris Hazemeijer (1872-1939) of the electrical engineering company bearing the same name (Hermsen, 2008). Hazemeijer was a creative entrepreneur who initiated his venture in 1907 within an empty textile factory in Hengelo. Seven years later, he relocated to Tuindorpstraat. There, the company flourished into a global player in switch systems for industries, distribution networks, and residences. In 1922, Hazemeijer founded a new company, Hazemeyer Signaal Apparatenfabriek, later known as Hollandse Signaal Apparaten (currently Thales). During the war, the Hazemeijer complex suffered significant damage from bombings (BOEi, n.d.). However, post-war growth continued, especially after the merger with Heemaf Hengelo to form Holec. The company, which then had two other locations in Hengelo, relocated entirely to the Westermaat industrial estate in 1998 and is now known as Eaton Holec.

Currently, the complex is (partially) redeveloped from heavy industry into an attractive mix-used location. This transformation encompasses a diverse array of amenities, including offices catering to various sectors such as medical professionals, architects, advisors, and governmental bodies. Additionally, the complex features conference facilities, a technology museum, and a restaurant. Looking ahead, plans are in motion to introduce residential apartments on top of the main building, B04, further enriching the dynamic blend of functionalities within the Hazemeijer complex.

Although the Hazemeijer complex is not listed as a national or municipal monument, they do possess (high) monumental value. The eight factory halls are designated with the dual designation of cultural-historical significance. The complex and the surrounding area scores high on all aspects. This includes the architectural and urban value, as well as rarity and recognizability (Gemeente Hengelo, 2022).

For this research, the analysis focuses solely on buildings C03 and C04. These two factory halls are interconnected, forming a standalone complex that is fully repurposed into a restaurant and technology museum called “Oyfo”, while the other factory halls are still (partially) under redevelopment.

Monastery of the Order of Capuchin Friars Minor, Tilburg

The second case to be studied is the monastery of the Order of Capuchin Friars Minor located in the Tilburg, Noord-Brabant. The monastery is positioned within a residential area and has a total plot of approximately 12.500 square meters. The monastery and its garden are completely enclosed by a monastery wall and can be reached via the main entrance on the Korvelseweg.

In 1882, the monastery began with 24 brothers. It consisted of two levels with an attic. The cells were conventionally situated along the outer walls and the cloister, while the corridor ran through the center. In 1909, an additional floor was added to the garden side, housing a library and study room. In 1937, another floor was added to the monastery, providing more space for all the brothers. This was a remarkable intervention, raising the existing roof and inserting a third floor. Consequently, in 1983, a major renovation of the monastery took place, involving the removal of the monastic cells to make way for rooms with individual bathrooms. The corridor was relocated to face the cloister, and windows were added to the side and rear facades on the upper floor for increased daylight entry.

The number of Capuchin friars has been declining for some time. This is due to a lack of new recruits, as well as a decrease in the number of friars due to deaths. Therefore, a new (social) function was sought to preserve the ideas of the Order. This resulted in a design that includes a youth hospice, student rooms for religious students, apartments and in the church a party that offers support to people who have difficulty participating in society.

However, before these new functions can be implemented, extensive construction activities are required for the entire monastery complex. This includes, for example, the construction of an entresol floor within the church, built between 1880 and 1882, to increase the number of usable square meters. Additionally, the renovation and conversion of the former monastery rooms into living apartments and student accommodations are necessary as well as partial demolition of the monastery complex.

The monastery, as well as the workhouses and church are national monuments registered, respectively, by the numbers 521078, 521079 and 521080. According to the Rijksdienst for Cultureel Erfgoed (RCE), the whole complex holds significant cultural heritage value as an example of spiritual development, particularly representing the flourishing of religious orders and congregations in the nineteenth century (Rijksdienst voor Cultureel Erfgoed, 2002). Architecturally, it is important due to its style, distinctive use of materials, and ornamentation, all within the context of the simple yet traditional shapes of the Capuchin order.

Vicarage Gereformeerde Kerk, Rijssen

Situated at Huttenwal 18 in Rijssen, the historic vicarage stands as a remarkable architectural relic, tracing its origins back to its construction in 1922. Crafted by architect H. Wilms from Oegstgeest, this residence was intricately designed to complement the adjacent Gereformeerde Kerk. The building was constructed for Reverend Horjus, who accepted a call to the Gereformeerde Kerk in Rijssen in the 1923. However, the building was too small for him and another familiar name in the city, purchased the residence for 6,800 guilders. Bosma held the positions of town secretary, civil registrar, and elder in the newly constructed Gereformeerde Kerk.

Despite its modest proportions, the vicarage is decorated with distinctive architectural elements. From its finely crafted multi-pane windows to the commanding presence of a bay window adorning the façade and the so-called “bishop's mitre” on top of the chimneys, each detail speaks to the craftsmanship and attention to detail prevalent during its construction.

In the year 1938, the vicarage underwent a significant expansion, marked by the addition of approximately 13 square meters of additional living space through the construction of a rear extension on both living floors. Due to this extension 3 livings spaces were increased in size and one extra bedroom was created.

A century after its inception, Roelofs and Haase has repurchased the iconic vicarage with a visionary goal in mind: bringing it back to its origins and making it fully sustainable. The company aims at improving the sustainability level of the building with a former energy consumption of 399 kWh per square meter. By reducing energy consumption and restoring the original details, the building is intended to serve two distinct functions: an office and museum space in the front for the company itself, and a residential rental unit in the rear portion of the building.

4. Literature review results

The systematic literature review identified several design issues commonly encountered in the transformation of monumental buildings. The analysis of relevant articles, following the PRISMA guidelines, revealed diverse design issues and solutions implemented to address these challenges. Table 1 summarizes key findings categorized by design issue, historical and current functions, solutions and impacts. In this section, the results from the literature review are discussed and organized according to four of the six Brand layers.

4.1. Space plan

In the first layer of Brand’s model, the "space plan," it is apparent that solutions to noise pollution sensitivity are found exclusively in the horizontal structural elements, such as floors and ceilings. On the other hand, flexible design solutions, are tackled through vertical elements like movable walls or box-in-box designs (De Gregorio et al., 2023; Scolaro & De Medici, 2021). While movable walls provide straightforward adaptability, the box-in-box design offers added benefits like maintaining the original building's climate regulation, since the environmental quality can be regulated within the box (Wastiels, L. et al., 2016).

Furthermore, it is apparent that in about half of the cases, the impacts of the solutions were not explicitly quantified. However, where impacts were described, they often showed significant improvements, such as a 20 dB reduction in footstep noise and achieving appropriate workplace illuminance levels (Balocco & Calzolari, 2008; Gola et al., 2022).

4.2. Services

In the “services” layer, energy efficiency is a main topic. This includes energy that is consumed for lighting as for cooling and heating. On the one hand, energy efficiency is a design issue were solutions such as LED lighting in combination with occupancy sensors are applied (Khalil et al., 2018; Salata et al., 2015). This replacement of lamps is applied in order to reduce the overall energy use. While in other cases a design issue creates energy efficiency as an issue. In this example the installation of air-conditioners to reduce heat stress, increased the energy consumption (Al-Obaidi et al., 2017).

In addition, within the “services” layer, the creation of wet spaces presented contrasting approaches, with successful integration in shophouses avoiding structural damage by placing bathrooms at the rear (Fusinpaiboon, 2022), while inadequate measures in a residential conversion led to moisture problems and damage (Yildirim & Turan, 2012).

4.3. Skin

According to Table 1, the skin layer shows many issues related to the appearance of the monument. The issues are caused both by historical characteristics as when new additions to the monument are created (T. C. Ferreira et al., 2023; Kamali Tabrizi & Abdelmonem, 2024; Kelly & Koo, 2024). In case of damage to historical characteristics, solutions were found that closely resemble the original, while in case of additions a clear distinction between old and new must be visible.

In addition, this layer also provides solutions with respect to energy efficiency which is shared with the ”Services” layer. Where solutions in the “Services" layer are energy consumers, this layer provides mainly passive solutions such as improved insulation (Mortarotti et al., 2017; Šekularac et al., 2019).

4.4. Structure

The final layer observed in the literature, has the lowest rate of change: the “structure” layer. This layer reveals a significant tension within the approaches taken. On one hand, solutions like installing roof lights for daylight access and deconstructing disordered structures to improve accessibility, represent proactive measures (Shirzadnia et al., 2023; Xiao, 2023). Aiming at enhancing functionality and preserving the building's utility. On the other hand, there is a notable contrast with approaches such as not intervening in fire safety issues or the minimal structural repair interventions, which reflect a more passive stance towards certain challenges (Piatkowska, 2017).

Table 1: Results literature review following the PRISMA guidelines

Design issue	Historical function	Current function	Solution	Impact	Author
Space plan					
Noise pollution sensitivity	Hospital	University (study rooms)	Rubber flooring (Artigo Elastic Granite)	Footstep noise reduction of 20 dB	(Gola et al., 2022)
Noise pollution sensitivity	Not specified	Café	Camouflage (lowered) flat ceiling + include absorptive material	-	(How & Din, 2022)
Low accessibility (visually impaired)	Mosque	Mosque	Paths with tactile surfaces	-	(Tutal, 2018)
Daylight access	Medieval headquarter	Library	Solar tubes + redirecting and diffusing false ceiling	<300 lux workplace illuminance	(Balocco & Calzolari, 2008)
Flexible design	Industrial hall	Museum	Box-in-box	No need to change thermo-hygrometrics of the original envelope	(De Gregorio et al., 2023)
Flexible design	Industrial hall	Residential + education + retail	Movable walls	-	(Scolaro & De Medici, 2021)
Services					
Low accessibility	Church	Church	Lift installation + WiFi system providing text and audible information	-	(Naniopoulos & Tsalis, 2015)
Energy consumption of lighting	Monastery	University	Substitution of current lighting fixtures with LED	Reduction in total costs of ownership and energy consumption (after 7 years)	(Salata et al., 2015)
Energy efficiency	City hall	City hall	3D model for installation + location chiller on roof covered by parapets	Complete removal of (flat) roof	(Yazdani Mehr & Wilkinson, 2018)
Energy consumption of lighting	Residential	Museum + research center + guest house	Occupancy sensors	Reduce 30% of lighting energy	(Khalil et al., 2018)
Creation of wet spaces	Shophouses	Residential	Placing bathrooms directly on the rear of the building	No cutting in floors (plumbing system on rear façade)	(Fusinpaiboon, 2022)
Creation of wet spaces	Residential	Guest house	No specific measures	Creation of extra moisture and damage to vaulted ceilings and walls	(Yildirim & Turan, 2012)
Low ventilation + heat stress	Commercial + residential	Hotel	Mechanical ventilation + air-conditioners	Increase in electricity use + reduction in temperature inside	(Al-Obaidi et al., 2017)
Skin					
Heat stress vulnerability	Not specified	Not specified	Light colored flat roofs + tinted and reflective glazing	14% and 5% reduction of cooling load respectively	(Hatamipour & Abedi, 2008)
Energy efficiency (one-brick wall)	Residential buildings	Residential buildings	Polyurethane insulating layer coated with low thermal conductivity plaster thickness	Reduction of 69% in transmission heat loss+ formation of thermal bridges	(Mortarotti et al., 2017)

Energy efficiency	Residential	Residential	Polystyrene (5 cm) + brick (6,5 cm) + mortar coating (1,5 cm) (insulation from the inside)	U-value decrease of 79%	(Šekularac et al., 2019)
Façade damage (cornices of stone/terracotta)	Not specified	Not specified	Fiberglass replica	Improvement of safety	(Kelly & Koo, 2024)
Addition to the monument	Castle	Recreational	Addition to the ruin that provides visitor facilities in weathering steel	Clear visual distinction between the monument and the addition	(Kamali Tabrizi & Abdelmonem, 2024)
Atmospheric stains façade	Hospital	Hotel	Alkaline-based prewash + concrete cleaner	-	(Gola et al., 2022; Saved from the Brink of Destruction - Prosoco, 2021)
Damaged roof tiles	Residential	Residential	Replacement with similar pieces	-	(T. C. Ferreira et al., 2023)
Revitalize exterior	Church	Mixed	Avant-garde solutions	Improved tourism/income	(Szuta & Szczepański, 2020)
Structure					
Daylight access	Industrial hall	Office	Roof lights	No change to external view	(Shirzadnia et al., 2023)
Fire safety	Church	Museum	(No intervention) Cubic capacity of highest parts	-	(Piatkowska, 2017)
Timber frame repair	Residential buildings	Residential buildings	Epoxy repairs	Unusual temperature profiles + restriction of movement	(Worthing & Dann, 2000)
Lack of drawings	Not specified	Not specified	3D laser scanning	Accurate data + expensive	(Verma & Yadav, 2023)
Low accessibility	Industrial hall	Museum/restaurant	Deconstruction of disordered expanded structures	New reasonable circulations for all users	(Xiao, 2023)

5. Findings

Based on the information gathered from interviews and archival research, the framework was developed (Table 2). The results are derived exclusively from the three case studies described in the methodology.

The design issues are categorized according to the layers of Brand's model on the vertical axis. On the horizontal axis, the historical function, the solution and the impact of the solution to the design issue are described. In the following sections, the results, see Table 2, from the case study analysis are discussed and organized according to the six Brand layers.

5.1. Stuff

Within the "stuff" layer of Brand's model, noise pollution emerges as a significant issue, primarily driven by two factors. The first factor is the use of hard materials, such as concrete and steel, in the (original) construction of the industrial halls. These materials reflect sound, creating reverberations and therefore exacerbating the problem of noise pollution. This phenomenon is especially notable in the parts of Hazemeijer where large, open spaces are common.

Similarly, the church within the monastery in Tilburg possess the same challenge, where the original design aimed to project the speaker's voice as far as possible across the large space. However, also in this case, the design feature is not desirable anymore for current uses. Highlighting the second cause of noise pollution sensitivity as a design issue: a change in the building's function. Different uses impose varying degrees of acoustical requirements; for example, music classrooms in the Hazemeijer complex generate more noise and require better acoustics compared to adjacent office spaces built in the industrial hall.

To address the issue of noise transmission while preserving the building's character, strategies must be carefully considered. An interviewed architect emphasized that solutions within the "stuff" layer typically do not necessitate alterations to the historic structure itself, which is preferable from a preservation standpoint. A similar approach was suggested by a development manager for the Hazemeijer complex, a large area with diverse users and numerous visually similar halls. In this context, effective signage was required. While the logical solution might be to place signs directly on the buildings, the façades are among the most distinctive features of the halls. Consequently, the signage solution was implemented adjacent to the buildings, ensuring the preservation of their characteristic value.

5.2. Space plan

Within the "space plan" layer, noise pollution continues to be a significant issue, stemming from the same causes described in the "stuff" layer. However, this layer also introduces daylight access and flexibility in design as issues.

In both the monastery as the industrial hall, a box-in-box construction is utilized. This method allows for the creation of spaces that are separated from the large, open areas and provides rooms that can be fully regulated without the influence of the original shell of the building. This construction method effectively addresses the noise issue by creating a contained environment where sound can be better managed and controlled.

When addressing the second design issue, which is achieving a flexible design, the causes differ between the two cases. In the church, flexibility was primarily driven by the need to restore the church to its original form whenever required. Conversely, in the Hazemeijer complex, flexibility was necessary not to revert to the original industrial hall but to accommodate the future needs of various renters. Therefore, while the goal of flexibility is shared, the underlying motivations differ.

In both scenarios, the requirements and desires evolve over time. According to multiple interviewees, a sustainable design incorporates a degree of adaptability. “By including flexibility in the design, the number of alterations to the monument over the years is reduced, preserving its integrity while keeping it in use and generating revenue for its maintenance.”, a director states.

However, the results show that there is a difference in the level of sustainability between the two cases. In the adaptive reuse of the monastery, the architect chose to use biobased materials for the interior construction within the church instead of (synthetic insulated) system walls. Although both solution can be easily disassembled. The wooden structure is cleaner to work with and results in less moisture within the highly monumental church due to prefabrication.

5.3. Services

From the case study analysis, it can be concluded that building services are present in various forms and sizes, yet they are often extensive and spread throughout the monument. Generally, these installations are significantly outdated, consuming excessive energy or failing to meet current standards (regulations), including those related to fire safety. Design issues in this layer also arise from changing comfort requirements and types of use. For instance, while elevators were not common in historical buildings, they have become indispensable in public buildings today, providing accessibility to all groups along with facilities like disabled restrooms.

The case studies indicate that from a monumental preservation perspective, it is crucial to preserve the existing installations as much as possible. This approach avoids the need to lay new cables and pipes through historic parts of the building or demolish sections like floors to create access to the installations.

Solutions for the heating installations primarily focus on replacing the heat generator rather than the distribution network or heat emitters. In the monastery, a biomass installation was chosen due to the availability of ample storage space for wood chips, whereas the limited roof space for PV panels made a heat pump less suitable due to high electricity consumption, according to email conversations. Conversely, the Hazemeijer complex had sufficient flat roofs available, making an all-electric transition feasible.

The vicarage adopted a combination of both solutions. It utilizes a high-temperature heat pump connected to the existing radiators, supplemented by pellet stoves in the existing shafts, simplifying the routing of supply lines. In this way, no large storages for wooden chips were required, while also the amounts of PV panels can be strictly limited to the flat roofs of the building, being an important condition for the client.

Additionally, the results showed a preference for surface-mounted solutions for electrical installations. This method avoided extensive demolition work and allowed for easier determination of cable routes during future modifications.

5.4. Skin

In the analysis of the "skin" layer, it was found that in two of the three cases (the Hazemeijer complex and the vicarage), the exterior was the most valuable part in terms of monumental significance. In the monastery, parts of the ground floor and the interior of the church were also described as extremely rare by the Rijksdient voor Cultureel Erfgoed (RCE).

Design issues in this layer are primarily caused in two ways: by a damaged (or aged) façade and by the addition of insulation to reduce energy consumption. Additionally, in the vicarage, it was found that original parts were no longer present based on the complete specification with drawings from 1921.

Damage to the façade is caused by the duration these buildings are exposed to various factors, including UV-radiation, atmospheric deposition, water, and significant temperature fluctuations, resulting in damage or weathering. In all cases, it is evident that these damaged parts are restored as much as possible, or otherwise replaced with identical (used) components. Interviews with employees from construction companies and developers emphasized that reusing materials is a more sustainable choice than using new parts and are therefore preferred. In addition, these reused materials already exhibit the weathering that cannot be easily replicated, such as with the roof tiles of the vicarage.

In addition to damaged parts, design issues in this layer are caused by the addition of insulation. It was observed that cases transformed earlier, use fewer biobased insulation materials, such as the completed transformation in Hengelo. The primary reason cited by project managers for not implementing these materials was the increased costs. In the other two cases, being currently in the construction phase or design phase, biobased insulation materials are applied.

A sustainability consultant noted that although the insulation capacity of biobased materials is lower (with a higher lambda value), their phase shift is better. This means that heat enters the building only after several hours, when the outside temperature is lower (at night), allowing the peak to be managed with ventilation. Additionally, these materials have better capillary action, which is particularly important since insulation can sometimes lead to significant moisture problems. Making the building airtight causes the natural ventilation system of the monument to disappear. In combination with the presence of thermal bridges, due to the many architectural details and materials, the issue will exacerbate due to condensation. Therefore, alongside effective insulation, interviewees stress the importance of incorporating (mechanical) ventilation systems and ensure that insulation materials have good capillary properties.

5.5. Structure

In the analyzed cases, no changes were made to the actual structural elements of the monuments. However, interviews highlighted the critical importance of thorough documentation of these structures. Particularly in the larger projects, understanding the current structure and the materials used is essential before making any modifications. Architects emphasized that documentation serves a dual purpose during transformation. On one hand, historical documents are crucial for identifying the most valuable parts of the monument from a preservation perspective. On the other hand, maintaining a detailed (preferably digital) record of the building’s current state is vital for future reference, serving as a "snapshot in history", according to an architect.

The significance of documentation is evident in the results. For example, in the case of the vicarage, Roelofs and Haase had access to a complete specification and drawings of the original construction, based on data from their hard disk. This allowed for a comparison with the current state and facilitated efforts to restore the building to its original condition.

Another notable solution stems from the design issue of increasing the energy efficiency of the complex. In contrast to the solutions found thus far, this solution was not applied within the building itself. At the Hazemeijer complex, two factory halls were connected through a transparent space, referred to by the developer as an "adjacent unheated space." The sidewalls of the halls were already partially joined, and by merging them, two exterior walls were eliminated, reducing surface area of energy loss. In addition, this approach allowed for the creation of a spacious entrance without requiring alterations to the exterior façade of the original monument. Therefore, respecting the monumental value of it.

5.6. Site

The presence of design issues in the "site" layer of Brand's model is unique due to the eternal rate of change this layer possesses according to Brand. In the case study of the Hazemeijer complex, this layer is particularly impacted by evolving climate conditions. Including more frequent and intense rainfall events. Initially, the focus of the project manager was on disconnecting rainwater from the sewage system to manage runoff more effectively. However, addressing the site's infiltration capacity was also crucial, as many areas around the monuments were predominantly paved, limiting water absorption.

The importance of the site surrounding the monument has gained further recognition. A development manager highlighted the need for a greater emphasis on increasing green spaces in future projects. Historically, much of the area around these type of buildings was paved, but with current climate conditions and urban environmental considerations, incorporating greenery has become increasingly vital. “Green spaces help manage stormwater, reduce heat island effects, and improve overall environmental quality in urban settings where these monuments are often located.”.

5.7. Comparing with literature

In examining the design issues presented in the case studies and literature, several key patterns and insights emerge across the different brand layers: stuff, space plan, services, skin, structure, and site.

Firstly, noise pollution sensitivity is a prevalent issue in both the case studies and the literature. Solutions such as acoustic panels, carpets, and rubber flooring are commonly used to mitigate this problem. The impacts of these solutions include easy replaceability and effective reduction in resonance or echo. However, from the practice, it becomes clear that noise pollution cannot be easily measured and should therefore be proofed on a trial-and-error basis. In addition, the case studies show that solution for these design issues can also be found in the stuff layer, therefore decreasing the invasiveness of the transformation process.

Secondly, energy efficiency is a major focus, particularly in the services layer. The use of solar panels and LED lighting are prevalent strategies in both frameworks aimed at reducing long-term energy consumption. However, the literature does not provide any insights in design issues occurring due to heat generation systems. In contrast, all three case studies show changes in the heat generation system. Depending on the type of (legal) protection the cases have, the heat generation system (including heat transmitters) are replaced or partially preserved.

Low accessibility is another critical issue addressed across the case studies open to the public and data from the literature. A lift installation is the most common solution to this problem, although the specific implementation can differ. In some cases the lift installation is placed in current shafts, while in other cases the lift installation should be transparent for increased visibility and daylight penetration. With the latter being a design issue solved in the literature by adding new openings in the shell of the monument, while in the case studies the solution is found within the building. While new penetrations in flat roofs may not significantly affect the monument’s visual appearance, preserving the original structure without such modifications is generally preferred from a conservation perspective.

Furthermore, the skin layer is frequently addressed in both frameworks with solutions focusing mainly on preserving or improving energy efficiency and aesthetic qualities. With respect to energy efficiency, a trend can be seen in the case studies with the use of biobased insulation material, while the literature uses synthetic insulation and mineral wools. Furthermore, in both frameworks façade damage or restoration is mainly restored by using second-hand materials to maintain a similar appearance to the original parts.

Finally, a major difference between the case studies and the literature in combination with Brand’s model, are the results of the site layer. In one of the case studies, infiltration capacity was increased by installing infiltration crates to manage flood risk and enhance the overall sustainability of the project.

Table 2: Developed framework based on case study method

Design issue	Historical function	Current function	Solution	Impact
Stuff				
Noise pollution sensitivity	Monastery	Residential + social	Furnishing elements (curtains, sofa, plants, etc.) + acoustic panels	Easily replaceable + reduction of resonance + not fixed/permanent solution
Noise pollution sensitivity	Industrial hall	Museum + education + restaurant	Carpet on the floors + acoustic panels	Reduction of echo + easy applicable/removable
Signage	Industrial hall	Museum + education + restaurant	Concrete columns at the entrance	Similar appearance as characteristic buildings + not sustainable
Noise pollution sensitivity	Industrial hall	Museum + education + restaurant	1 meter insulation around ventilation channel + acoustic panels + carpet	Reduction of resources + reduction in transmittance between rooms
Space plan				
Noise pollution sensitivity	Monastery	Residential + social	Box-in-box construction	Fully controllable environment in box
Flexible design	Monastery	Residential + social	Fully demountable (prefab) wooden construction	Monastery can be (almost) fully returned to original condition + less moisture inside monument
Daylight access	Monastery	Residential + social	Transparent partition walls	Increased supervision + daylight penetration
Noise pollution sensitivity	Industrial hall	Museum + education + restaurant	Box-in-box construction + use of large spaces (“air”) + acoustic roof panels (partially)	- (only subjective)
Flexible design	Industrial hall	Museum + education + restaurant	System walls	Easy removable and quickly installable to change space requirements
Noise pollution sensitivity	Industrial hall	Museum + education + restaurant	(Lightweight) metal stud walls with double plasterboard + taped seams + box-in-box construction	Rw-value MS walls of 51 dB (only loud noises can be heard) + transmission via ventilation ducts
Services				
Low accessibility	Monastery	Residential + social	(Transparent) lift installation	Access to all floors without compromising on daylight + monumental values. Increase in costs.
Low accessibility	Monastery	Residential + social	Electric door closers	Smooth flow for physically limited visitors and inhabitants + limited width of doors
Energy consumption electricity	Monastery	Residential + social	Solar panels on flat roof + Metsolar slate panels + LED lighting	Minimum impact on monumental value + reduction of electricity consumption from grid
Energy efficiency	Monastery	Residential + social	500 kW biomass installation + domotica system	Reduction in gas consumption + conservation of heat emitters
Energy consumption lighting	Residential	Residential + office	Solar panels on flat roof + storage	No effect on visual appearance
Energy efficiency	Residential	Residential + office	Heat pump with high supply temperature + pellet stoves in existing chimney (additional heating)	No gas connection + conservation of heat emitters and pipes. Use of flue gas discharge duct for pellet supply
Addition of wet spaces	Residential	Residential + office	Drain above meter cupboard shaft	Reduction of additional shafts

Outdated electrical installation	Residential	Residential + office	Replacement of electric installation (partly constructed as surface-mounted)	Increased safety + addition of power current
Low accessibility	Industrial hall	Museum + education + restaurant	Lift installation	Access upper floors to wheelchair users + no structural adjustments
Energy consumption electricity	Industrial hall	Museum + education + restaurant	Solar panels on the flat roofs	No impact on aesthetic appearance + reduction electricity consumption
Low accessibility	Industrial hall	Museum + education + restaurant	Installation of disabled toilet	-
Daylight access	Industrial hall	Museum + education + restaurant	Installation of LED lighting (partially)	-
Energy efficiency + ventilation	Industrial hall	Museum + education + restaurant	Heat recovery installation for mechanical ventilation	Reduced energy consumption + extra ventilation channels
Flexible design	Industrial hall	Museum + education + restaurant	Installations in open space + clamped to existing structure + surmounted	Reduction of drilling holes + milling slots
Skin				
Daylight access	Monastery	Residential + social	Replacement of stained glass windows, replaced on interior wall	Monumental parts are kept on place, while fulfilling daylight requirements
Energy efficiency	Monastery	Residential + social	Biobased insulation (from inside) of façade	Reduction of heat loss + increased phase shift + increased costs
Energy efficiency (glazing)	Monastery	Residential + social	Rear windows	No adaptation to existing frame + increased insulation value
Damaged exterior	Residential	Residential + office	Restoration where possible + replacement with comparable second hand	Increase in life span + more original elements
Missing chimneys	Residential	Residential + office	Prefab replicate of original based on drawings.	Lightweight + no cold bridges
Different color scheme	Residential	Residential + office	Scrape off to original layer + paint based on specifications	Restoring the original appearance
Damaged façade	Residential	Residential + office	Replacement with original facing bricks in highest monumental parts + cutting joint	Waterproof façade + preservation of visual appearance
Energy efficiency	Residential	Residential + office	Cellulose insulation roof + synthetic floor and façade insulation (from inside)	Rd value of 5,4 for the roof, energy certificate A+++ (in combination with other measures) + no damage to exterior
Energy efficiency (glazing)	Residential	Residential + office	Partially replaced with HR++ glazing and partially with vacuum glass	Improved insulation and conservation of existing frame in front of building
Daylight access	Industrial hall	Museum + education + restaurant	Replacement of sectional door for glass façade	Increase in daylight + improved appearance and insulation
Damaged frames and windows	Industrial hall	Museum + education + restaurant	Replacement of original steel frames for new (insulated) aluminum frames with HR++ glass	Improved appearance + increased insulation + removal of asbestos

Structure				
Lack of drawings	Monastery	Residential + social	3D BIM model + building history research	Current state is documented for the future + insights on (most) valuable parts
Energy consumption	Industrial hall	Museum + education + restaurant	Connection of two factory halls with a new construction + draft portal	Two exterior facades less/connected + reduction in energy/heat loss
Site				
Infiltration capacity	Industrial hall	Museum + education + restaurant	Installation of infiltration crates around the building	Reduction of the risk of flooding

6. Discussion and Conclusions

Monumental building transformations are crucial and are likely to become even more important in the future. The adaptive reuse of these buildings offers multiple benefits, driving the preservation of cultural heritage. However, there are significant challenges across different fields that must be addressed, including those in design. This research demonstrates that these challenges can indeed be solved. Various creative methods and solutions can be applied, depending on the context in which the design issue arises.

This section starts with highlighting the main lessons that can be learned from the research. Then, in section 6.2, the results of the study are placed in a broader perspective: focusing on how these interventions address the three pillars of sustainability. Finally, in section 6.3 the limitations of this research are discussed with recommendations for further research.

6.1. Contributions

From the results, it can be concluded that design issues can be present across all layers of Brand's model. These issues can sometimes be addressed within a single layer or may require interventions across multiple layers. Moreover, solutions implemented in one layer can create or exacerbate design issues in another layer, further complicating the transformation process. Overlooking the multi-layered nature of these issues can lead to incomplete solutions, ultimately compromising the overall sustainability of the monument. Therefore, a holistic approach that considers all layers is crucial for achieving long-term success.

Furthermore, a primary conclusion derived from this study is the absence of universally applicable solutions for specific design issues. A one-size-fits-all approach is inadequate, and the emphasis should be on developing tailored strategies that reflect the specificities of the given scenario. This study showcases some of these solutions and can be used by practitioners as inspiration for addressing similar challenges in their own projects.

Moreover, a critical insight pertains to the significance of considering the original usage of the monument when planning for adaptive reuse. The analysis indicates that retaining the original layout and function of a structure minimizes the emergence of design issues. For instance, the Hazemeijer building, originally a factory hall with limited sanitary provisions, would require substantial plumbing work if converted into residential units. Conversely, repurposing it into a museum requires way less design issues to occur. This underscores the pragmatic approach of aligning new functions closely with the building's original design, thereby reducing the number of design issues.

Finally, this study compared findings from both practice as literature. Based on this analysis, the alignment between the issues identified in the literature and those observed in practice can be observed. Both domains exhibit a trend towards bespoke solutions, emphasizing the necessity for tailored interventions. However, this study revealed a significant gap between practice and literature: in practical applications, the Brand's layers "site" and "stuff" are introduced, which cannot be observed in the literature.

Overall, it becomes clear that construction professionals such as Roelofs and Haase need to be aware that design issues can be present in all Brand's layers. A detailed analysis of the current and previous state, in combination with a careful documentation of this information, is crucial to start with. By examining the existing state, functions must be found that closely resemble the characteristics of the building. Then, a flexible approach needs to be adopted to address these issues.

6.2. People, planet and profit

By creating more awareness about design issues in monumental building transformations, practitioners might be more likely to execute these transformations and the risk of uniformed decision-making can be reduced. This, in turn, contributes to the three pillars of sustainability as explained in the following sections.

6.2.1. Social sustainability (people)

Monuments often served as shelters for a diverse range of users over many decades, adapting to evolving social and functional requirements. As comfort standards and accessibility expectations have shifted over time, many historical buildings are increasingly perceived as inadequate for modern needs (Gil-Mastalerczyk & Gardyńska-Kieliś, 2023). Consequently, "low accessibility" emerges as a recurring design issue in both the case studies and the literature.

However, based on this study, multiple adequate solutions to these kinds of problems can be implemented, including lift installations, transparent design elements, and improved signage. These modifications not only address modern accessibility demands but also enhance the social function of the monument by making it accessible to a broader audience. This increased accessibility allows more people to appreciate and experience the values of the monument, while simultaneously ensuring its preservation through continued use. Although the need for such modifications underscores the ongoing challenge of balancing heritage preservation with contemporary requirements, the benefits of opening these historic structures to the public and maintaining their relevance in the community are significant.

6.2.2. *Environmental sustainability (planet)*

Monuments, by their very nature, have typically outlived their original energy over time. The "original energy" invested in their construction has often been depreciated, making their continued use a testament to their enduring value. Instead of opting for demolition, a process that would squander this embedded energy, adaptive reuse allows these monuments to retain their historical and cultural significance while contributing to environmental sustainability (Elsorady, 2017). In this regard, adaptive reuse itself represents a significant contribution to environmental sustainability.

Nevertheless, being aware of the environmental impact of adjustments and additions to the monument can further contribute to environmental sustainability. In line with the third conclusion, maintaining the original function and design of the monument can significantly reduce the environmental impact in terms of a decrease in construction waste and a lowered carbon emissions (O'brien, 2021). While simultaneously, the historical integrity and cultural value of the monument are maintained, which is essential for both environmental and heritage conservation.

In addition, when adding new elements to a monument are inevitable, careful consideration must be given to the choice of materials used. In this research, a discernible trend emerges in the use of second-hand materials that closely match the original materials used in the monument. This approach helps maintain the historical integrity and visual consistency of the building while minimizing environmental impact. Additionally, the use of biobased materials has become more prevalent, particularly in recent transformations. These materials facilitate improved moisture transport, which is vital for the preservation of the monument and introduce a higher phase shift. This means that the building can be less insulated because the peak heating demands align more effectively with the cooler times of day, optimizing thermal performance and contributing to the monument's overall sustainability.

6.2.3. *Economic sustainability (profit)*

By repurposing the cultural heritage and preserving the original construction, costs can be reduced compared to new construction. No significant expenses related to demolition, disposal and new material procurement are required. In addition, according to the results of this research, the costs can be further lowered since second-hand materials are presented as viable solutions to missing or damaged parts.

However, in cases where the original parts cannot be preserved and second-hand materials are not available or are insufficient to meet the project's needs, costly replicas or custom-made materials may be required. This can significantly increase project expenses, as replicating historic elements with high precision involves considerable craftsmanship and materials, which often come at a premium. Additionally, the use of biobased materials, which are increasingly popular in the recent transformations, can also impact the budget (Yadav & Agarwal, 2021).

The challenge lies in finding a balance between adapting the monument to meet modern requirements and managing the associated costs. It is crucial to consider both the financial implications of material choices and the potential for increased expenses due to the need for advanced technologies. Additionally, the balance extends to the users of the building. While it is important to adapt the monument to accommodate contemporary needs, it is equally important for users to adapt to the unique characteristics and constraints of the historic structure.

6.3. Limitations and further research

This research presented multiple design issues encountered in the adaptive reuse process of monumental buildings. However, there are also some limitations present in this study which will be further discussed in this section.

Firstly, this research primarily concentrated on the technical aspects of adaptive reuse in heritage conservation. However, a crucial element that influences the success of these transformations, the regulatory frameworks, was merely included. From the findings, it is evident that monuments with varying levels of protection by governmental organizations offer different degrees of flexibility in their adaptation. Monuments that are not fully protected may allow for more extensive modifications, which can include both positive and negative consequences. On one hand, greater flexibility can lead to the replacement of original elements with new materials, which may enhance the building's longevity and functionality. On the other hand, such interventions can result in the loss of valuable historical components, potentially diminishing the building's historical integrity. Given these considerations, further research should focus on how different levels of regulatory protection can either support or hinder effective conservation strategies. In addition, the studies should determine the optimal balance between preserving original materials and incorporating new ones by evaluating the longevity and performance of both preserved and new materials.

Secondly, this research identified design issues in the "site" and "stuff" layers of Brand's model that were not prominently discussed in the existing literature. Specifically, the site layer highlighted only one design issues and the stuff layer primarily focused on noise pollution. The limited scope of design issues observed in these layers suggests a gap in the literature. Further research should be conducted to delve deeper into these layers, particularly the stuff layer. Since the high rate of change associated with this layer often results in relatively minor impacts, therefore developing strategies that enhance the effectiveness of adaptive reuse while minimizing disruption.

Finally, this study should be regarded as an initial step in the analysis of design issues in adaptive reuse projects. The research involved a limited number of interviewees and case studies, which constrains the reliability of the findings. To enhance the robustness of the data, further research is necessary. Future studies should include a larger and more diverse pool of experts and should focus on specific types of monumental buildings, such as multiple industrial or religious structures. This approach will facilitate a more comprehensive comparison between different types of monuments, leading to more generalizable insights and improved understanding of design issues across various contexts.

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9. Appendix

Table 3: Overview of interviewees with corresponding data

	Interviewee									
Descriptor	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Job title	Director	Director	Development manager	Architect	Architect	Sustainability advisor	Project manager	Project development officer	Acoustic advisor	Director
Years of experience	10	20+	25	13	18	2	7	12	30	57
Number of completed historic transformations	40+	+/- 10	+/- 25	+/- 5	+/- 15	+/- 35	3	5	50+	50+
Case study projects involved	1	1 and 2	1	2	2	2	3	3	1	1 and 2
Profession	Conceptual (co-)developer	Contractor and developer	Developer	Architecture	Architecture	Consulting firm	Contractor	Contractor and developer	Consulting firm	Installer
Interview length (min)	38	43 + 46	44	63	63	27	41	31	36	51