REBIRTH OF THE CHURCH

WOODEN INFILLS AS A SOLUTION TO VACANCY

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ABSTRACT

By 2030, 1,700 churches will become vacant, adding to the 1,530 already repurposed. Repurposing these spaces is time-consuming and costly, often leading to demolition when no potential is identified. This research explores how modular wooden building systems with adaptable, remountable elements can create customizable, multistory spaces in vacant churches. Moreover, it addresses the key questions: What are the criteria for a modular building system that could be used as an infill within vacant churches? Which of the existing modular building systems could be a potential solution as an infill to fit within vacant churches? How modular is the most potential modular building system as an infill within vacant churches? What are the technical requirements of the system concerning the various functions it is designed to accommodate? The study concludes that developing wooden adaptable infills is feasible if factors such as adaptability, interchangeability, efficient placement, and material efficiency are prioritized.

KEYWORDS: *Remountable, Timber-construction, Monumental architecture, Repurpose, Church, Vacancy, Modular, Adaptable.*

I. INTRODUCTION

1.1. Problem statement

Nowadays, the reusability of buildings has become a pressing concern, far surpassing its significance 60 years ago. Contemporary architectural design must address many factors, including climate change, material scarcity, pollution from the construction industry, economic considerations, and more. While evaluating new construction's environmental and social impacts is critical, equal attention must be paid to the adaptive reuse of existing structures. In the Netherlands, this principle is already evident in transforming vacant offices, schools, and other buildings into housing. According to the Centraal Bureau voor de Statistiek (CBS), 9,565 houses were created in 2022 by converting vacant buildings. Beyond functional properties like offices and schools, many religious monuments, such as churches, face the challenge of vacancy. Data from the Rijksdienst voor Cultureel Erfgoed (RCE) indicates that there are 7,110 churches, synagogues, mosques, and temples in the Netherlands, with 1,530 of these already repurposed for non-religious functions. Furthermore, by 2030, approximately 1,700 additional churches are expected to become vacant (Ministerie van Onderwijs, Cultuur en Wetenschap, 2021). At the same time, metropolitan areas such as Amsterdam, The Hague, and Rotterdam offer diverse opportunities for repurposing vacant churches, and regions like Zeeuws-Vlaanderen present unique challenges. This rural area, spanning 875.80 square kilometers with a population of approximately 105.499 (Eurostat, 2019), is often referred to as "land on its own" due to its geographic isolation, bordered by Belgium and the surrounding water of the Westerschelde. Declining support for community facilities has compounded accessibility issues in the region (van der Wouw, 2017). In the past decade, many churches in Zeeuws-Vlaanderen have been vacated and placed on the market without viable plans for reuse, particularly in smaller villages where developers are scarce. Between 2003 and 2013, the number of churchgoers in the Diocese of Breda halved, leading to the closure of 27 churches (Omroep Zeeland, 2016). Church attendance has declined, with only 12% of individuals aged 15 and older attending services regularly in 2022, down from 14% in 2019 (Houben, 2023). Once vital to the social fabric of towns and cities, these buildings now stand as neglected artifacts (Versloot, 2020).

Repurposing vacant churches faces several obstacles. These structures' architectural and spiritual significance, monumental status, and costs associated with renovation or adaptation discourage potential developers (Lancellotta et al., 2022). Moreover, strict regulations and complex permit procedures further hinder the process (Woudt, 2013). Besides, environmental considerations, particularly the impact of material choices, are increasingly crucial in determining viable reuse strategies. A promising solution lies in developing a modular, remountable timber infill system designed to adapt vacant churches for new uses while preserving their architectural integrity. Timber offers a lightweight, sustainable, and versatile construction material, making it an ideal choice (Pajchrowski et al., 2013). Such systems could provide temporary or permanent solutions without requiring mechanical connections between the infill and the original structure, thereby minimizing physical modifications to the historic building. The modular system should support multistorey spaces and adapt to different church types while preserving their architectural and cultural significance. To achieve this, the system must be lightweight, easily disassembled, and adaptable in size and configuration. Potential construction methods include on-site techniques, surface unit systems, and CNC-fabricated structures. The final choice will depend on factors such as production feasibility, transportation logistics, and compatibility with the existing building fabric. Using timber as the primary material and focusing on modularity, the proposed system could ease permitting processes and lower costs due to its temporary and reversible nature. Furthermore, the remountability of the system would enable its reuse in other settings, enhancing its sustainability credentials (Kaufmann et al., 2018). This study addresses the question: *How can a modular wooden building system be developed with adaptable elements to create customizable, remountable, multistory spaces within vacant churches?*

II. METHOD

2.1. Research method

To get an answer to the question, *"How can a modular wooden building system be developed with adaptable elements to create customizable, remountable, multistory spaces within vacant churches?"* the method of research-by-design will mainly be applied. Furthermore, the methods of literature study, case-study analysis, and content analysis will be used. The methods and strategies for the different sub-questions will be elaborated in the next section.

2.2. Sub-questions as a framework

The main question of this research is divided into four sub-questions. The order of these questions forms the framework of the study while covering all the needed information to answer the main question. The four sub-questions of this research are:

- What are the criteria for a modular building system that could be used as an infill within vacant churches?
- Which of the existing modular building systems could be a potential solution as an infill to fit within vacant churches?
- How modular is the most potential modular building system as an infill within vacant churches?
- What are the technical requirements of the system concerning the various functions it is designed to accommodate?

To address the first sub-question, 14 criteria will be created based on *requirements* and *design principles* for such infill. Most of these criteria allow for binary (yes/no) evaluation, enabling the identification of the modular system with the most significant potential for repurposing vacant churches. The *requirements* are derived from the unique characteristics of churches, such as high ceilings, irregular dimensions, and challenging building locations, while the design principles are derived from the design objective. All these criteria are based on a literature study.

For the second sub-question, 24 modular building systems, primarily originating from the Netherlands, will be analyzed based on the criteria from the first sub-question. The systems are chosen based on the availability and recognition within the building industry. The criteria will be answered through a binary evaluation, except for one question. The most suitable system will undergo further analysis in the third sub-question.

Thirdly, a case study analysis will address the sub-question, *"How modular is the most potential modular building system as an infill within vacant churches?"*. For this purpose, three churches were selected: the St.-Willibrordusbasiliek in Hulst (15th century) **[see Appendix 1]**, the Onze-Lieve-Vrouw-Hemelvaartkerk in Philippine (1954) **[see Appendix 2]**, and the Maria Hemelvaartkerk in Graauw (1855) **[see Appendix 3].** The selection of these churches was based on several properties. First, all three buildings are located in the Zeeuws-Vlaanderen region, providing a geographically consistent basis for analysis (van der Wouw, 2017). Second, they are Roman Catholic churches renowned for their complex architectural detailing. Thirdly, each church represents a distinct period and architectural style, enabling a thorough study of how the system adapts to varied contexts. These differences provide a foundation for evaluating the modular system's flexibility and performance. The modular building system identified in the second sub-question will be applied to all three churches. The primary objective is to maximize usable space within each structure. The design parameters include a ceiling height of 3,000 millimeters on the ground floor, if possible, and 2,600 millimeters on the upper floors, with column spacing based on a standard modular element of 600 millimeters. Besides, the columns have a measurement of 180 by 180 millimeters, and the beams have a height of 500 millimeters. The evaluation criteria for the system will focus on several key aspects:

- Interchangeability: The system's adaptability across the three churches.
- Unusable Space: The total area within the building made unusable by the system.
- Preservation of Architectural Elements: The extent to which the system maintains visibility of the churches' original architectural features.
- Material Efficiency: The amount of wood waste generated, particularly when walls are tilted.

This analytical framework ensures a systematic approach to determining how modular the most potential building system is for repurposing vacant churches.

To address the fourth and final sub-question, *"What are the technical requirements of the system concerning the various functions it is designed to accommodate?"*, the St. Willibrordus Basiliek will be analyzed to identify the challenges and opportunities associated with zoning for each intended function. Because of the shape and size of the church, creating certain functions will be the most challenging in this location. The proposed functions include housing, workspaces, a market, a food hall, a community center, workshops, and commercial spaces. The zoning analysis will focus on key technical aspects critical to successfully implementing these functions within the church. These aspects include:

- Heating and Cooling: Evaluating the current thermal performance of the church to ensure energy efficiency and identifying what measures have to be taken within the building system.
- Acoustics: Addressing current sound control to facilitate functions after implementing the new infill.
- Ventilation: Analysing the presence of a ventilation system as a possibility to place certain functions.
- Fire Safety: Analysing compliance with fire safety regulations for occupant protection.
  In the building regulation in the Netherlands (Bouwbesluit 2012), it is stated that for the functions of residential function, meeting function, shopping function, office function, and other functions, the escape route can not be longer than 30 meters (*Bouwbesluit 2012 - artikel 2.101. aansturingsartikel*, no date).
- Daylight Access: Assessing natural light availability to create a functional and pleasant environment for specific functions.
  The same regulation document mentions the amount of daylight access per function. In the case of the living and office functions, daylight is required, 10% and 2,5% daylight surface (*Bouwbesluit 2012 - afdeling 3.11. Daglicht*, no date).

This systematic evaluation will provide a complete understanding of the technical requirements needed to adapt the modular system for the varied functions intended for vacant churches.

III. RESULTS

3.1. Criteria

3.1.1 Building System Requirements

Completely made out of wood
Research by Pajchrowski et al. (2013) concluded that wood, as a building material, is sustainable in transport, production, assembly, and disassembly. Because it is lightweight, it forms a versatile construction material that can be moved, built, and disassembled with lower energy consumption than other building materials. Also, the material itself sequesters carbon. Often combined with carbon-emitting materials, this leads to a carbon-neutral building.

Construction method
The construction method of the infill has a lot to do with the possibilities and the required equipment to install certain elements. To better understand the available modular building systems made for Dutch regulations, all sorts of construction methods are analyzed. Therefore, wooden-based systems can be compared with non-wooden-based systems. Furthermore, it gives a better understanding of which building methods are mainly applied and if wooden-based systems are common in this construction method. The possible construction methods are:

- Steel
  Steel framework placed on top of a wooden or concrete prefabricated floor.
- HSB (timber frame construction)
  Prefabricated wooden walls made out of a timber frame construction (Kaufmann et al., 2018).
- CLT (Cross Laminated Timber)
  A wood product that is made out of glued solid-sawn lumber. The grains are glued perpendicular to the adjoining layers. It can be made as complete prebuilt walls and floors, or as a post-and-beam construction. (Kaufmann et al., 2018).
- Glulam (Glued Laminated Timber)
  A wood product that is made out of glued solid-sawn lumber. The grains are glued parallel to the longitudinal axis (Kaufmann et al., 2018).
- LVL (Laminated Veneer Lumber)
  A wood product made of multiple layers of veneer and bonded together with heat and pressure. Like CLT, this product can be made in different elements (Kaufmann et al., 2018).
- HKB (HoutKern construction method)
  Construction of wooden columns and floors that are connected with a steel node.

Not all these construction methods are criteria for the building method; the opposite occurs here. Almost every method would not be an ideal solution for this purpose. Only CLT and LVL could be used due to their properties in size, weight, and applicability.

Lightweight
Even though some churches have stood for over 500 years, it suggests that these buildings are renowned for their structural resilience. The opposite was concluded from the research of Theodossopoulos, D. and Sinha, B.P. (2008); these buildings have, among others, problems with lateral instability. Maximizing internal space necessitates lightweight construction systems, making steel and concrete impractical due to their weight and difficulty in transport and placement. Consequently, construction systems are evaluated based on material properties, with steel and concrete classified as heavy, while wood-based systems are considered lightweight.

Can the elements be carried by 2
Certain areas within a church cannot accommodate mechanical support for lifting or moving components. In most cases, it is possible to use specific lifting devices within a building, but that is not always the case. Therefore, two individuals must manually transport elements, limiting their weight to a maximum of 42.5 kilograms (Ministerie van Sociale Zaken en Werkgelegenheid, 2024). This requirement favors systems constructed from lightweight wooden materials, as previously discussed. The analysis also considers whether systems are composed of modular elements or prebuilt structures.

Specifically, HSB, CNC wood, and LVL systems meet this criterion when designed as separate elements using lightweight wood within specific dimensions. Among these, LVL emerges as the most promising option due to its combination of structural strength, compact dimensions, and lightweight properties (Kaufmann et al., 2018).

Multistory possible
As previously noted, churches are distinguished by their distinctive shape and substantial size (Lancellotta et al., 2022). Failing to utilize the vertical space within the interior would result in inefficient use of available space. Consequently, the modules should be designed to be stackable or capable of incorporating multiple floors. The completed projects of the manufacturer answer this criterion.

Demountable
As the problem statement highlights, the reusability and adaptability of buildings and building systems are becoming progressively more significant. Reusing a system at a different location necessitates the ability to disassemble the entire system into individual building elements.

Stable without inner walls
The dimensions of the elements in a building system that can be accommodated within a church are constrained by the size of its entrance. Among the three selected churches, the smallest door measures 1900 mm in width and 2600 mm in height **[see Appendix 4]**. Consequently, complete load-bearing walls would be too large to pass through and would limit the design flexibility of the building system. Therefore, a structural system comprising columns and beams is necessary to create spaces within vacant churches effectively. Also, it gives more freedom and flexibility in the design and use of the system when it's built. So, a system made out of a post-and-beam structure provides this flexibility.

Housing
There is an urgent need for housing in the Netherlands (Ministerie van Algemene Zaken, 2023b). This need is especially acute in temporary housing, such as student housing and asylum seekers. Therefore, the modular system should be able to accommodate housing. The system's use and declaration by the manufacturer answer this criterion.

Made for other functions
The location of churches can differ from being in a metropolitan area to a village surrounded by countryside. The infills should be able to accommodate different functions according to the needs of the region in which they are located; in that way, the system will be reusable and durable (van der Wouw, 2017).

Adaptable in size
The ability to change the infill in specific configurations would provide a solution that can be interchangeable between different churches. Besides, it gives the possibility of using the infill for various functions. The manufacturer's use of the system and declaration will also answer this criterion.

Can be made in specific measurements
These kinds of buildings are known to have irregularities, tilted walls, and inconstant spacing between columns (Lancellotta et al., 2022). Therefore, the system should be adaptable and within specific sizes to apply to multiple churches.

Inside module
As mentioned above, the ability to be built within another building already requires a few criteria. This criteria helps to illustrate which of these building systems is already designed to be built within a building. In other words, it is designed for the same purpose as the problem statement. Furthermore, these kinds of systems are made out of elements to be built within a building. Modules that are made for an outdoor environment not only have a completely waterproof membrane or materials that have a waterproofing function, but are more likely to be rebuilt entirely out of modules.

3.1.2 Design Principles

Possible to merge installations in the construction.

This criterion has more to do with the architectural value of a church (Roca et al., 2019). Therefore, it can be seen as a design principle. The possibility of hiding ventilation systems, water pipes, and other systems would make the system more applicable to churches. Therefore, the focus will be on the appearance of the infill within the church instead of the technical appliances. Furthermore, the infill will appear more temporary instead of permanent.

Easily remountable
The other design principle that will be implemented in the design itself is the ability to demount and remount the building system quickly. This means the system can primarily be built with essential tools, providing a system that can reuse almost every component multiple times. These criteria help create sustainable solutions.

3.2. Potential modular building system

In the second phase of this research, 24 modular building systems were evaluated based on 14 criteria to identify the most suitable system for further analysis in the third sub-question **[see Appendix 5]**. Eight systems were excluded early on for not being entirely constructed from wood. Additionally, only two systems comprised separate elements light enough to be carried by two individuals, while most others were preassembled and unsuitable for installation within churches. Few systems offered the flexibility for specific measurements, and only one met the requirement of being constructed entirely within the church. Considering all criteria and the need for an adaptable indoor modular building system suitable for various churches, only the Respace system met all the requirements and was selected for further analysis. Although the Circlewood system shows potential, it necessitates significant mechanical support for installation and is not designed for use in other buildings.

3.3. Implying the modular building system of Respace

In general, the modular element of 600 millimeters is challenging to apply in all three churches **[see Appendix 9]**. Moreover, the standard heights of 2600 and 3000 millimeters create mostly an unusable space underneath the ceiling, but also too much leftover space **[see Appendices 6 to 8]**.

3.3.1 Interchangeability

When considering whether it is possible to reconstruct a system or its necessary components within another church without modifying any elements, the answer is no. An analysis of the required components for these churches **[see Appendix 9]** reveals that while many of the measurements are shared, none have identical dimensions across all elements. Additionally, the Church of Hulst's elements offer the most interchangeable system among the three, as the percentages of shared columns and beams indicate.

3.3.2 Unusable space

As seen in the drawings of the Respace modules **[see Appendices 6 to 8]**. In all three churches, there is a rest space underneath the ceiling. The church of Graauw, already 200 square meters, is unusable due to a lack of free height on the upper floor. In the church of Philipinne, this is around 300 square meters, and in Hulst, this will be around 200 square meters. Besides, there is much leftover space just because the elements can not be built directly against the walls and columns due to the architectural aspects of the structure. For all three buildings, the unusable space is even higher than the previously mentioned surfaces if all columns and space between the system and the original structure are calculated. Additionally, implementing the system in such a way obstructs the amount of daylight reaching the ground floor due to the height at which these windows start.

3.3.3 Preservation of Architectural Elements

The Respace system drawings within the churches **[see Appendices 6 to 8]** demonstrate that the visibility of the architectural elements in these buildings is significantly limited. In the cases of Graauw and Philippine, large portions of the ceiling are neither visible nor accessible. In the Church of Hulst, while the ceilings are visible, this is restricted to vantage points on the second or sixth floor of the building. Consequently, implementing the system in this configuration would result in most of the church's architectural features, except for the columns, being concealed from a person's view.

3.3.4 Material Efficiency

The variety of required elements **[see Appendix 9]** demonstrates that significant customization is necessary to implement such a system effectively. The number of components derived from the standard 600-millimeter size is substantially lower than that of those with adapted dimensions. Furthermore, in all analyzed churches, the Respace system is not constructed directly against the existing structure **[see Appendices 6 to 8]**. These drawings assume the walls are perfectly straight; however, churches built before the 1900s often have tilted walls (Lancellotta et al., 2022). These imperfections significantly increase the need for custom elements, reducing the system's modularity. Additionally, the built-in design of the system results in material waste due to its limited adaptability to such conditions. The literal material efficiency and waste of materials are too complex to calculate since the inner walls and floors have to be custom-made, as well as the columns and beams. Ultimately, they could only be calculated after building the system.

3.4. Technical requirements

3.4.1 Heating and Cooling

The St. Willibrordusbasiliek, similar to the two other churches under study, lacks insulation. The space plan and section **[see Appendix 1]** clearly illustrate that most walls are approximately 1000 millimeters thick. The substantial stone mass of churches with walls of this thickness contributes to maintaining a more stable indoor temperature in naturally ventilated settings, as demonstrated by the findings of Vella et al. (2020). While modular infill structures will still require insulation for specific functions, such as residential and office use, the inherent thermal stability of the environment reduces the need for heating and cooling compared to outdoor conditions.

3.4.2 Acoustics

Church ceilings' height, dimensions, and curved shapes create spaces with distinct acoustic characteristics (Girón, Álvarez-Morales, and Zamarreño, 2017). Only a limited number of spaces are sufficiently small and enclosed by four walls to produce easily managed acoustics. Furthermore, few of the open spaces adjoining the main area exhibit reverberation levels that are more manageable than those found in other parts of the church **[see Appendix 10]**. Consequently, acoustic measures must be integrated into the modular infills for many proposed functions, such as housing, workshops, commercial spaces, or community centers. Without such measures, the excessive reverberation could make these and other spaces unsuitable for their intended purposes.

3.4.3 Ventilation

The architectural drawings of the church **[see Appendix 11]** depict the presence of a mechanical ventilation system complemented by natural ventilation through the windows. In the central nave, located on the west side of the church, the ventilation ducts and channels are positioned beneath a wooden floor. In contrast, additional supply and exhaust ducts are under a stone floor on the east side. However, the airflow provided by both natural and current mechanical ventilation systems cannot support specific functions. An improved ventilation system would be required for housing, offices, food markets, and workshops.

3.4.4 Fire Safety

The St. Willibrordusbasiliek has three main exits **[see Appendix 12]**. However, as illustrated in the drawings, one section of the church lies beyond the 30-meter emergency exit radius. While the indicative radius provides an approximate escape distance, the distance from specific points exceeds 30 meters, especially on the unreachable part. Consequently, no potential functions can be assigned to this area without adding an extra escape route. Furthermore, in the case of a multistorey infill, the portion of the space exceeding the 30-meter limit would increase significantly with each added floor.

3.4.5 Daylight Access

As observed in this case **[see Appendix 1]** and in many other churches, large windows are characteristic features that allow significant daylight to enter the building (Theodossopoulos and Sinha, 2008). However, an essential property of the building is that these windows begin at 3050 millimeters from the ground floor, making it challenging to provide adequate daylight for certain functions at this height. Additionally, most windows are composed of stained glass, which reduces the amount of light transmitted and does not allow visibility into or out of the building. For functions located on the first floor and above, it is feasible to achieve the recommended 10% daylight surface area **[see Appendix 13]**, particularly for housing on the south side of the church, where daylight exposure is optimal. Therefore, residential and office functions can be effectively accommodated within the building from the first floor upwards. Housing is most suitable for the south side, while office spaces can be placed on the north and south sides.

IV. CONCLUSION AND DISCUSSION

4.1 Conclusion

In conclusion, addressing the main question, *"How can a modular wooden building system be developed with adaptable elements to create customizable, remountable, multistory spaces within vacant churches?"* several insights emerge. First, the criteria for a modular building system for use in vacant churches, as explored in the first sub-question, "*What are the criteria for a modular building system that could be used as an infill within vacant churches"*, primarily relate to the physical context of production, transport, and assembly, with most being based on functional requirements rather than design goals. Significant mention here is that a large number of these criteria have to do with the construction of the infill. These criteria were based on the given information that there is not always room inside the church for mechanical support to lift certain elements. These criteria formed the foundation for evaluation, although a revision of these criteria could be considered after answering the second sub-question. Regarding the second sub-question, *"Which of the existing modular building systems could be a potential solution as an infill to fit within vacant churches?"*. While several existing modular systems show potential, only one satisfies all the criteria: Respace's system. The systems that were analysed for this sub-question were created within the Netherlands or were made for the Dutch regulations. The system of Respace was the only building system that was designed as an indoor module, whereas others are designed as outdoor modules. However, the most promising system, when analyzed in the third sub-question, *"How modular is the most potential modular building system as an infill within vacant churches?"* is found to lack sufficient modularity and adaptability for church infills. Additionally, the current standard building measures often lead to inefficiencies, material waste, and unusable spaces within these buildings. Moreover, reusing churches in such a way contrasts with the architectural preservation and the impact on the interiors of churches. The infill should not only be able to adapt to the building measurements, but also should form a contrast with the church to highlight its sacred architectural features. The fourth sub-question, "*What are the technical requirements of the system concerning the various functions it is designed to accommodate?"* reveals that technical requirements for accommodating various functions extend beyond the infill itself, including improvements to ventilation and fire safety. Effective placement of functions and minimal material use are essential for optimizing these systems. Ultimately, it is concluded that no infill is explicitly made for the purpose described in the current analysis. It can be said that a modular wooden system for customizable, remountable, and multistory spaces can be developed, provided that the identified criteria, adaptability, material efficiency, modularity, and integration with existing building requirements, are prioritized while ensuring the preservation of the church architecture.

4.2. Discussion

Analyzing the methods and results of this research highlights some critical observations. Looking at the analysis of the infills, a few things can be said. First of all, the amount of criteria could be enlarged in a follow-up research. Besides, this study focused on modular infill systems, primarily from the Netherlands, with one exception from Belgium, ensuring compatibility with the local regulations. While this would be a suitable selection in terms of rules, a broader analysis of systems throughout Europe might have revealed additional systems ideal for this problem. In addition, in analyzing the one system that met the requirements, the analysis of a more significant number of churches might have given different insights into the applicability and interchangeability of the selected system. However, the diversity of the studied churches provided a clear understanding of the practical use and challenges of the Respace system. The analysis of the technical requirements suggested a potential functional division within church spaces; although this analysis remains specific for one case, it depicts the requirements of the building system. Future research should explore these aspects further for broader relevance. The research-by-design method is still the most applicable in this kind of research. Expanding the research scope and duration would possibly strengthen the findings and understanding of modular infill systems in churches.

REFERENCES

1. Ardui, C. (2024) *drie-vlaamse-kerken-tonen-hun-langetermijnwaarde-en-typologische-veerkracht*. https://www.dearchitect.nl/297132/drie-vlaamse-kerken-tonen-hun-langetermijnwaarde-en-typologische-veerkracht?giftCode=80NZVGaSIsPxKBBGbfXK0YoWBlicy4ddEeeWZoOQ4JnwyCo9ReYTurT_OEPGuGmY&social=copy.

2. Berkelland (2024) *Visie op religieus erfgoed Berkelland*. https://lokaleregelgeving.overheid.nl/CVDR715657/1#:~:text=Bij%20het%20opstellen%20van%20deze,daarbij%20uitgewisseld%20en%20belangen%20afgewogen.

3. Bhandari, S. *et al*. (2022) 'A review of modular cross-laminated timber construction: Implications for temporary housing in seismic areas,' *Journal of Building Engineering*, 63, p. 105485. https://doi.org/10.1016/j.jobe.2022.105485.

4. Boer, de (1911) *Beschryvinge van de kerck der stadt Hulst, ontleend aan de 'Beschryvinge van de stadt Hulst' anno 1685*. Hulst, Netherlands: Ned.Herv.Gemeente.

5. *Bouwbesluit 2012 - artikel 2.101. aansturingsartikel* (no date). https://www.bblonline.nl/docs/wet/bb2012/hfd2/afd2-12/par2-12-1/art2-101?q=vluchtroute

6. *Bouwbesluit 2012 - afdeling 3.11. Daglicht* (no date). https://www.bblonline.nl/docs/wet/bb2012/hfd3/afd3-11?q=daglicht.

7. Centraal Bureau voor de Statistiek (2023) '9,6 duizend woningen door transformaties in 2022,' *Centraal Bureau Voor De Statistiek*, 5 November. https://www.cbs.nl/nl-nl/nieuws/2023/45/9-6-duizend-woningen-door-transformaties-in-2022#:~:text=In%202022%20werden%203%2C1,pand%20in%20plaats%20van%2010).

8. CUBE homes (no date) *CUBE homes*. https://www.cube-homes.com/nl.

9. De Groot Vroomshoop (no date) *Bouwsystemen*. https://degrootvroomshoop.nl/bouwsystemen/.

10. *De mogelijkheden* (no date). https://www.gewoonhout.nl/modules/.

11. *DMT Modular Building | Startpagina* (no date). https://www.dmtmodular.nl/nl.

12. *Een kijkje in onze Homes Factory | Homes Factory* (no date). https://www.homesfactory.nl/het-proces.

13. Finch Buildings (2024) *Finch Buildings — product*. https://finchbuildings.com/product-2/.

14. *Flexgoed biedt altijd de ruimte die je nodig hebt* (2024). https://vdldemeeuw.com/nl/flexgoed/.

15. *Geplande buitengebruikstellingen kerken - Reliwiki* (no date). https://www.reliwiki.nl/index.php/Geplande_buitengebruikstellingen_kerken.

16. Girón, S., Álvarez-Morales, L. en Zamarreño, T. (2017) 'Church acoustics: A state-of-the-art review after several decades of research,' *Journal Of Sound And Vibration*, 411, pp. 378–408. https://doi.org/10.1016/j.jsv.2017.09.015.

17. HDO Groep BV - Bouwen met aandacht - Houtmodulebouw (2024) *HDO Woonmodules - HDO Groep BV - Bouwen met aandacht - Houtmodulebouw*. https://hdo-groep.nl/product/hdo-woonmodules/.

18. Heijmans (no date) *Heijmans ONE | Houten woningen voor kleine gezinnen*. https://www.heijmans.nl/nl/flex/heijmans-one/.

19. *Hodes producten* (zonder datum). https://www.hodes-huisvesting.nl/hodes-producten.

20. *Hoe bouwen we* (no date). https://www.barli.nl/hoe-bouwen-we.

21. Houben, H.S.M. (2023) *Religieuze betrokkenheid in Nederland*. https://www.cbs.nl/nl-nl/longread/statistische-trends/2023/religieuze-betrokkenheid-in-nederland?onepage=true.

22. HOUTbaar (2020) *HUIS - Houtbaar*. https://www.houtbaar.nl/huis/.

23. Kaufmann, H., Krötsch, S. and Winter, S. (2018) *Manual of Multi-storey Timber Construction*. Detail.

24. Lancellotta, R. *et al.* (2022) *Geotechnical Engineering for the Preservation of Monuments and Historic Sites III*, *CRC Press eBooks*. https://doi.org/10.1201/9781003308867.

25. Ministerie van Algemene Zaken (2023a) *900.000 nieuwe woningen om aan groeiende vraag te voldoen*. https://www.rijksoverheid.nl/onderwerpen/volkshuisvesting/nieuwe-woningen.

26. Ministerie van Onderwijs, Cultuur en Wetenschap (2019) *Omgevingsvergunning en advies herbestemming*. https://www.cultureelerfgoed.nl/onderwerpen/herbestemming/omgevingsvergunning-en-advies-herbestemming.

27. Ministerie van Onderwijs, Cultuur en Wetenschap (2021) *Eén op de vier kerkgebouwen heeft een nieuwe functie*. https://www.cultureelerfgoed.nl/actueel/nieuws/2020/11/30/een-op-de-vier-kerkgebouwen-heeft-een-nieuwe-functie.

28. Ministerie van Onderwijs, Cultuur en Wetenschap (2022) *Herbestemming*. https://www.toekomstreligieuserfgoed.nl/herbestemming.

29. Ministerie van Sociale Zaken en Werkgelegenheid (2024) *Wat zegt de wet over tillen en dragen?* https://www.arboportaal.nl/onderwerpen/tillen-en-dragen/wat-zegt-de-wet-over-tillen-en-dragen.

30. *Modulair bouwen - Daiwa House Modular Europe - Modulaire woningen* (2024). https://www.daiwahousemodular.eu/modulair-bouwen/?_gl=1*1fjioxi*_up*MQ..*_gs*MQ..&gclid=Cj0KCQiAkJO8BhCGARIsAMkswyjbpIkoFcqlN2m1d9ToBjIFTEcW7dJBny2JbckH8yCL1jQseB7tAZwaAlX3EALw_wcB.

31. Omroep Zeeland (2016) 'Leegstaande kerken raak je aan de straatstenen niet kwijt (video),' *Omroep Zeeland*, 30 August. https://www.omroepzeeland.nl/nieuws/10138797/leegstaande-kerken-raak-je-aan-de-straatstenen-niet-kwijt-video.

32. *Onze woningen - Tala* (2024). https://www.tala.nl/onze-woningen/.

33. Oosterhoff (without date) *CircleWood®*. https://www.circlewood.eu/.

34. Pajchrowski, G. *et al.* (2013) 'Wood as a building material in the light of environmental assessment of full life cycle of four buildings,' *Construction and Building Materials*, 52, pp. 428–436. https://doi.org/10.1016/j.conbuildmat.2013.11.066.

35. Plegt-Vos (no date) *Modulaire woningen van hout | Plegt-Vos*. https://www.plegt-vos.nl/appartementen/flexwonen/.

36. Respace (2024) *Het inbouwsysteem - Respace*. https://respace.nl/het-inbouwsysteem/.

37. Roca, P., Lourenço, P.B. and Gaetani, A. (2019) *Historic Construction and Conservation*, *Routledge eBooks*. https://doi.org/10.1201/9780429052767.

38. *Skilpod | modulaire prefab woningen in houtskeletbouw* (no date). https://skilpod.com/nl/woningen.

39. *Stapelbare flexwoningen - Houten Thuis* (no date). https://thenewmakers.com/product/houten-thuis/.

40. Startblock (no date) *Startblock | Onze aanpak*. https://startblock.nl/onze-aanpak/.

41. THEBOXSYSTEM (2024) *THEBOXSYSTEM | THEBOXSYSTEM*. https://theboxsystem.nl/theboxsystem/.

42. Theodossopoulos, D. and Sinha, B.P. (2008) 'Structural safety and failure modes in Gothic vaulting systems,' *Eighth International Seminar on Structural Masonry* [Preprint]. https://www.pure.ed.ac.uk/ws/files/8768078/Structural_Safety_and_failure_modes_in_Gothic_vaulting_systems.pdf.

43. *URSEM3D Modules - URSEM Modulaire Bouwsystemen* (2021). https://www.ursem.nl/producten/modules/.

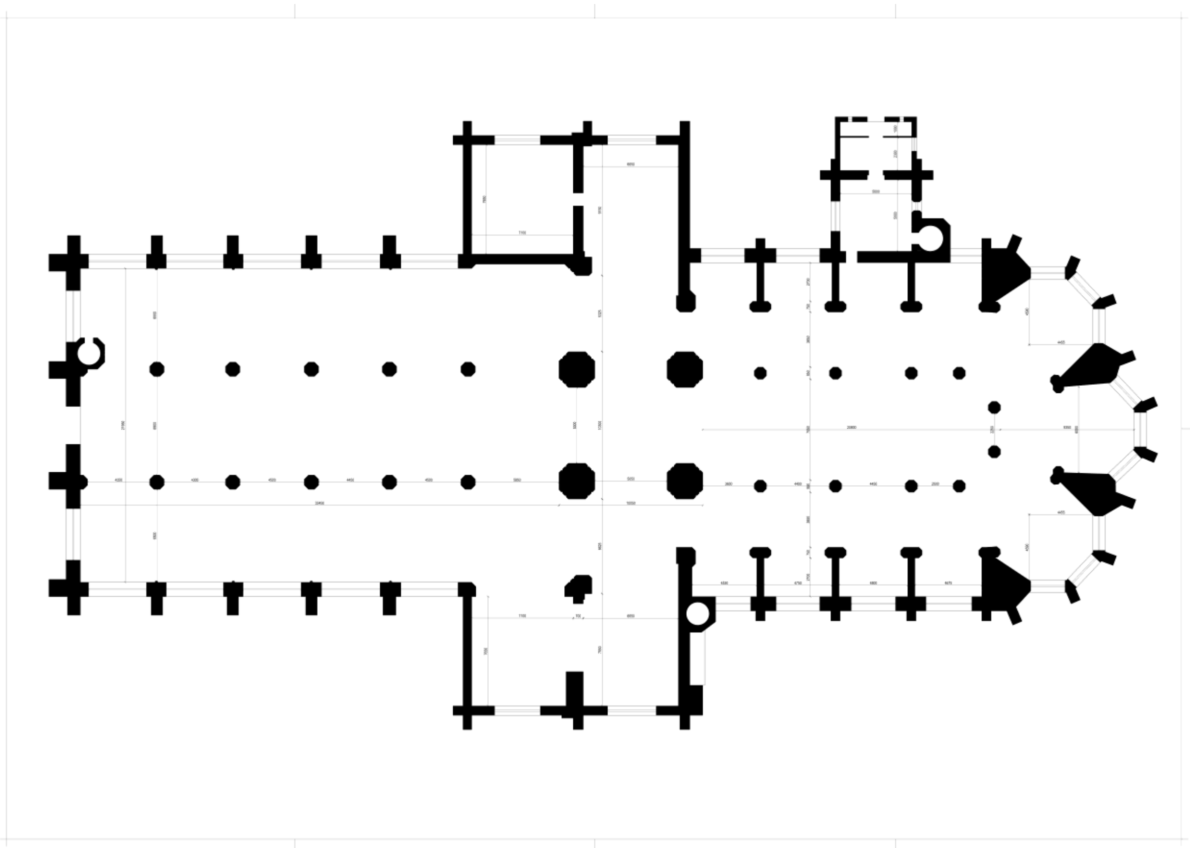
44. Vella, R.C. *e.a.* (2020) 'A study of thermal comfort in naturally ventilated churches in a Mediterranean climate,' *Energy And Buildings*, 213, p. 109843. https://doi.org/10.1016/j.enbuild.2020.109843.

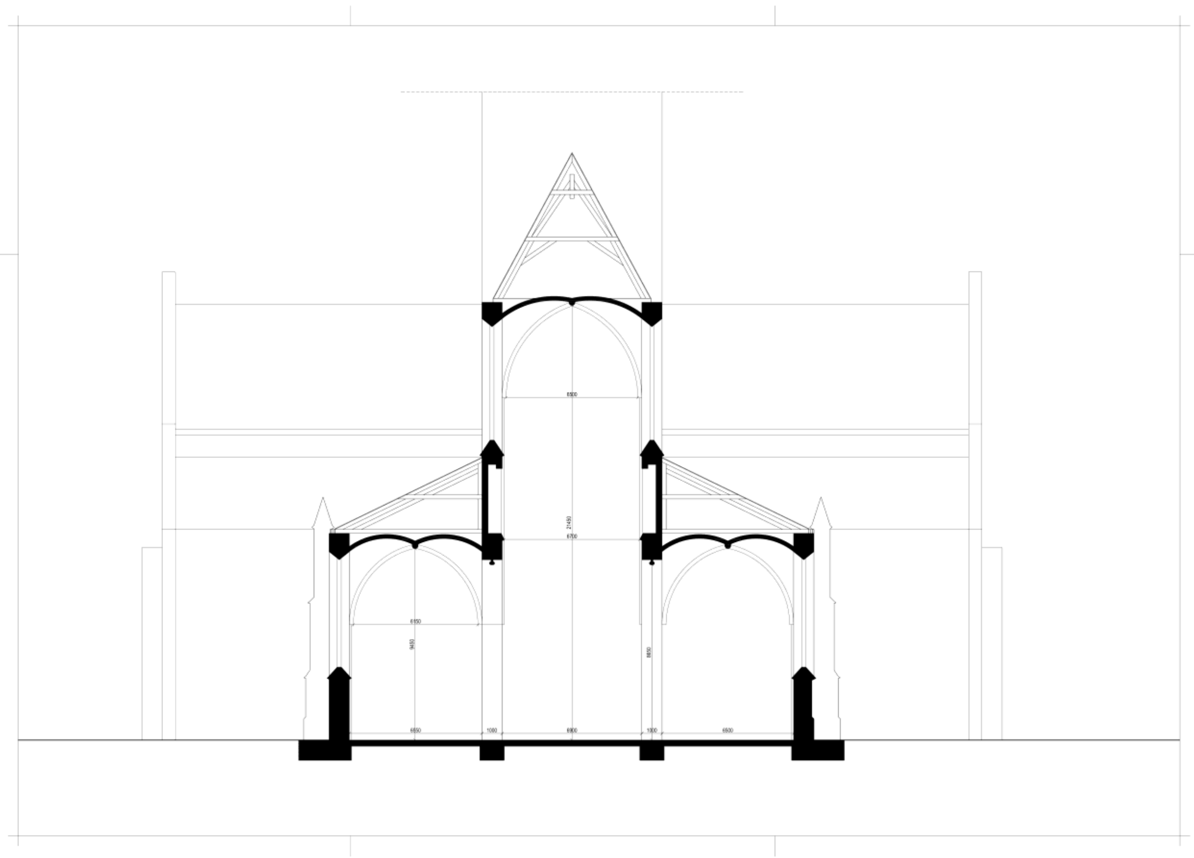
45. Versloot (2020) *Repurposed church buildings and their changing public perception through the course of history in the Netherlands*. Delft University of Technology.

46. Woudt (2003) *Herbestemming van monumenten: probleem of uitdaging?* masterscriptie. Rijksuniversiteit Groningen. https://frw.studenttheses.ub.rug.nl/1320/1/05075.pdf.

47. Wouw, van der (2017) *Zeeuws-Vlaanderen; een landje apart?*, *www.dezb.nl*. https://www.projectenportfolio.nl/images/d/de/ZS-zeeuws-vlaanderen-een-landje-apart.pdf (Accessed: October 16, 2024).

APPENDIX 1





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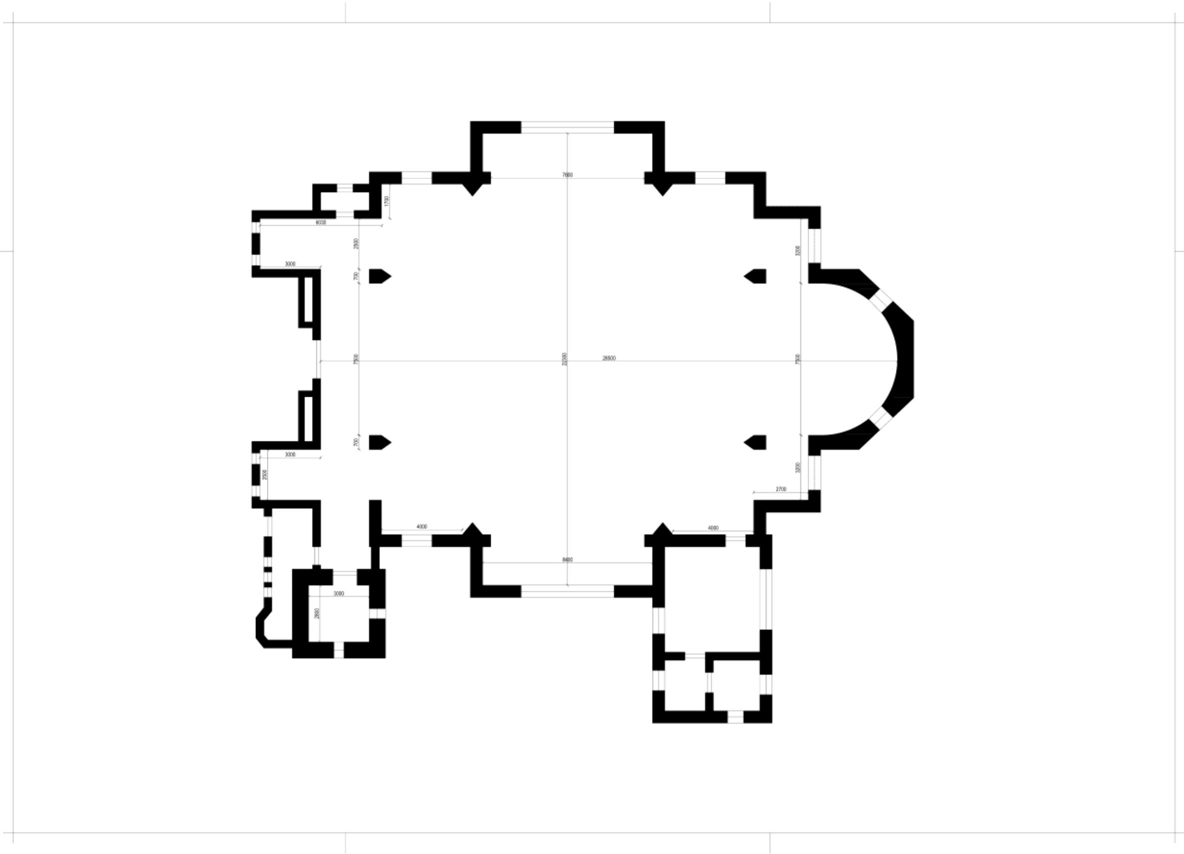

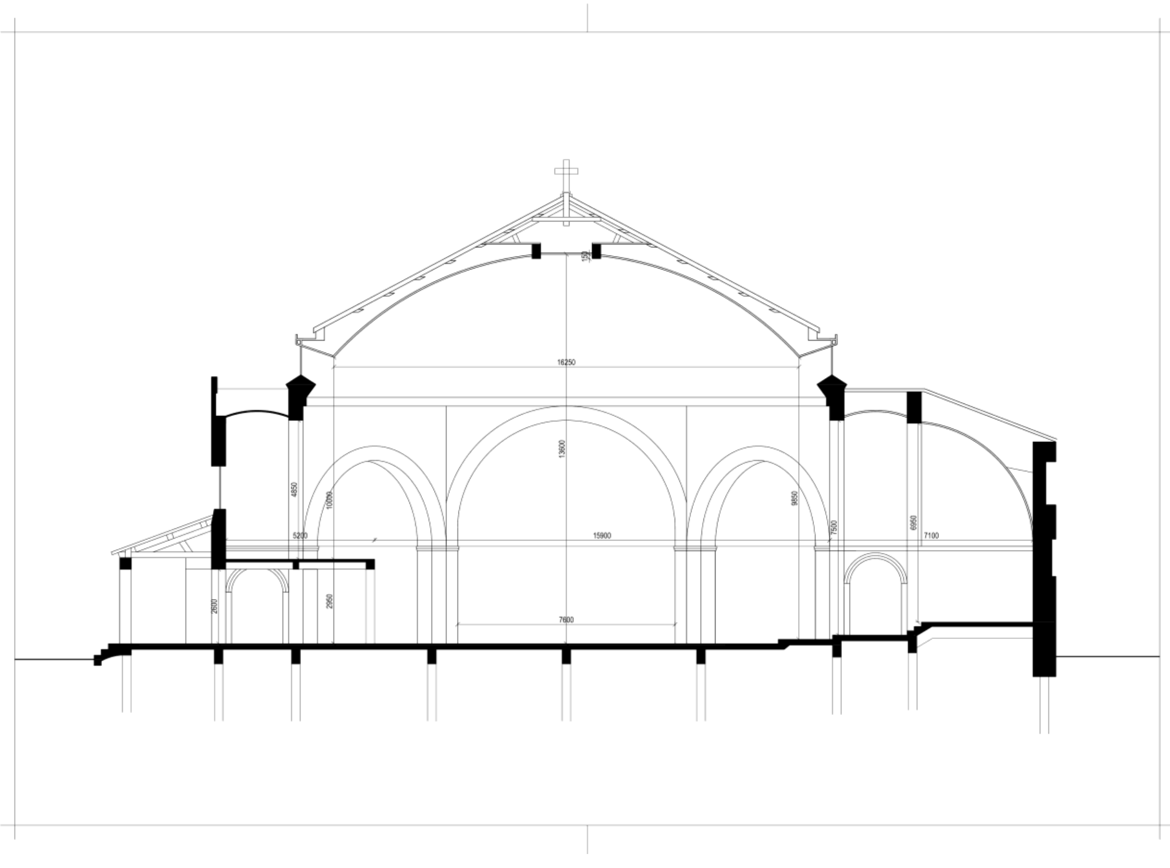

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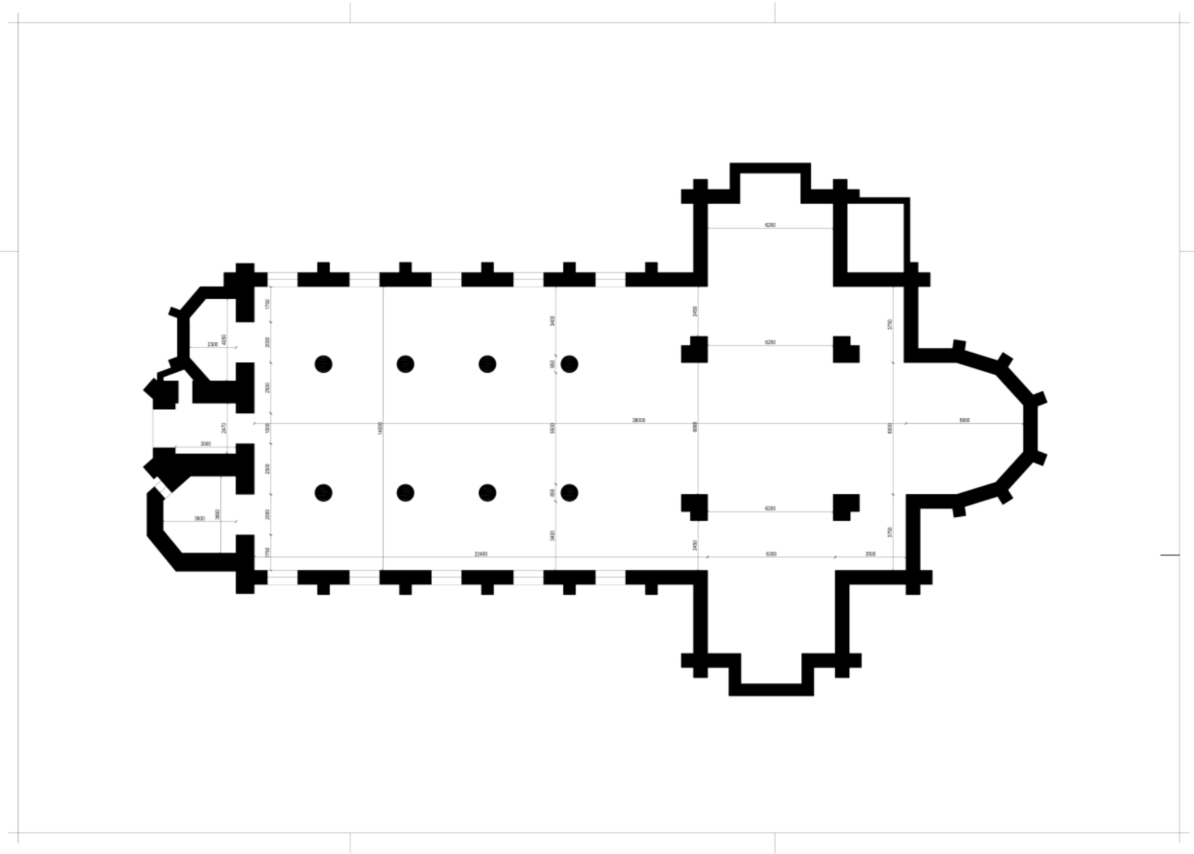

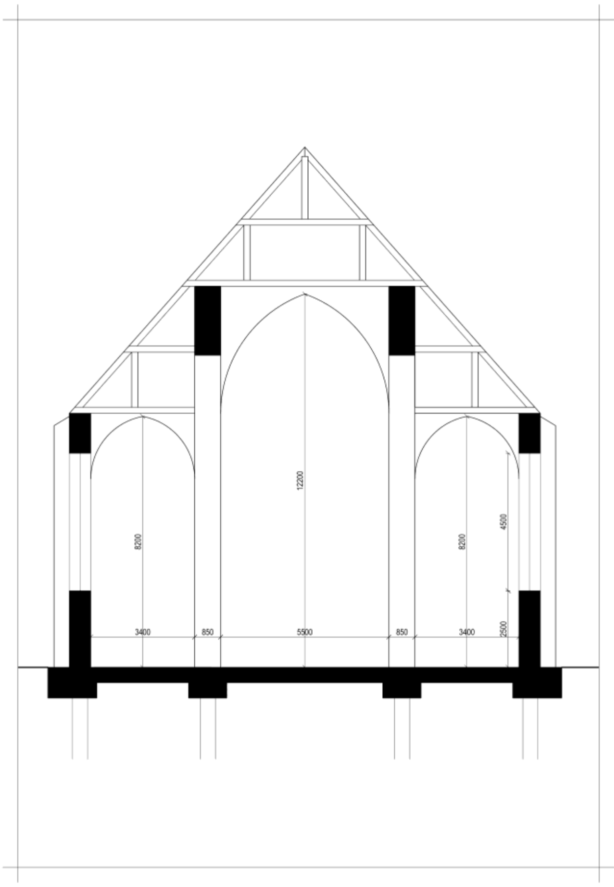

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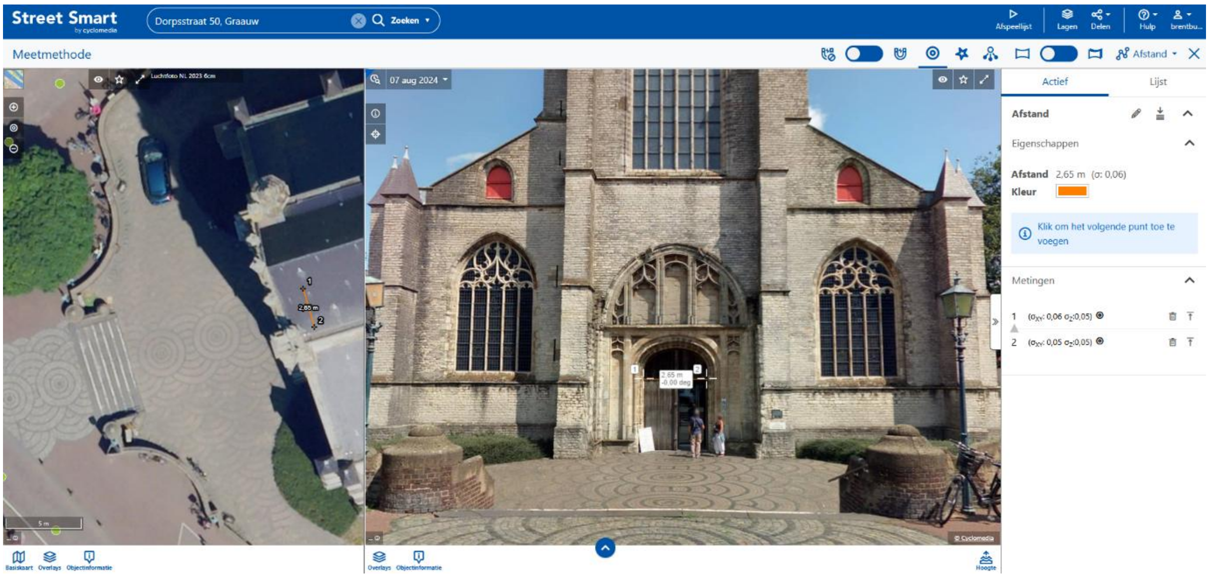
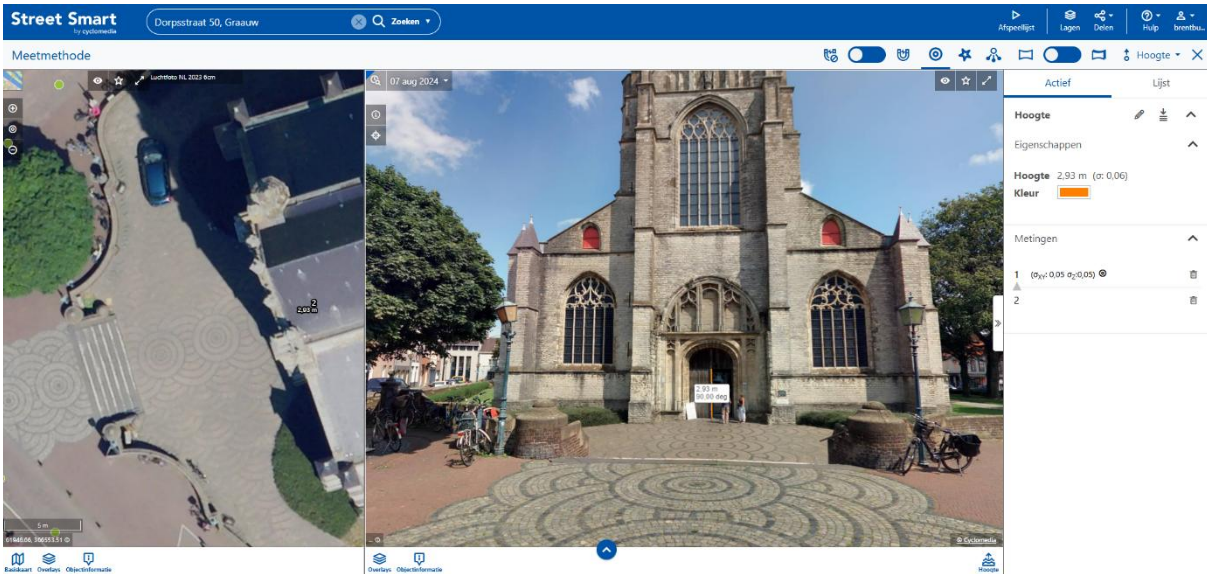

Street Smart
Dorpsstraat 50, Graauw
Zoeken
Meetmethode
07 aug 2024
Actief
Lijst
Afstand
Eigenschappen
Afstand 2,65 m (σ: 0,06)
Kleur
Klik om het volgende punt toe te voegen
Metingen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Zoeken
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Eigenschappen
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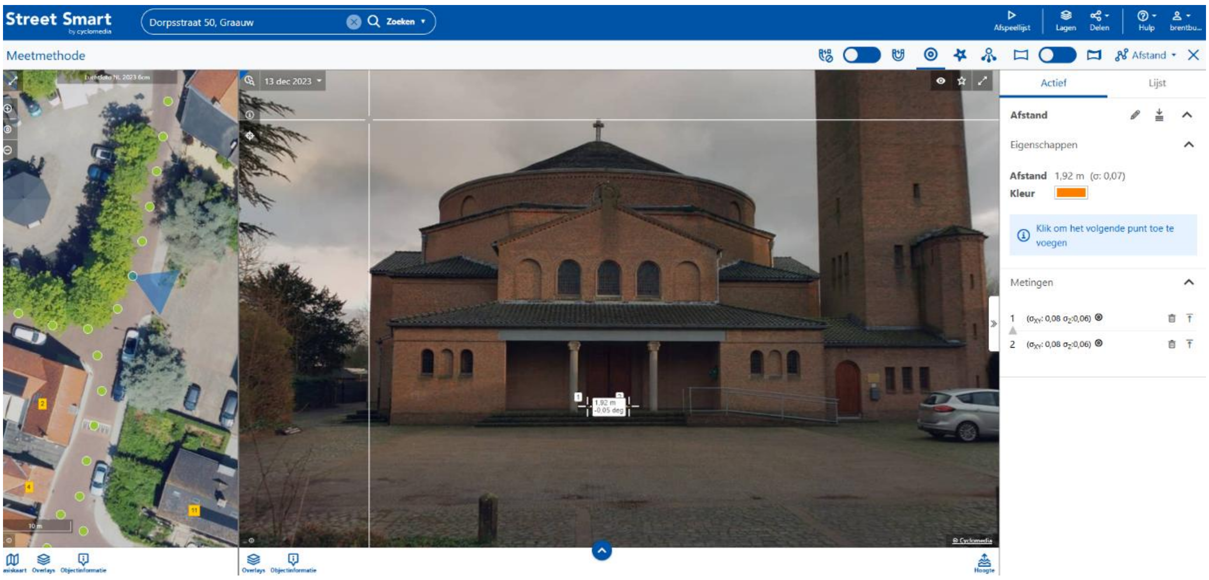
Kleur
Metingen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Dorpsstraat 50, Graauw
Zoeken
Meetmethode
13 dec 2023
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Afstand
Eigenschappen
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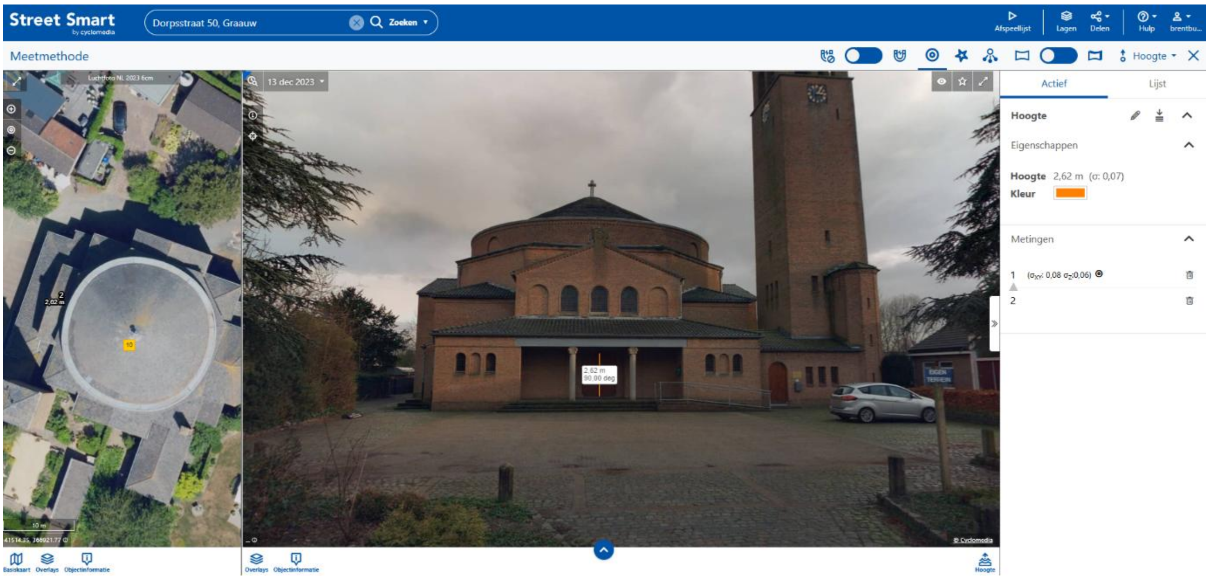
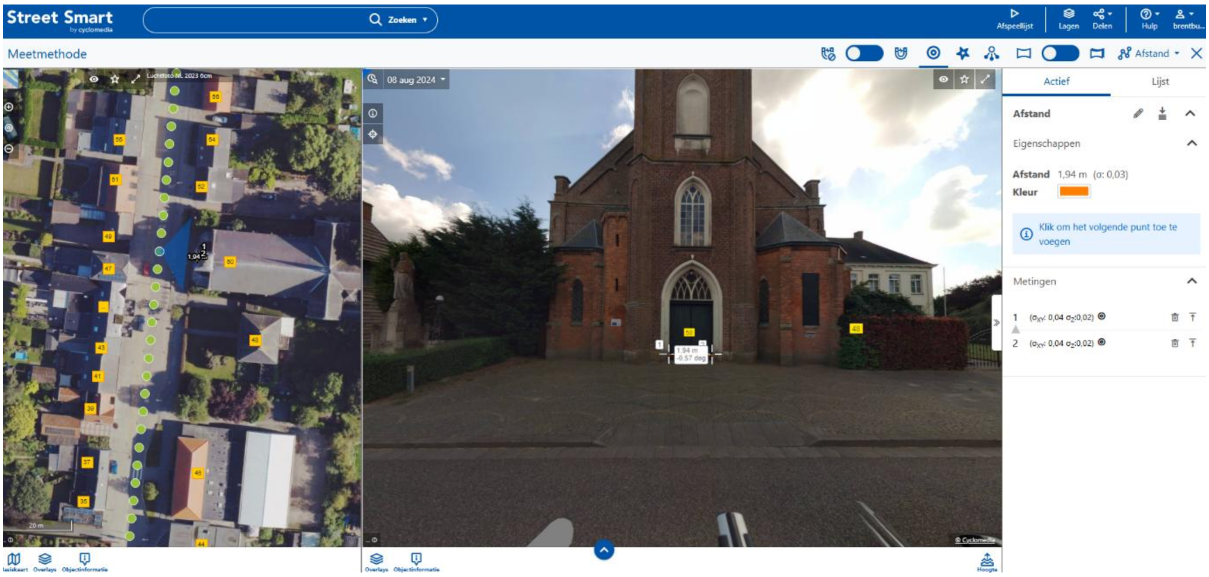
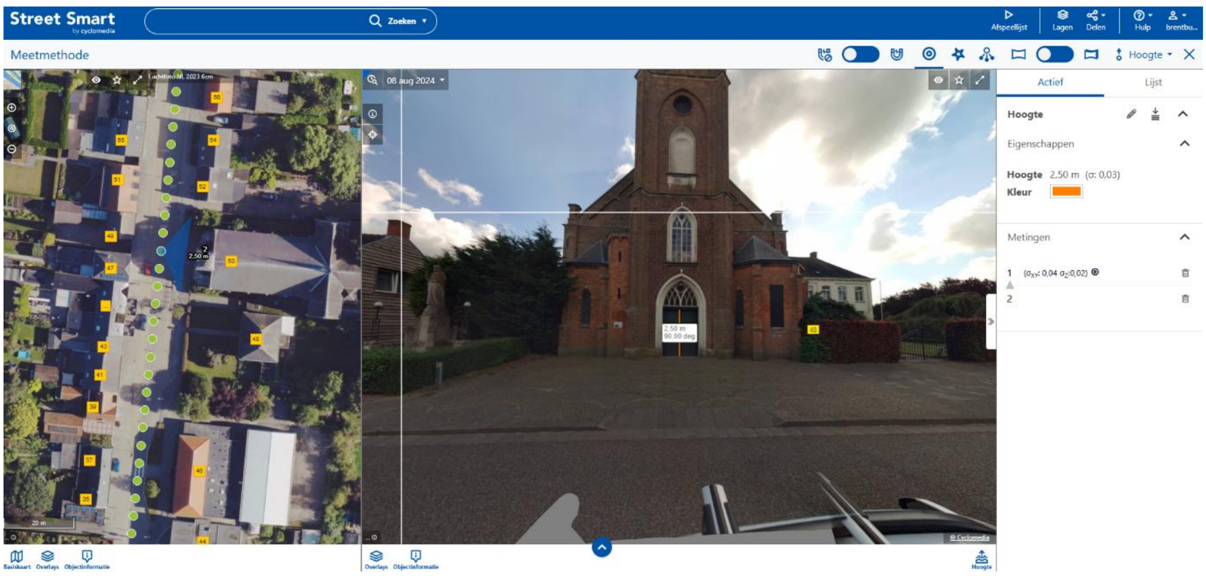
Kleur
Klik om het volgende punt toe te voegen
Metingen


Street Smart
by cyclomedia
Dorpsstraat 50, Graauw
Zoeken
Afspeellijst
Lagen
Delen
Hulp
Meetmethode
Hoogte
13 dec 2023
2,62 m
90.00 deg
Actief
Lijst
Hoogte
Eigenschappen
Hoogte 2,62 m (σ: 0,07)
Kleur
Metingen
Basiskaart
Overlays
Objectinformatie
© Cyclomedia


Street Smart
by cyclomedia
Zoeken
Afspeellijst
Lagen
Delen
Hulp
Meetmethode
Afstand
08 aug 2024
1,94 m
Actief
Lijst
Afstand
Eigenschappen
Afstand 1,94 m (σ: 0,03)
Kleur
Klik om het volgende punt toe te voegen
Metingen
Basiskaart
Overlays
Objectinformatie
Hoogte
© Cyclomedia


Street Smart
by cyclomedia
Zoeken
Afspeellijst
Lagen
Delen
Hulp
Meetmethode
Hoogte
08 aug 2024
2,50 m
90.00 deg
Actief
Lijst
Hoogte
Eigenschappen
Hoogte 2,50 m (σ: 0,03)
Kleur
Metingen
Basiskaart
Overlays
Objectinformatie
© Cyclomedia

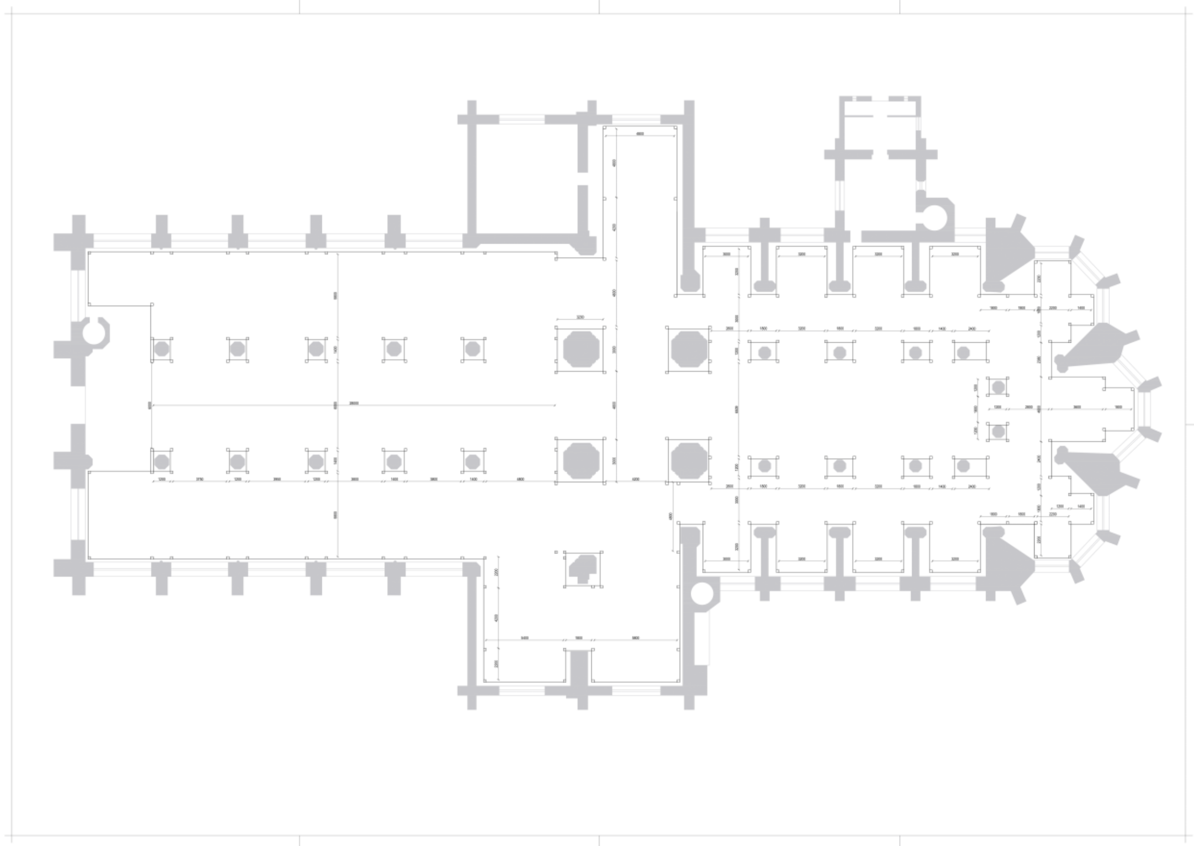
APPENDIX 5

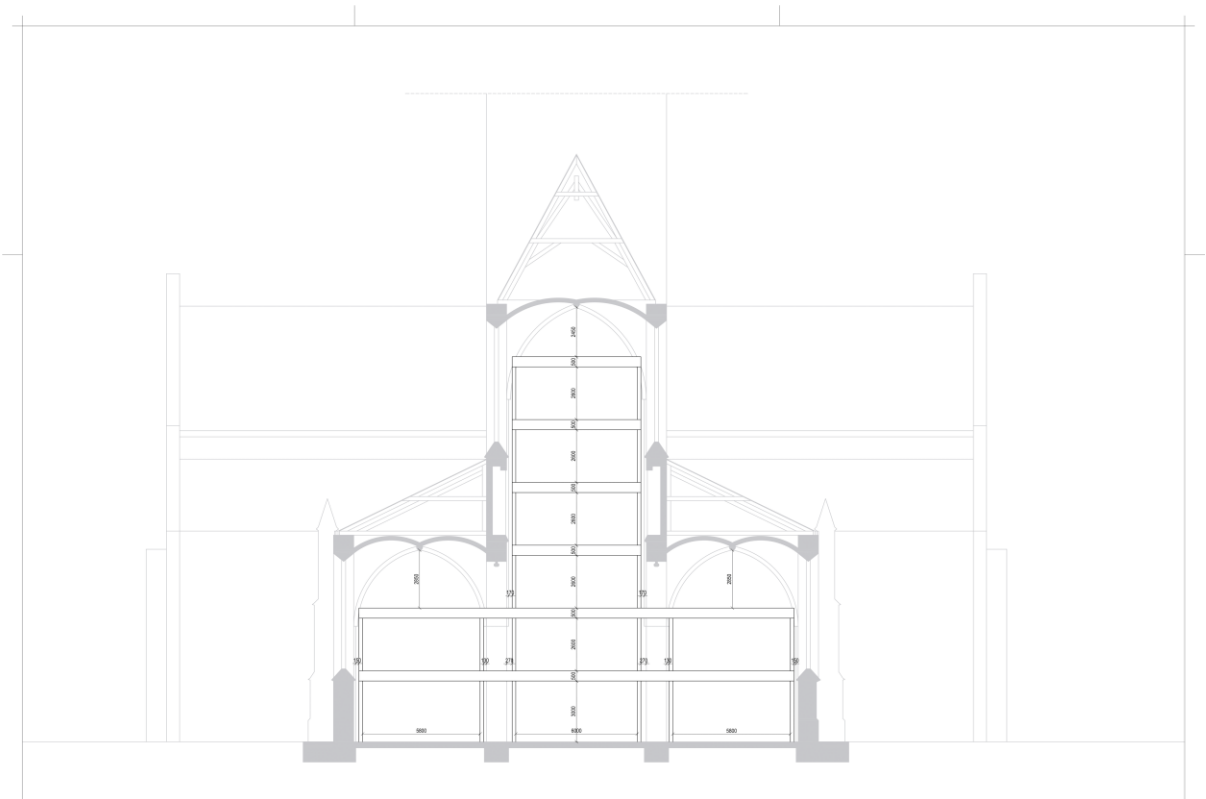
Company	Modular system	Completely made out of wood?	Construction method	Lightweight?
Barli		Yes	HSB	Yes
Circlewood	CircleWood	Yes	HKB	Yes
Cube Homes	Cube Homes	Yes	HSB	Yes
Daiwa House Modular	Daiwa House Modular	No	Steel	No
De Groot Vroomshoop	Modulinn	Yes	HSB	Yes
De Groot Vroomshoop	Houtmodulebouw	Yes	CLT	Yes
De Groot Vroomshoop	Festing bouwsysteem	No	Steel	No
VDL De Meeuw		No	HSB	No
DMT-Modular		No	Steel	No
Finch Buildings	Finch Modules	Yes	CLT	Yes
geWOONhout		Yes	LVL	Yes
HDO	Woonmodules	Yes	HSB	Yes
Heijmans	ONE	Yes	CLT	Yes
Hodes Huisvesting		No	HSB	No
Homesfactory		No	Steel	No
TBI	Houtbaar	Yes	LVL	Yes
Plegt-Vos		Yes	CLT	Yes
Respace		Yes	LVL	Yes
Skilpod		Yes	HSB	Yes
Startblock		Yes	CLT	Yes
Tala		Yes	CLT	Yes
The Boxsystem		No	Steel	No
The New Makers		Yes	CNC Wood	Yes
Ursem	Ursem CLT system	No	CLT	No

Can the elements be carried by 2?	Multistory possible?	Demountable?	Stable without inner walls?	Housing?	Made for other functions?
No	Yes	Yes	No	Yes	No
No	Yes	Yes	Yes	Yes	Yes
No	Yes	Yes	No	Yes	Yes
No	Yes	Yes	No	Yes	No
No	Yes	Yes	Yes	Yes	Yes
No	Yes	Yes	Yes	Yes	No
No	Yes	Yes	Yes	Yes	Yes
No	Yes	Yes	No	Yes	Yes
No	Yes	Yes	No	Yes	Yes
No	Yes	Yes	Yes	Yes	No
Yes	Yes	Yes	Yes	Yes	No
No	Yes	Yes	No	Yes	No
No	Yes	Yes	No	Yes	Yes
No	Yes	Yes	No	Yes	Yes
No	Yes	Yes	Yes	Yes	No
No	Yes	Yes	Yes	Yes	No
No	Yes	Yes	No	Yes	No
Yes	Yes	Yes	Yes	Yes	Yes
No	Yes	No	No	Yes	No
No	Yes	Yes	No	Yes	No
No	Yes	Yes	No	Yes	No
No	Yes	Yes	Yes	Yes	Yes
No	Yes	Yes	No	Yes	No
No	Yes	Yes	No	Yes	No

Adaptable in size?	Can be made in specific measurements	Inside module?	Possible to merge installations in construction?	Easily remountable?	Potential system
Yes	No	No	Yes	No	No
Yes	Yes	No	Yes	Yes	Maybe
No	No	No	Yes	No	No
No	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
No	No	No	Yes	No	No
No	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	No	No	Yes	Yes	No
Yes	Yes	No	Yes	No	No
Yes	Yes	Yes	Yes	Yes	Yes
No	No	No	Yes	No	No
No	No	No	No	No	No
No	No	No	Yes	No	No
Yes	No	No	Yes	No	No
Yes	Yes	No	Yes	No	No
Yes	No	No	Yes	No	No

APPENDIX 6





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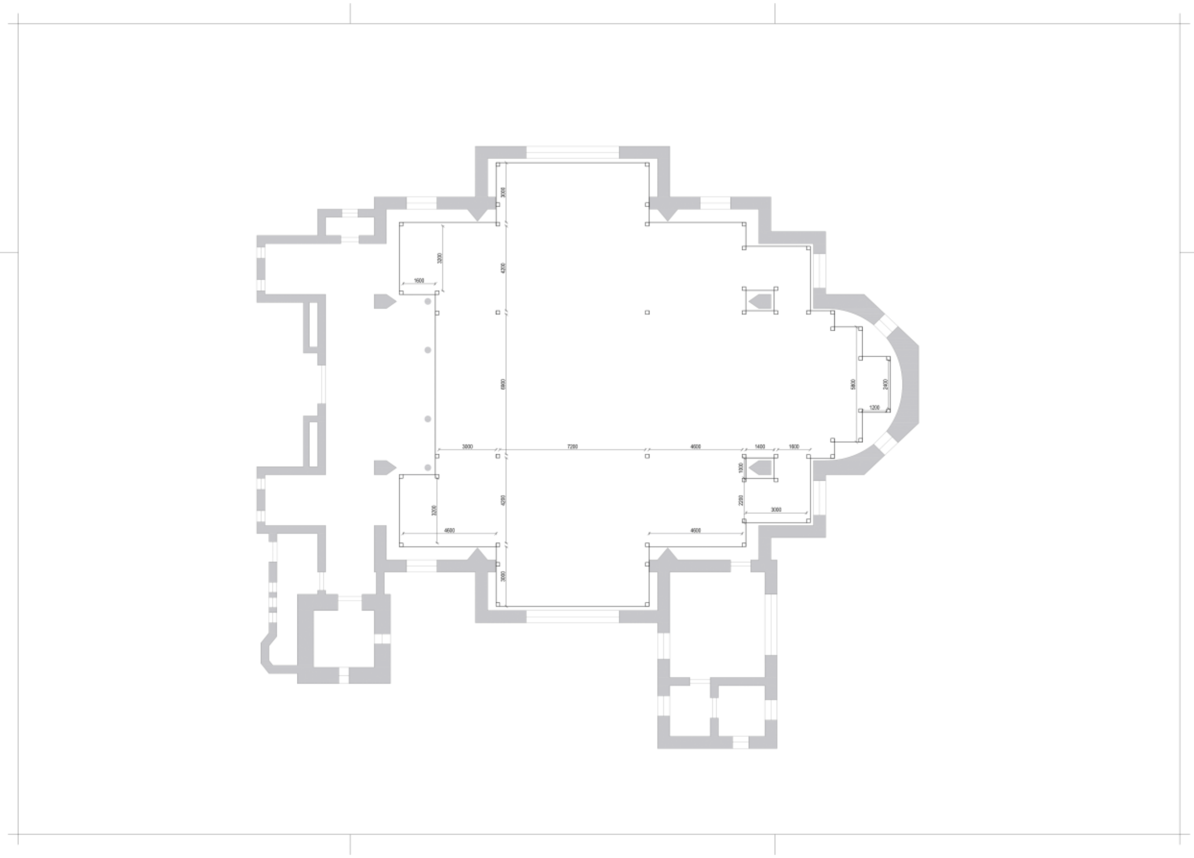

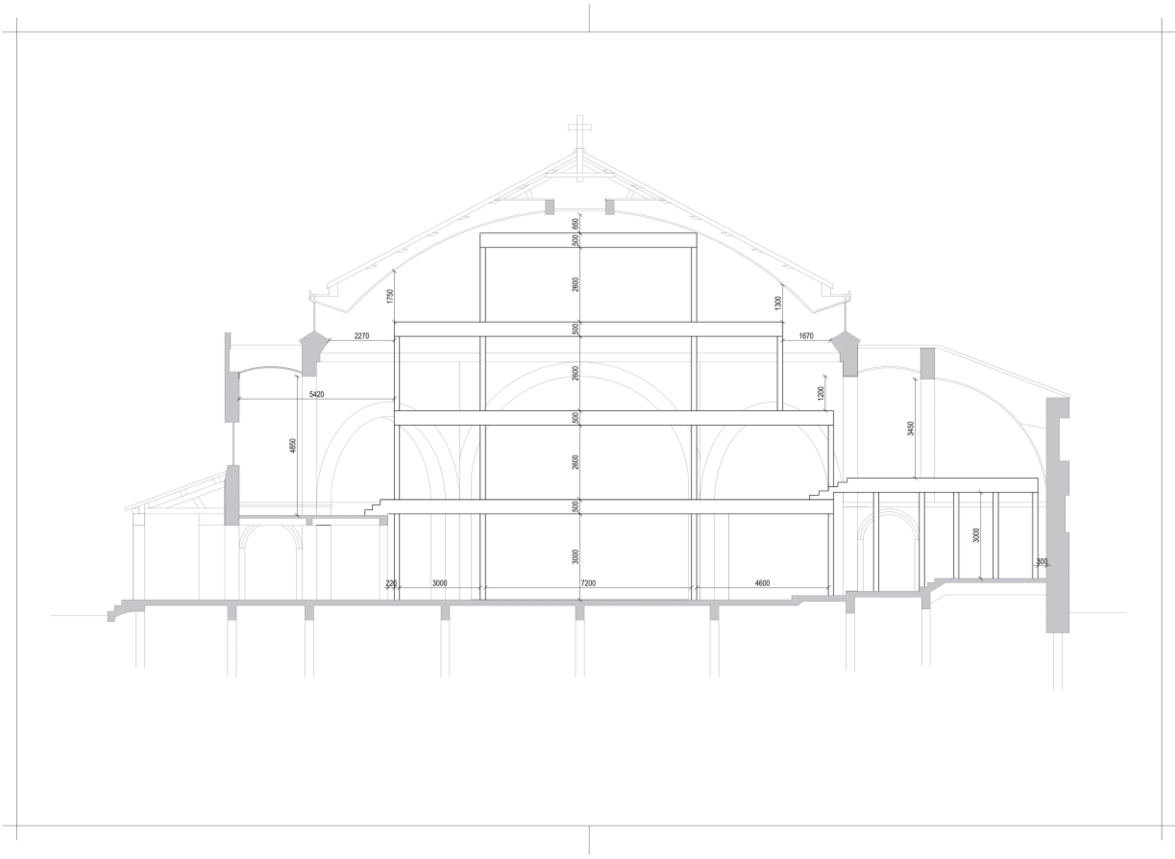

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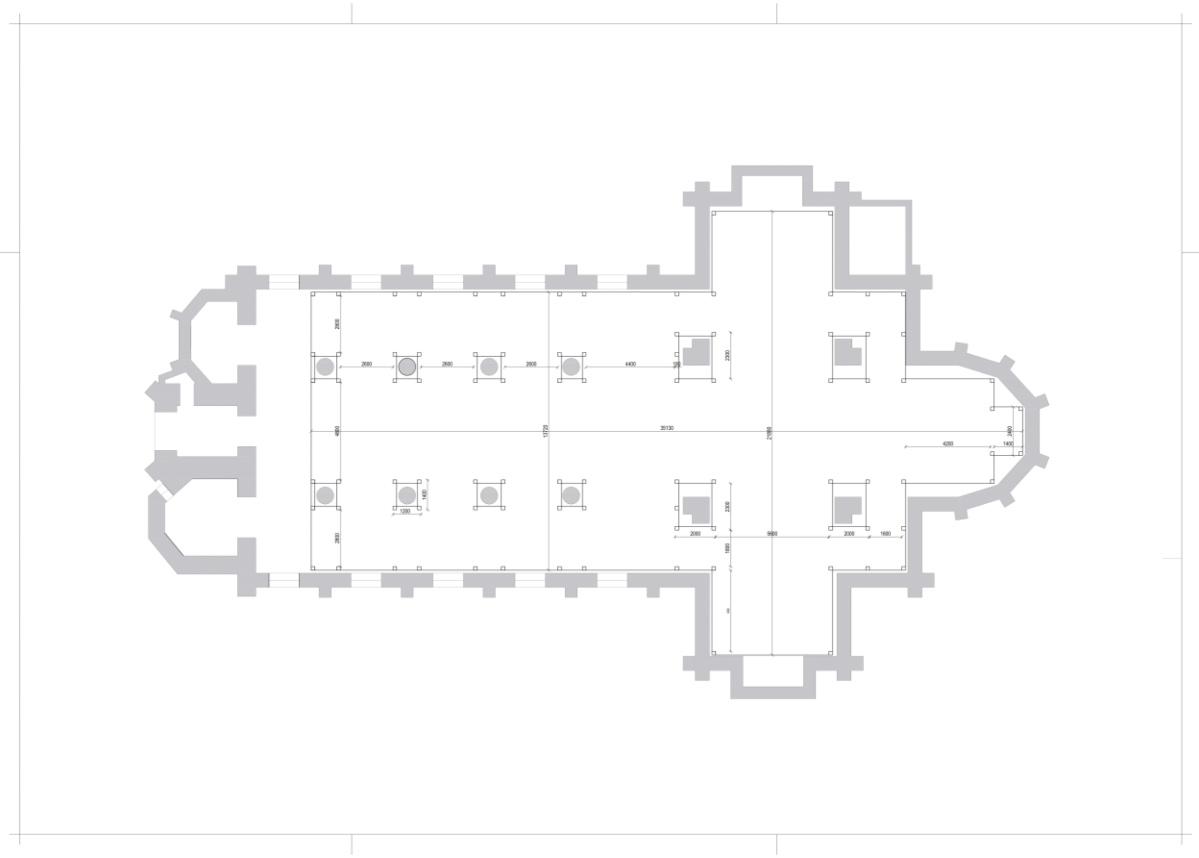
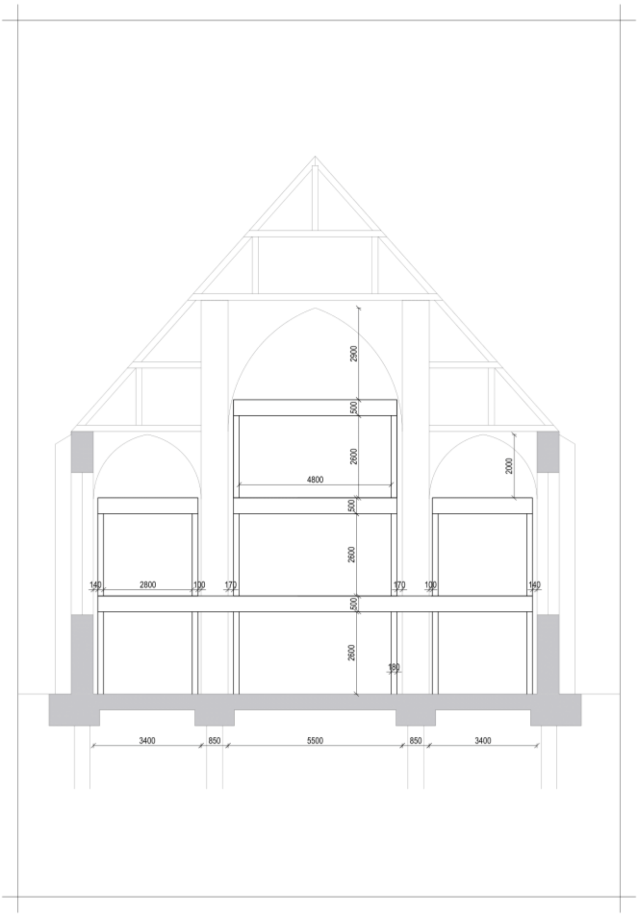



2900
500
2600
4800
2000
500
2600
140
2800
100
170
170
100
140
500
2600
3400
850
5500
850
3400

APPENDIX 9

Church	Element	size	amount	Derived from Respace ratio
Graauw	Column	3000 mm	0	[redacted]
	Column	2600 mm	204	
	Beams	1200 mm	4	2x 600
	Beams	1400 mm	56	2x 600 + 200
	Beams	1800 mm	20	3x 600
	Beams	2000 mm	24	3x 600 + 200
	Beams	2400 mm	2	4x600
	Beams	2600 mm	42	4x600 + 200
	Beams	2800 mm	32	4x600 + 400
	Beams	4000 mm	8	6x600 + 400
	Beams	4400 mm	18	7x600 + 200
	Beams	4800 mm	44	8x600
	Beams	5600 mm	24	9x600 + 200
Total Columns			204	
Total Beams			274	

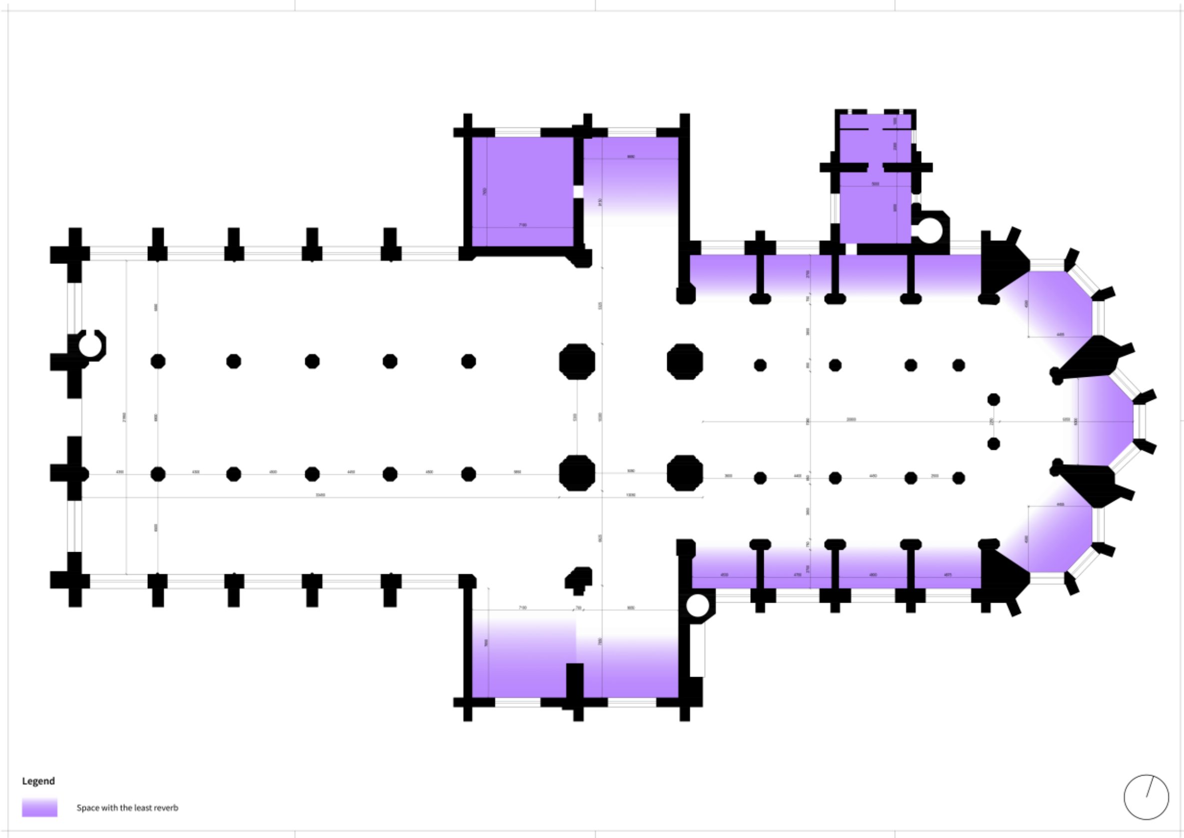
Columns	Graauw	Philipinne	Hulst
Graauw	[redacted]	637,50%	52,85%
Philipinne	15,69%	[redacted]	32,10%
Hulst	189,22%	1626,25%	[redacted]

Church	Element	size	amount	Derived from Respace ratio
Philipinne	Column	3000 mm	50	[redacted]
	Column	2600 mm	32	
	Beams	1000 mm	6	600 + 400
	Beams	1200 mm	18	2x 600
	Beams	1400 mm	6	2x 600 + 200
	Beams	2400 mm	1	4x600
	Beams	3000 mm	10	5x600
	Beams	3200 mm	2	5x600 + 200
	Beams	3400 mm	2	5x600 + 400
	Beams	4600 mm	12	7x600 + 400
	Beams	5800 mm	1	9x600 + 400
	Beams	7000 mm	19	11x600 + 400
	Beams	7200 mm	24	12x600
Total Columns			82	
Total Beams			101	

Beams	Graauw	Philipinne	Hulst
Graauw	[redacted]	876,61%	1555,30%
Philipinne	474,87%	[redacted]	393,37%
Hulst	4288,79%	9773,65%	[redacted]

Church	Element	size	amount	Derived from Respace Ratio
Hulst	Column	3000 mm	210	[redacted]
	Column	2600 mm	386	
	Beams	1200 mm	164	2x600
	Beams	1400 mm	24	2x600 + 200
	Beams	1800 mm	68	3x600
	Beams	2000 mm	8	3x600 + 200
	Beams	2200 mm	24	3x600 + 400
	Beams	2400 mm	6	4x600
	Beams	2600 mm	6	4x600 + 200
	Beams	3000 mm	102	5x600
	Beams	3200 mm	50	5x600 + 2
	Beams	3600 mm	8	6x600
	Beams	4200 mm	104	7x600
	Beams	4600 mm	4	7x600 + 400
	Beams	4800 mm	16	8x600
	Beams	5200 mm	4	8x600 + 400
	Beams	5400 mm	8	9x600
	Beams	5800 mm	50	9x600 + 400
	Beams	6000 mm	64	10x600
	Beams	6600 mm	2	11x600
	Beams	7000 mm	54	11x600 + 400
Total Columns			596	
Total Beams			766	

APPENDIX 10



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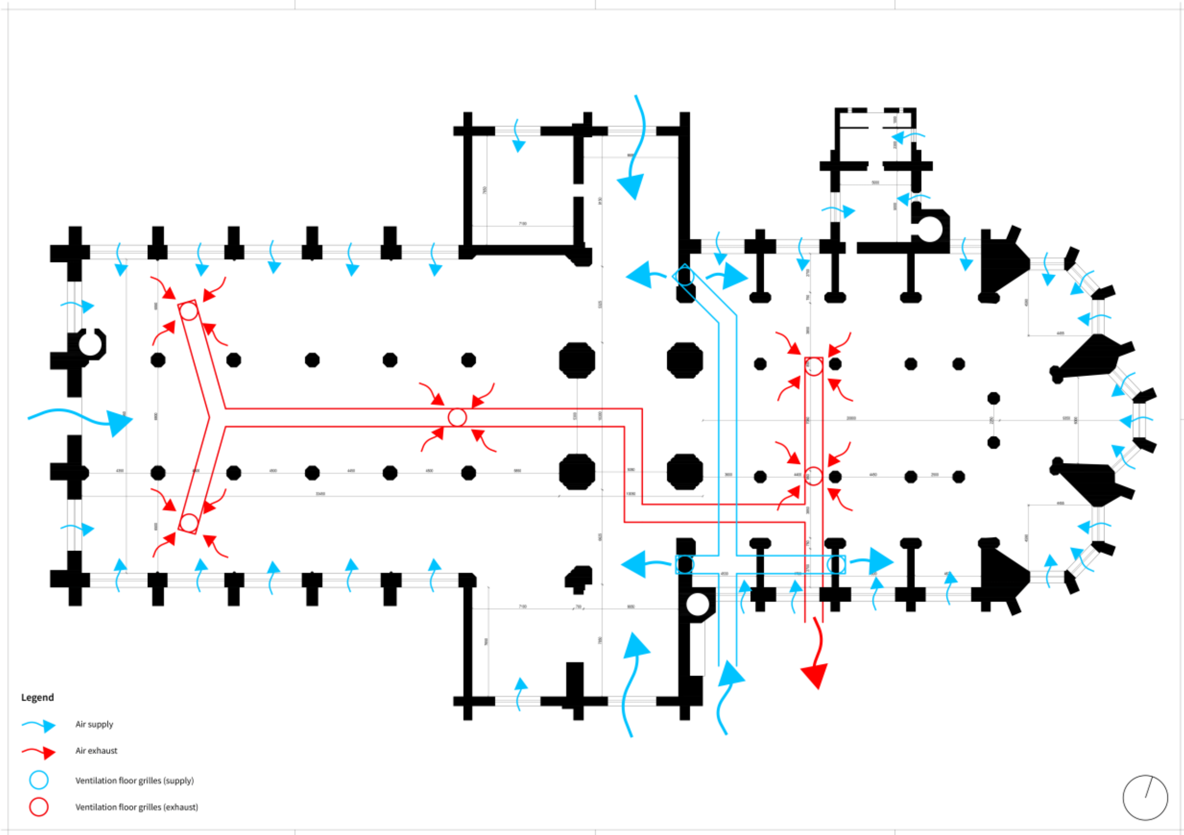

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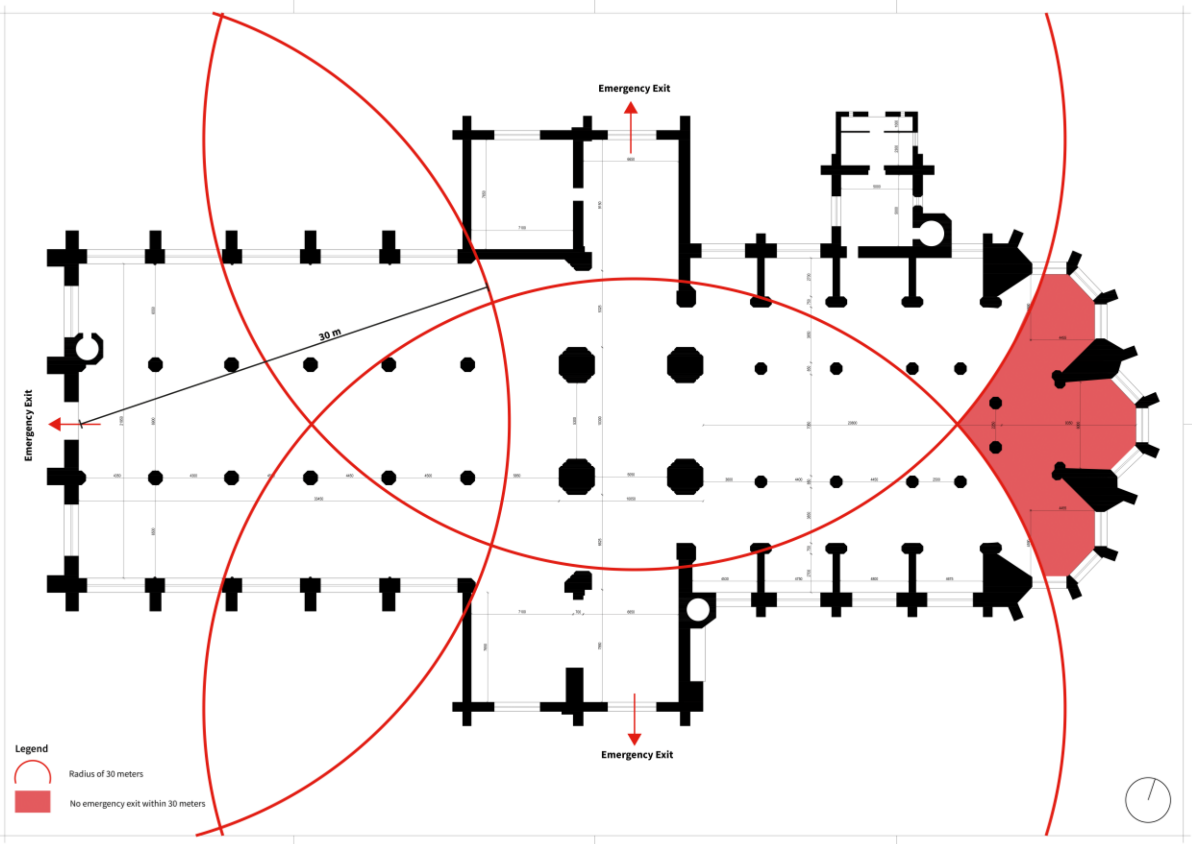

APPENDIX 13