



A S S E M

B L E D

A G A I N

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Assembled Again: Material Memory and Computationally Crafted Patterns of re-used bricks in Contemporary Half-Timber Architecture

Lund University | Department of Architecture and Built Environment

ASEM01 | Degree Project in Digital Architecture and Emergent Futures
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Statement of Authorship and Use of AI: Unless otherwise stated, all images, visualisations, diagrams, models, and photographs presen-

ted in this thesis were produced by the author.

Artificial intelligence (AI) tools were used in a limited and supportive capacity throughout this project. ChatGPT was used for language editing, proofreading, and grammatical revision. Whisper-Transcribe 2.1.1 was used to transcribe recorded interviews. Gemini Pro in Firefly was used to generate the images of reused brick terrazzo samples presented on pages 52–53, based on the author's own photographs of the brick categories.

All design decisions, analyses, interpretations, and conclusions presented in this thesis remain the sole responsibility of the author.



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Thank you

To my supervisor, Henrik Almquist. To Frederik Kaalund Andersen at Nord-Sten. To my pottery teacher Matilda Eidelöf. To my biggest supporter Michael Jensen, for lending me your car and crushing bricks with me.



Abstract

This thesis, *Assembled Again – Material Memory and Computationally Crafted Patterns of Re-used Bricks in Contemporary Half-Timber Architecture*, investigates how computational design methods can translate individually distinct reused brick fragments into expressive architectural façade systems. By combining material classification, digital pattern generation, and principles of robotic fabrication, the project explores how variation can be composed rather than eliminated.

The research is situated within the historical context of half-timbered architecture in Skåne and eastern Denmark, resulting in the architectural application of a contemporary half-timber villa in Hæsnæs, Denmark. Here, infill masonry becomes a medium for negotiating between material memory, industrialised waste streams, and digital design systems. Rather than seeking uniformity, the thesis proposes a framework where irregularity, reuse, and computational logic collectively create architectural expression. The outcome suggests a hybrid condition in which human handmade artistic expression and digital processes collaborate to produce material-driven, non-standard architectural surfaces rooted in locality and reuse.

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01. INTRODUCTION /
RESEARCH FRAMEWORK

Introduction

Architecture is currently undergoing a quiet but fundamental shift, where material scarcity, digital tools, and changing notions of value begin to overlap. Within this shift, the role of waste materials is being reconsidered not as residue, but as potential.

This thesis explores how computational design methods can translate individually distinct, reused brick fragments into coherent architectural compositions. Using digital pattern generation as a mediating system, irregular and heterogeneous materials are reorganised into façade elements. Telling a story of material memory.

The project investigates a contemporary villa in Hesnæs, Denmark, situated within the historical context of half-timbered architecture in the Skåne region. Here, infill masonry becomes a site where craft, ornament, and computation intersect.

Rather than resolving material variation, the aim is to work with it — allowing digital systems to act as translators between material memory and architectural expression, producing a new aesthetic language rooted in reuse, locality, and variation.



Why?

In Prøvestenen, Copenhagen, there is a stockpile of reused bricks that are not being fully utilized; they are unsorted and individually distinct. Finding ways to use them would bring a significant positive change in environmental impact compared to the use of virgin materials.

What?

Designing a villa in the small Danish village of Hesnæs, Falster, relating to the historical context through a contemporary interpretation of traditional half-timbered housing, with a focus on visually interesting patterned infill masonry wall elements.

How?

Using digital tools to reimagine how these bricks can be utilized through digitally generated patterns.

Research
Question

How can digitally generated patterns enable the design of contemporary architecture using individually distinct, reused bricks?



“Berlinska huset” is one of the oldest half-timbered houses in Lund, Skåne. Probably built in the late 1600. Image source: Kulturen [2026].

Context

The architectural tradition of Skåne and eastern Denmark is grounded in a close relationship between material expression and construction logic. The half-timbered house, with its structural frame and infill masonry, has historically allowed for variation within a relatively simple and repetitive system. Brick infill was not only a functional closure, but also a surface where pattern, ornament, and local identity could be articulated. In this context, irregularity was not understood as deviation, but as part of a shared architectural language where material and expression were inseparable. Historical developments in brick

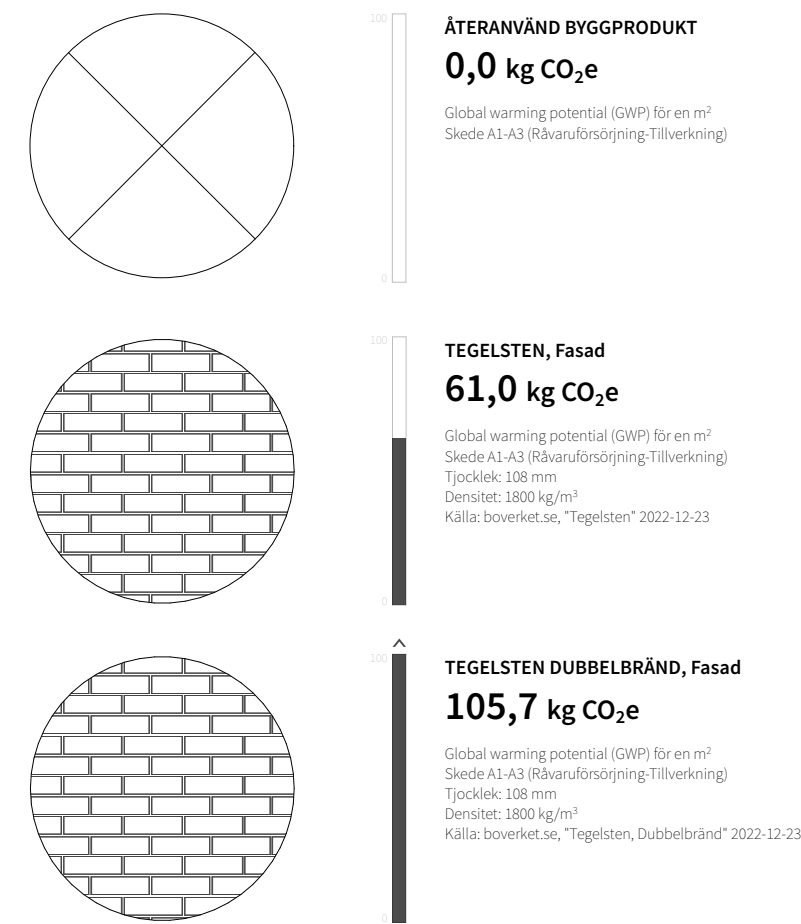
production further reinforce this relationship between material and locality. Between 1850 and 2005, brickworks operated at 278 locations across Skåne, forming a dense industrial and cultural network supported by railway infrastructure. This enabled brick to function as a medium of expression, evident in richly articulated façades such as those associated with “Skurup Gothic” (Tegelakademien, n.d.). Over time, however, this regional material culture was gradually reduced as industrialisation and later economic shifts prioritised efficiency, repetition, and standardisation over local variation.

During the twentieth century, brick production became increasingly centralised and optimised. With the introduction of steel, concrete, and glass as dominant building materials, brick shifted from a primary structural role to a surface material. This change coincided with a broader architectural tendency towards homogenisation, where variation was often reduced in favour of repeatable systems and controlled outcomes.

Today, this historical trajectory intersects with the environmental conditions of contemporary construction. Approximately 40% of global CO₂ emissions are linked

to the construction industry, placing material production at the centre of current climate challenges (Henning Larsen, 2026). Within this context, reuse has re-emerged as a necessary strategy for reducing environmental impact. However, reuse also introduces a fundamental condition: heterogeneity. Reclaimed materials are not uniform, but exist as fragments with differences in size, colour, surface condition, and structural integrity.

This condition becomes particularly visible in material stockpiles such as Prøvestenen in Copenhagen, where large quantities of dis-



Climate impact from production expressed in global warming potential per square metre.
Figure by the author, based on data from the Boverket Climate Database (2023)

carded bricks accumulate in highly varied states of degradation. Rather than forming a consistent material stream, these fragments exist as discontinuous and differentiated elements. At the same time, this heterogeneity can be understood as a form of material memory. Each fragment carries traces of previous use through patina, breakage, and weathering, forming a material archive embedded in the object itself.

In parallel, digital tools in architecture have expanded the capacity to engage with such complexity. Computational design environments allow for the processing of

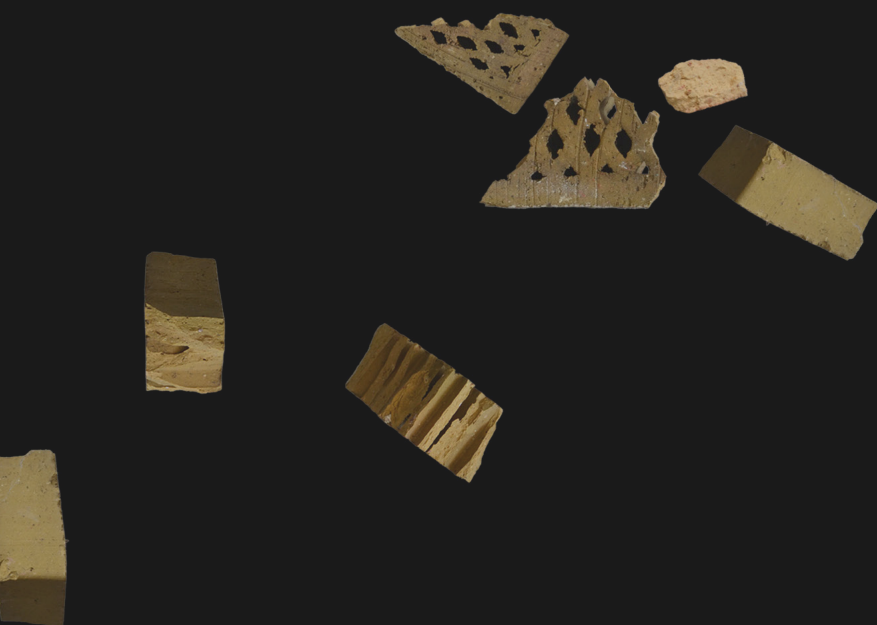
heterogeneous datasets, enabling designers to classify, organise, and translate variation into spatial and material outcomes. According to Akan, Kara and Selçuk (2023), computational technologies not only transform design methodologies, but also expand architectural perception by redefining what can be considered designable material. While computational design is often associated with formal optimisation or geometric control, its relevance in this context lies in its ability to operate through variation rather than against it. Instead of reducing differences between elements, digital systems can structure heterogeneity while

maintaining its internal diversity. Computation thereby becomes a framework for translation, where material variation is not eliminated but reorganised into legible architectural systems.

This shift also reframes the role of waste within architectural production. Waste is not understood as a fixed category, but as material without an assigned system of value or organisation. Within this perspective, architecture is not separate from material cycles of reuse and discard, but embedded within them as a continuous process of transformation. Uniqueness is not corrected or acciden-

tal, but composed through systems that recognise variation as a value rather than a problem. Variation is therefore not an obstacle to be resolved, but a condition through which new architectural expressions can emerge.

02. MATERIAL SOURCING







2026-03-13 Visit Nord-Sten

On the artificial island of Prøvestenen, east of Amager in Copenhagen, there is a large stockpile of recycled brick. This is where Nord-Sten's storage and processing facility is located.

During my visit on 13 March 2026, Frederik Kaalund Andersen explained the company's recycling process in detail.

Nord-Sten collaborates with several recycling centres across Denmark that deliver unsorted demolition materials containing brick. These materials are deposited on

site in large piles. Frederik noted that, in Denmark, brick and concrete are typically collected together in a shared waste stream. As a result, the company must first separate these materials before further processing. The concrete is also recycled by the company and used in other products at a later stage.

When a new delivery arrives, the material is initially sorted using a mechanical separator, which divides the incoming mass into three piles: concrete, brick, and small stone residues. The brick fraction is then transported via a conveyor belt to a tented sorting area, whe-

Flight photo of Prøvestenen, Copenhagen.
Image source: Styrelsen for Dataforsyning og Infrastruktur (2026)



Initial sorting





Conveyor belt transportation to sorting

re it is manually sorted, washed and packed onto pallets. These intact bricks are subsequently sold on the architectural salvage and reuse market.

Bricks that are crushed, broken, or otherwise unsuitable for direct reuse as whole units are transported on a separate conveyor belt and collected in a separate pile. This material—consisting of irregular brick fragments—has limited current applications and from now on referred to here as Category B – Medium Fragments. Nord-Sten sends this material to a partner company, where it is crushed into fragments of 4–16 mm and 0–8 mm,

sorted by colour, and then returned. Nord-Sten uses these fractions to produce materials such as brick terrazzo and façade panels.

At present, there is no established application for Category B brick fragments in their original state. However, this material is particularly well suited to the aims of this thesis. Digital design tools, pattern generation, and robotic fabrication could potentially enable new architectural uses for these irregular brick fragments.

Frederik also highlighted a key technical challenge related to me-

eting Nordic quality standards for brick products derived from Category B material. When bricks are crushed, interior surfaces are exposed that were not fired to the same temperature as the outer surface of the original brick units. As a result, the material becomes more prone to water absorption. Under rapid temperature fluctuations, this may lead to cracking due to freeze-thaw cycles.

In the façade elements proposed in this thesis, this could pose a risk if fragments are allowed to protrude from the surface with exposed interior faces. One possible strategy would be to grind down

and seal the surface of the façade elements. Avoiding the use of concrete in the material mix could also potentially help reduce this risk.

A selection—though not the entirety—of Nord-Sten’s material range is represented in the material library included in this thesis. Approximately 80% of the brick received by the company is sorted as yellow or beige brick, which also includes the traditional “Copenhagen brick mix”, containing traces of red clay.



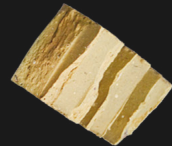
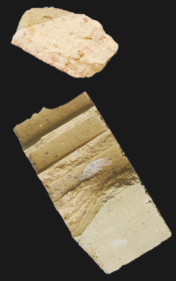
Unwanted brick pile



Unwanted brick pile



03. INPUT /
MATERIAL LIBRARY



Material categories and digitalization

The material categorisation process forms a central part of the project. It directly affects both the conditions for the design process and the final architectural expression. At the same time, it carries an underlying ideological position: that every fragment, regardless of colour, damage, or shape, should have the possibility to participate within the composition.

Initially, two possible approaches to the material library were identified.

One possible method is to categorise the bricks into broader groups based on characteristics such as

size, colour, and condition. During fabrication, a robotic system could then select components from these categories to assemble the generated pattern. Such an approach requires that the pattern generation itself allows for variation, since each reused element differs slightly due to the non-standardised nature of reclaimed material. By analysing the available material stock and developing an adaptable categorisation system together with a flexible pattern generation method, the fabrication process could become more manageable while simultaneously contributing to the architectural expression through irregularity, variation, and

imperfection.

A second possible method involves the digitalisation of individual elements at an early stage of the process in order to capture their specific characteristics as digital objects. This approach allows for a more precise translation between material and computational model, where each fragment can be individually recognised and positioned within the final composition. However, the method is highly dependent on extensive data acquisition and processing, raising questions regarding scalability and practical implementation. This approach is explored in Digital

Tool Integrations for Architectural Reuse of Salvaged Building Materials by Małgorzata A. Zboińska and Frederik Göbel (2025), which investigates how digital tools can facilitate the reuse of salvaged building materials that would otherwise be difficult or time-consuming to repurpose. The article discusses methods such as photogrammetry, robotic vision, machine learning, and computer vision as tools for the initial capture and organisation of material data.

For a larger real-world implementation of the system proposed in this thesis, a broader categorisation

method is considered the more feasible approach due to the production time required for individual scanning. At the same time, the increased level of abstraction introduced by categorisation is not only accepted, but considered architecturally valuable. The system does not attempt to fully control the individuality of each fragment, but instead operates through approximation and variation.

The workflow could also be a hybrid between the two methods. Larger components may contain more detailed digital information, while smaller fragments can be organised through broader categories

based on colour and size. These categories could follow existing sorting systems already used by Nord-Sten ApS (2026) for reclaimed crushed brick, where materials are divided into colour ranges and fractions such as 0–8 mm, 4–16 mm, and masonry aggregate. According to Skinner et al. (2013), convolutional neural networks (CNNs) present a suitable approach for this type of categorisation due to their capacity for image-based classification. Such systems can learn to distinguish characteristics including surface wear, colour variation, and defect patterns. Additional numerical data, such as size, weight, or material

composition, could further be integrated through complementary machine learning models. Once trained, such systems could continue improving over time through repeated use. In other words, the technological foundation required for automated material categorisation within a fabrication workflow already exists.

The material categories displayed on the following pages were developed for the material library. The system is organised according to ranges of size and colour. Size categories are represented by the letters A–E, while colour categories are organised according to

ranges within the RGB colour system and represented numerically from 0–5.

The smaller size categories, D and E, are based on the existing reclaimed brick fractions currently produced by Nord-Sten. The larger categories, A–C, were introduced within the thesis in order to accommodate larger brick fragments and more intact elements.

Together, these categories establish a scalable material framework capable of handling varying levels of fragmentation while maintaining a broad range of visual and material variation.

Material category A - Large fragments: 120–250 mm



A0

Dark:
 $\text{brightness} < 60$



A1

Red:
 $R > 120$
 $R > G + 20$
 $R > B + 20$



A2

Yellow:
 $R > 150$
 $G > 150$
 $B < 120$
 $\text{abs}(R - G) < 50$



A3

Green:
 $G > 120$
 $G > R + 20$
 $G > B + 20$



A4

Light:
 $\text{brightness} > 180$
 $\text{abs}(R - G) < 40$
 $\text{abs}(R - B) < 40$
 $\text{abs}(G - B) < 40$



A5

Orange:
 $R > 150$
 $G > 80$
 $G < 150$
 $B < 100$
 $R > G$

Material category B - Medium fragments: 40-120 mm



B0

Dark:
 $\text{brightness} < 60$



B1

Red:
 $R > 120$
 $R > G + 20$
 $R > B + 20$



B2

Yellow:
 $R > 150$
 $G > 150$
 $B < 120$
 $\text{abs}(R - G) < 50$



B3

Green:
 $G > 120$
 $G > R + 20$
 $G > B + 20$



B4

Light:
 $\text{brightness} > 180$
 $\text{abs}(R - G) < 40$
 $\text{abs}(R - B) < 40$
 $\text{abs}(G - B) < 40$



B5

Orange:
 $R > 150$
 $G > 80$
 $G < 150$
 $B < 100$
 $R > G$

Material category C - Coarse aggregate: 16–40 mm



C0

Dark:
 $\text{brightness} < 60$



C1

Red:
 $R > 120$
 $R > G + 20$
 $R > B + 20$



C2

Yellow:
 $R > 150$
 $G > 150$
 $B < 120$
 $\text{abs}(R - G) < 50$



C3

Green:
 $G > 120$
 $G > R + 20$
 $G > B + 20$



C4

Light:
 $\text{brightness} > 180$
 $\text{abs}(R - G) < 40$
 $\text{abs}(R - B) < 40$
 $\text{abs}(G - B) < 40$



C5

Orange:
 $R > 150$
 $G > 80$
 $G < 150$
 $B < 100$
 $R > G$

Material category D - Fine aggregate: 4-16 mm



D0

Dark:
 $\text{brightness} < 60$



D1

Red:
 $R > 120$
 $R > G + 20$
 $R > B + 20$



D2

Yellow:
 $R > 150$
 $G > 150$
 $B < 120$
 $\text{abs}(R - G) < 50$



D3

Green:
 $G > 120$
 $G > R + 20$
 $G > B + 20$



D4

Light:
 $\text{brightness} > 180$
 $\text{abs}(R - G) < 40$
 $\text{abs}(R - B) < 40$
 $\text{abs}(G - B) < 40$



D5

Orange:
 $R > 150$
 $G > 80$
 $G < 150$
 $B < 100$
 $R > G$

Material category E - Powder: 0-8 mm



E0

Dark:
 $\text{brightness} < 60$



E1

Red:
 $R > 120$
 $R > G + 20$
 $R > B + 20$



E2

Yellow:
 $R > 150$
 $G > 150$
 $B < 120$
 $\text{abs}(R - G) < 50$



E3

Green:
 $G > 120$
 $G > R + 20$
 $G > B + 20$



E4

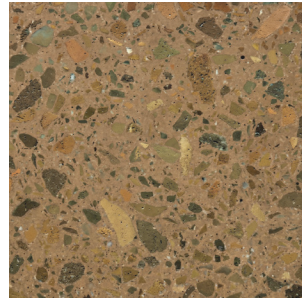
Light:
 $\text{brightness} > 180$
 $\text{abs}(R - G) < 40$
 $\text{abs}(R - B) < 40$
 $\text{abs}(G - B) < 40$



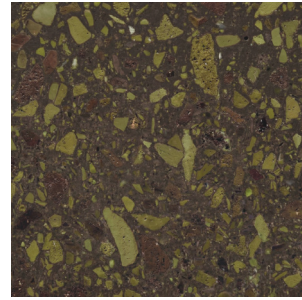
E5

Orange:
 $R > 150$
 $G > 80$
 $G < 150$
 $B < 100$
 $R > G$

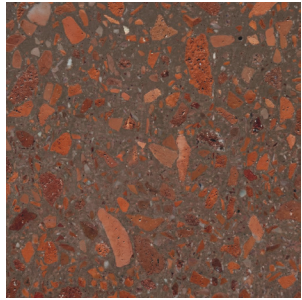
CO_D0_E0_C1_D1



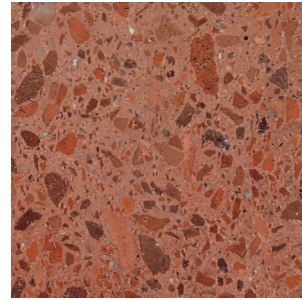
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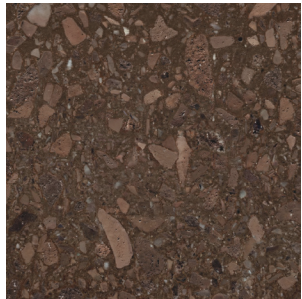
CO_D0_E0_C1_D1



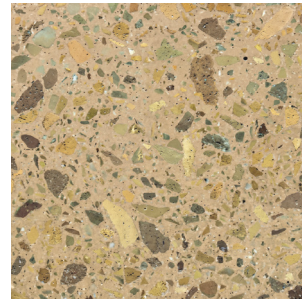
C1_D1_C0



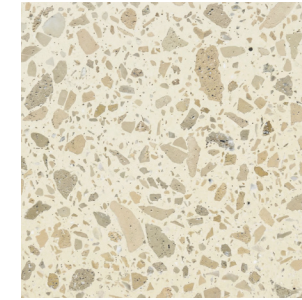
CO_D0_E0



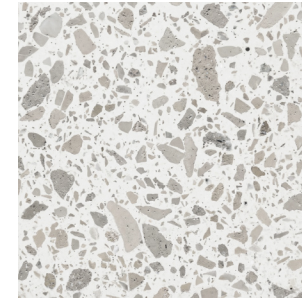
C2_D2_C3_D3_E3



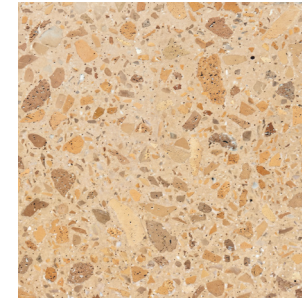
C2_D2_C4_D4_E4



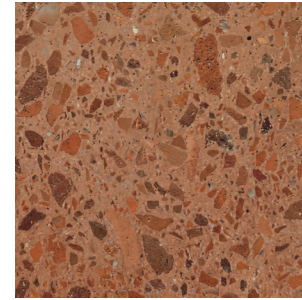
C4_D4_E4



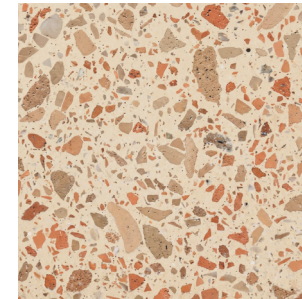
C2_D2_E2



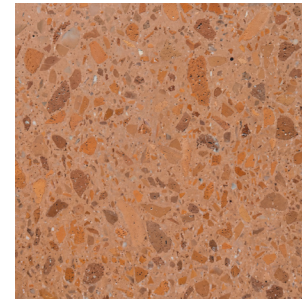
C5_D5_C5_D5_E5



C2_D2_E2_C5_C4

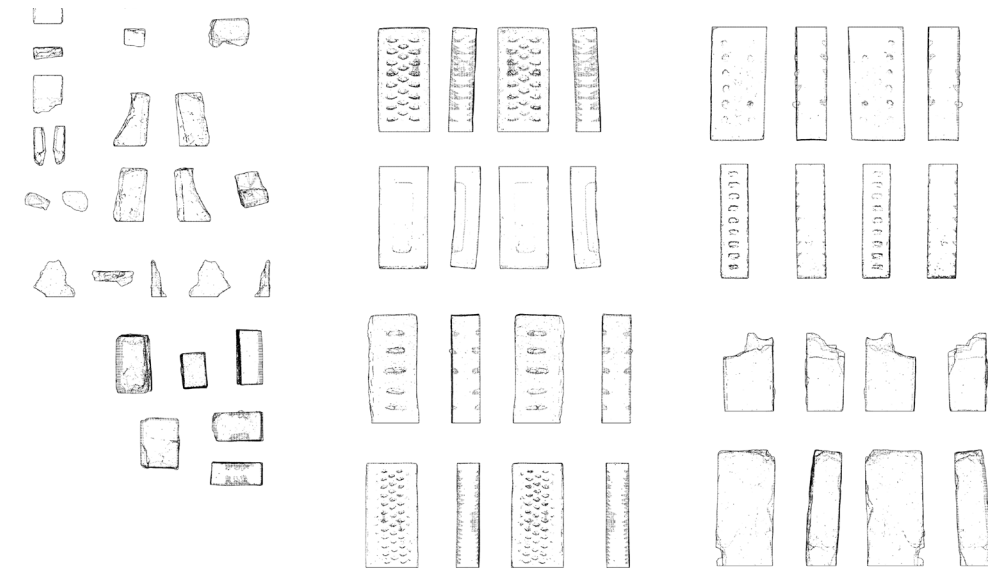
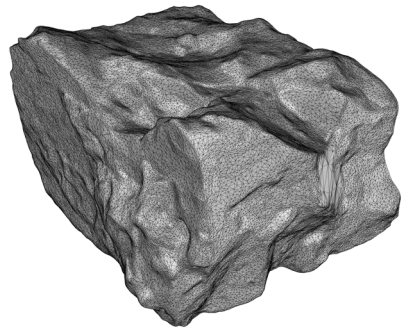


C5_D5_E5



These images of re-used brick terrazzo were generated using Gemini in firefly with input photos of material categories.

Scanned 3D mesh of brick fragment in Rhino



In order to visualise the digital prototype developed within this thesis, an experimental material library was produced through 3D scanning of selected brick fragments using the application RealityScan. The fragments were converted into mesh objects and imported into the computational

workflow. While this method proved effective for prototyping and visualisation, it would become impractical at larger production scales due to the time required for scanning and processing each individual element.

Robotic Pre-Processing and Classification of Reused Brick Materials

The following text constitutes the first part of a two-part interview conducted on April 21, 2026, with Björn Olofsson and Mathias Haage at Lund University, Faculty of Engineering (LTH). Olofsson and Haage are researchers with expertise in robotics and automation, particularly in relation to industrial systems and material handling.

The purpose of the interview was to contextualize the thesis project within a technical framework, to gather expert input, and to explore how the proposed design concept could be implemented in a real-world setting. The interview was structured into two thematic

sections: input, addressing processes and systems required prior to pattern generation, and output, focusing on the data required from the pattern generation process and its translation into fabrication.

The following section presents a synthesized summary of Part I (Input), based on the recorded and transcribed interview (B. Olofsson & M. Haage, personal communication, April 21, 2026).

The interview reveals that the feasibility of integrating robotics into the handling of reused brick materials is highly dependent on the le-

vel of pre-processing and system structuring prior to automation. A key distinction is established between fully automated systems, in which robots handle raw and unsorted demolition material, and semi-automated systems, where materials are pre-treated, sorted, or otherwise organized before entering robotic workflows. This distinction is critical, as industrial robotic systems are inherently optimized for repetitive tasks within controlled and predictable environments.

In the case of raw demolition input, robotics can be employed within a sorting pipeline that

combines sensing and classification. Bricks may be transported via conveyor systems through inspection stations equipped with cameras and sensors, where visual and geometric data are captured. These data enable classification based on parameters such as color, size and geometry. Machine learning methods, particularly neural networks trained on RGB image data, are identified as effective tools for interpreting such inputs, especially when compensating for irregularities caused by dirt, wear, or lighting conditions. However, the importance of controlled environments is emphasized; stan-

dardized lighting conditions significantly improve classification reliability, suggesting that sensing infrastructure must be carefully designed alongside robotic systems.

For geometric classification, the level of required precision determines the sensing strategy. Approximate size estimation may be achieved through 2D imaging, potentially combined with multiple viewpoints, while more detailed characterization necessitates 3D scanning technologies. These scans could possibly be carried into the pattern generation process. However, large-scale indivi-

dual 3D scanning introduces challenges related to data storage, computational load, and environmental impact. Consequently, a balance must be struck between data resolution and system efficiency. An alternative approach involves classifying bricks into predefined size and shape categories, as suggested but not represented in the workflow of this thesis. This method reduces the need for detailed individual models while maintaining sufficient differentiation for design purposes.

The development of a robust classification system is identified as

a central challenge. Such a system must balance granularity and practicality: overly detailed categories increase system complexity, while overly broad categories limit design control. Additionally, geometric variation within categories (e.g., rectangular versus triangular fragments) may be relevant for both aesthetic and fabrication considerations, suggesting that sub-categories could enhance design flexibility without significantly increasing system complexity.

A second key theme concerns the relationship between material availability and design processes.

Rather than designing independently of available materials, the interview proposes a feedback loop in which design is informed by existing material inventories. In this model, materials are pre-sorted into categories and managed through a kitting process, where specific quantities of categorized bricks are assembled according to design requirements. This enables near-individual specification while maintaining operational efficiency. It also supports a design approach that embraces variability, allowing patterns to adapt to available resources rather than enforcing strict uniformity.

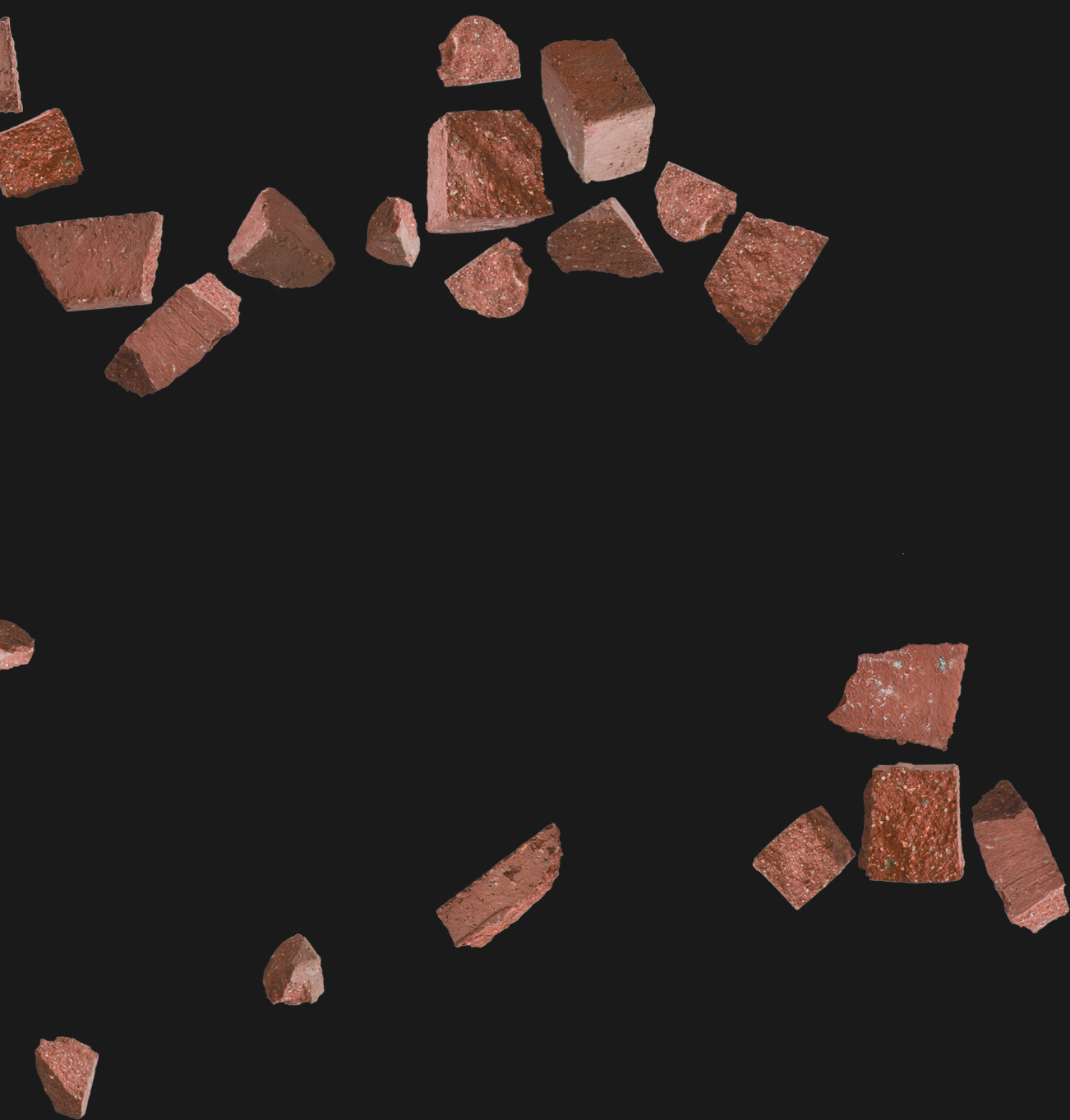
Importantly, the architectural intent underlying this approach explicitly incorporates material imperfection as a generative factor. Variations in color, size, and geometry are not treated as constraints to be eliminated but as qualities that contribute to the outcome. This tolerance for variation reduces the precision requirements of robotic systems, making automation more feasible. At the same time, it shifts complexity toward the definition of flexible design rules and classification frameworks that can accommodate such variability.

Temporal and logistical factors further influence system design. The required processing speed (cycle time) determines the sophistication of sensing and classification systems, while the location of automation—whether centralized in a factory or distributed on-site—introduces different constraints related to robustness, mobility, and material handling. In this thesis the elements are suggested to be cast vertically in a factory before being delivered to site. Additionally, upstream processes such as demolition can significantly impact downstream automation; materials sourced from a single structure may exhibit greater uni-

formity, simplifying classification and handling.

Overall, the input stage is not merely a preparatory phase but a critical determinant of the entire robotic fabrication workflow. Decisions made at this stage—regarding classification, sensing, logistics, and design integration—directly affect the complexity, feasibility, and adaptability of subsequent automated processes.

04. PATTERN GENERATION



What stories do we tell?

According to Akan et al. (2023), new computational technologies not only transform design strategies but also have the potential to reshape architectural perception as a whole. They compel us to reassess the limits of what is possible. This potential is often discussed in terms of geometry and form, as Akan et al. (2023) note, but it can also be explored through patterns and ornamentation—elements that have long been sidelined and, in many cases, criticized since the advent of the modernist movement. Initially, this dismissal arose from the increasing demands for efficiency and industrialization, and

later from the widespread belief that ornamentation was merely a superficial imitation of traditional practices, appearing as decorative scenery rather than substantive design. While I understand this perspective, it is important to recognize that the limitations which once shaped the trajectory of architectural movements no longer persist to the same extent.

In general one approach to digital pattern generation could be rule-based form generation (Larsen et al., 2016). If we establish enough computational rules—for example, through Grasshopper or Python—that generate constrains

for placing input objects over a predefined surface, we can achieve automatically generated patterns. These constraints could include color, density, and repetition. The results would vary based on the input and the rules of the algorithm, creating unique patterns. The challenge lies in connecting the different areas of rules and art: how can we create patterns that are architecturally interesting and work within a specific project by “sketching” through algorithms?

Perhaps the design process itself does not need to be entirely computational. A human creation

could serve as input, which is then processed by the algorithm, applying the input data alongside the defined rules of importance—outputting a digital language ready for robotic fabrication. In this way, digital tools extend the human hand and mind instead of replacing them, hopefully adding depth and feeling to the result. The limitations of creating non-standard surfaces and using non-standardized materials in architecture often lie in fabrication and craft, not in the idea generating itself. If digital tools can assist with fabrication, we can reintroduce a human aspect of expression that has been

largely absent in architecture over the last century.

Another approach to pattern generation could be through self-organization and parameter negotiation (Larsen et al., 2016), scripting pattern elements to “interact” with their neighbors and generate patterns based on this programming. The results would likely yield a signature expression for each script, creating endless variations based on, for example, the features of the first element placed in each pattern. This could produce interesting and lively facades, with units that appear coherent while each remains unique. However,

it could also limit the freedom to explore new patterns, constraining expression within the limitations of coding.

Pattern Generation Workflow

The following pages present the proposed pattern generation process developed for this thesis. The wall panel size (1.1 × 2.5 m) was established as a base module and subdivided into grids. The grid density was determined according to the size range of each corresponding category. A placeholder input pattern was imported into Grasshopper using an image sampler. Based on the sampled image, points on the grid were assigned RGB values. These points were then categorised into predefined colour categories using Python within Grasshopper.

To create a more dynamic and li-

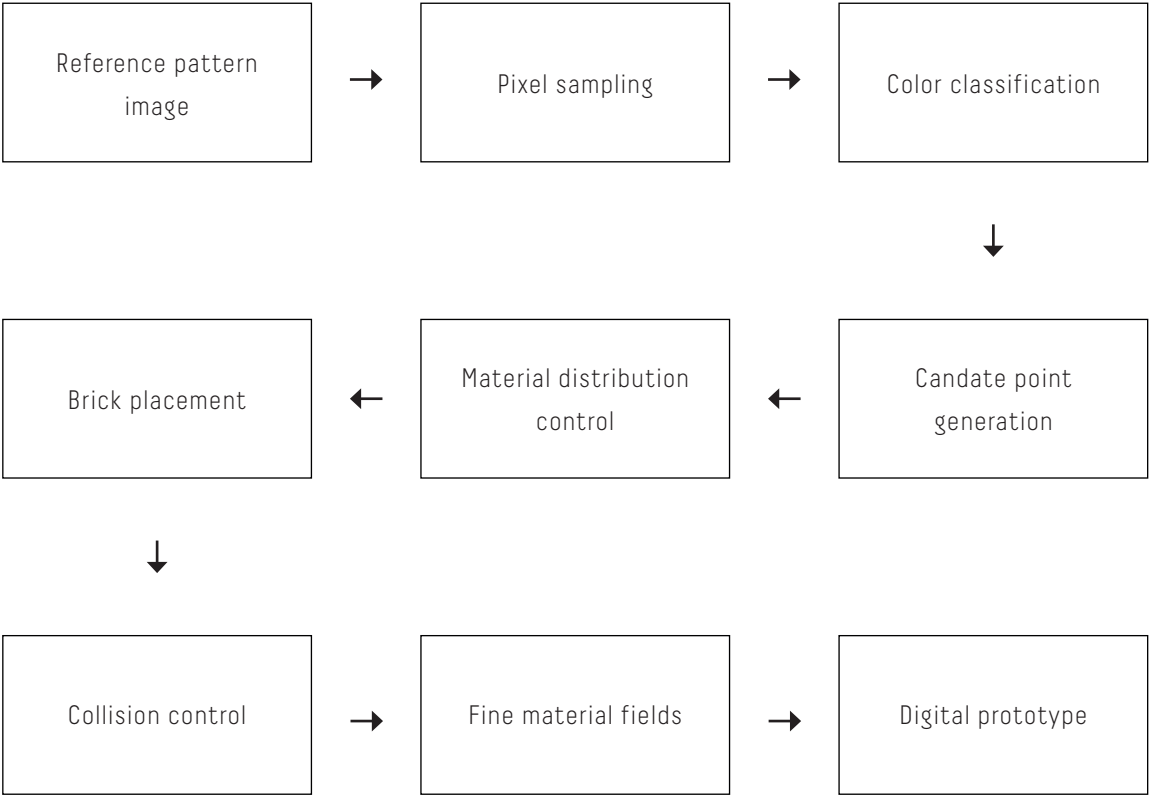
vely pattern, the points were randomly reduced and assigned rotation angles. This process also accommodated the availability of the different categories while providing control over the desired visual expression. Mesh inputs of bricks were organised into category layers in Rhino and linked into Grasshopper, where they were randomly distributed to corresponding points. This process was repeated for categories A and B.

Subsequently, colour fields were detected using a denser grid and an additional image sampler, generating shapes to be filled with categories C, D, and E in their

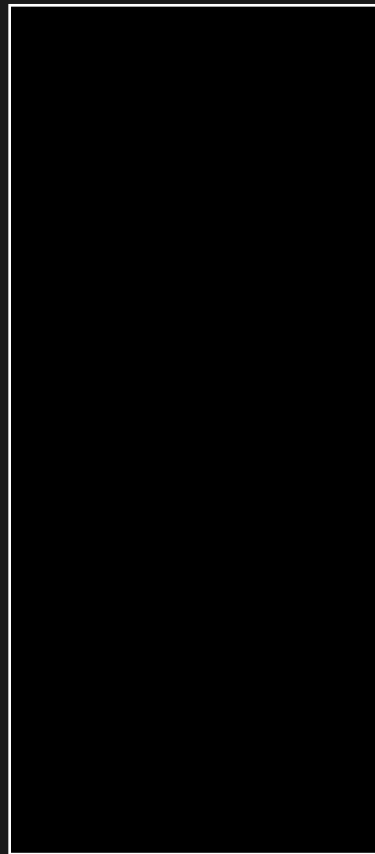
corresponding colours. Since the generated fields could contain multiple colour categories, the dominant category determined the final colour assignment. It was also possible to blend categories to achieve specific visual effects. The previously described pattern generation process represents the intended methodology for this thesis. However, due to time constraints, the colour-sorting stage had to be visualised manually (points 33–72 on the following pages). As a result, the placeholder image remained the sole input in the generation process, limiting the possibility of experimenting with multiple input variations.

The input image is representative of the stoneware tiles that were handmade and glazed with the intention of serving as source material for the facade panel patterns in the architectural application presented in this thesis. To demonstrate the interaction of these patterns both with one another and with the architectural context, a physical architectural model of the proposed design was produced.

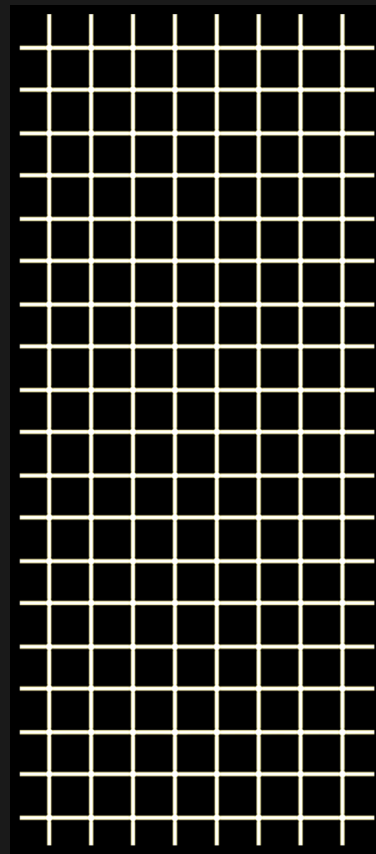
Pattern Generation Process in Short



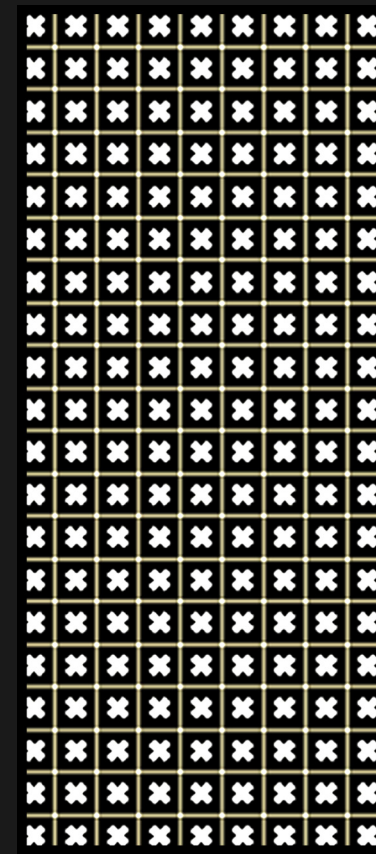
1,1 x 2,5 m



1. Surface representing facade element. The panel is cast horizontally in a mould.



2. The surface is divided in grasshopper, into pieces appropriate for the material category.



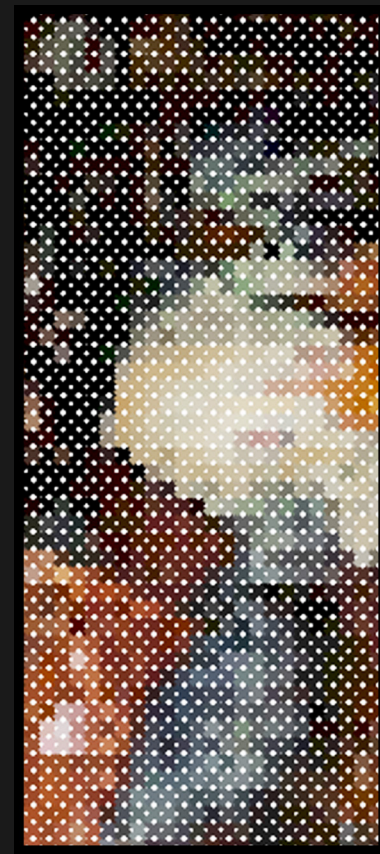
3. Points are generated in the center of each piece.



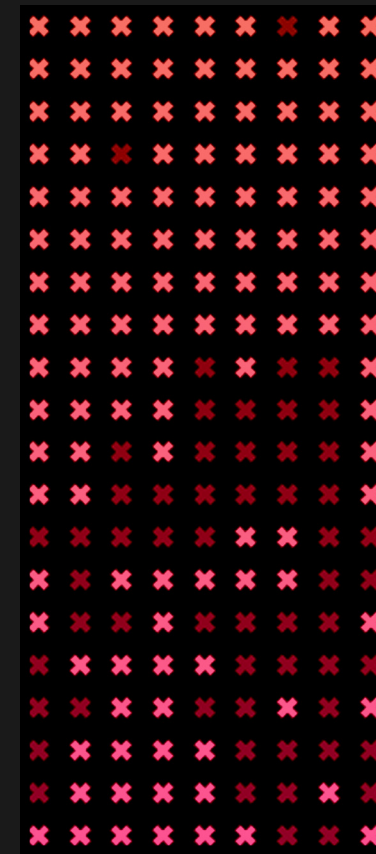
4. Placeholder pattern image in Image Sampler GH.



5. The points are coloured according to the RGB code of the underlying pattern image at each position.



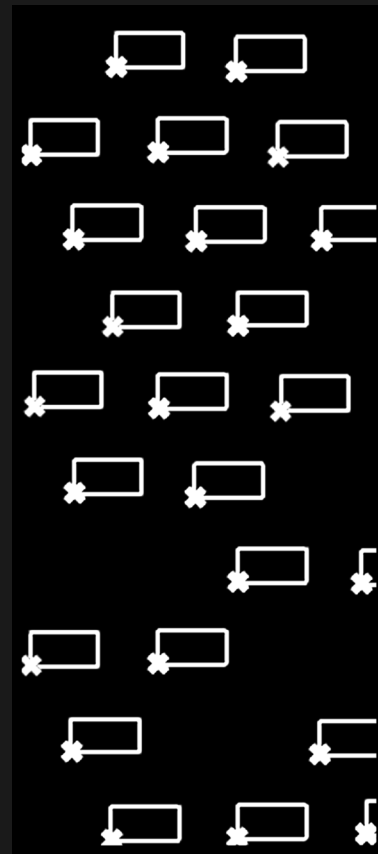
6. Demonstrating closer points here just to give a more clear illustration of the principal described in the previous step.



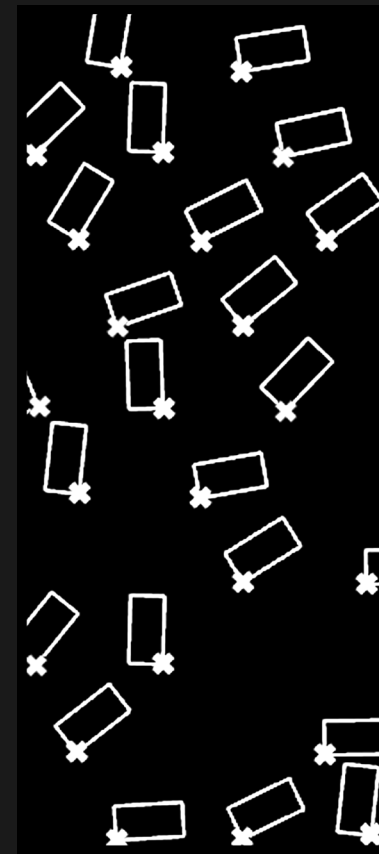
7. Gradient applied because of material categories. Will be developed further at a later stage.



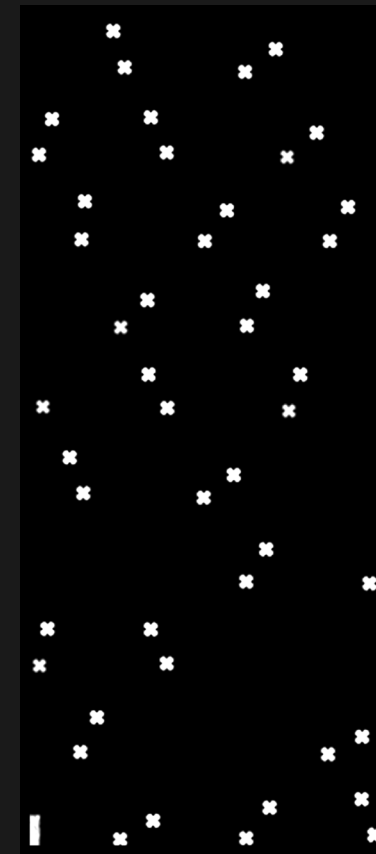
8. Random reduce since this is only the category A - large fragments, representing 20-30%



9. Rectangles are generated as initial placeholders for the bricks in category A.



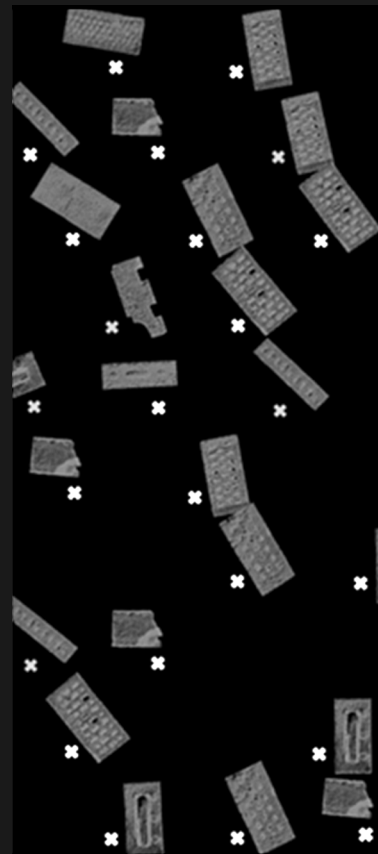
10. Random rotation.



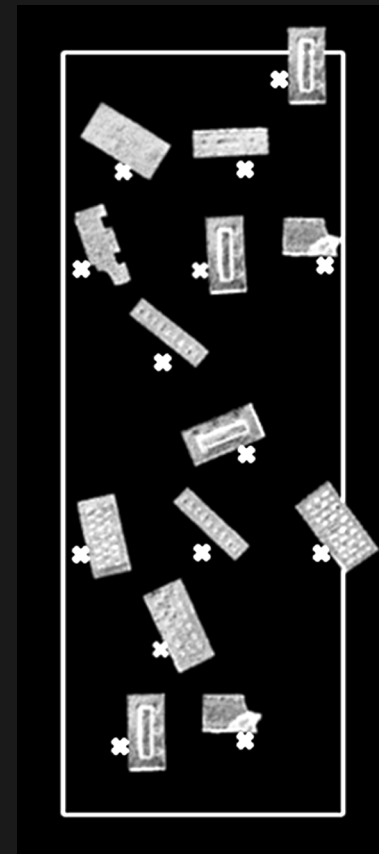
11. Centerpoint of each “brick” identified in order to use as base points for the digital library.



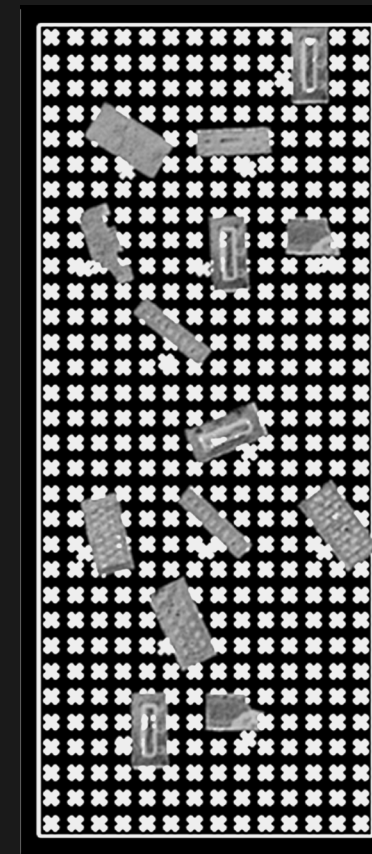
12. Centerpoint of random bricks in digital library category A moved to base points.



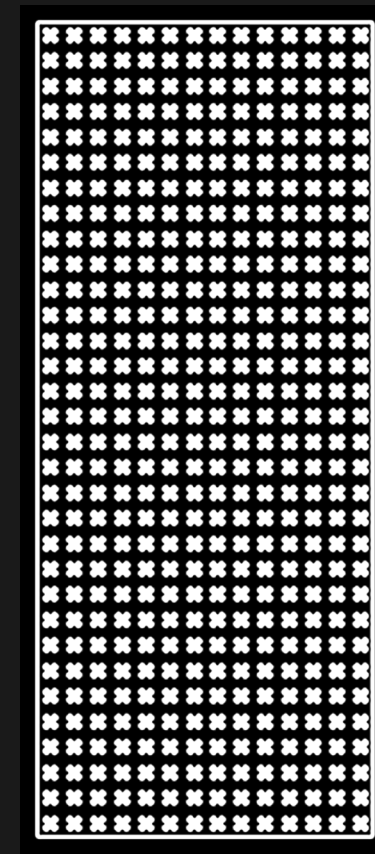
13. Rotation angle applied.



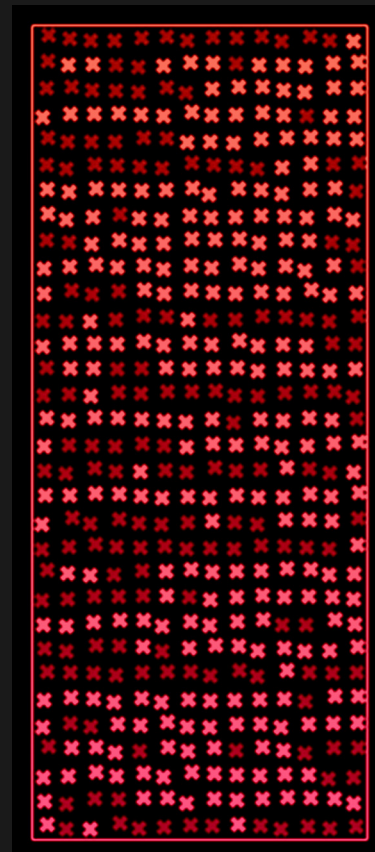
14. Bricks with origo outside category specific edge-frame removed.



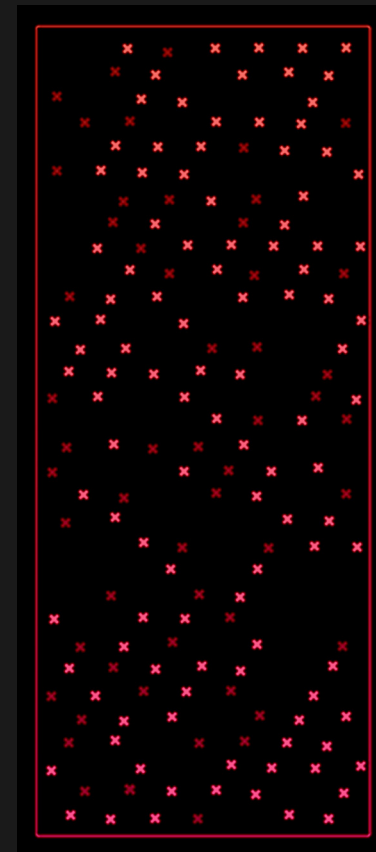
15. Grid for category B applied.



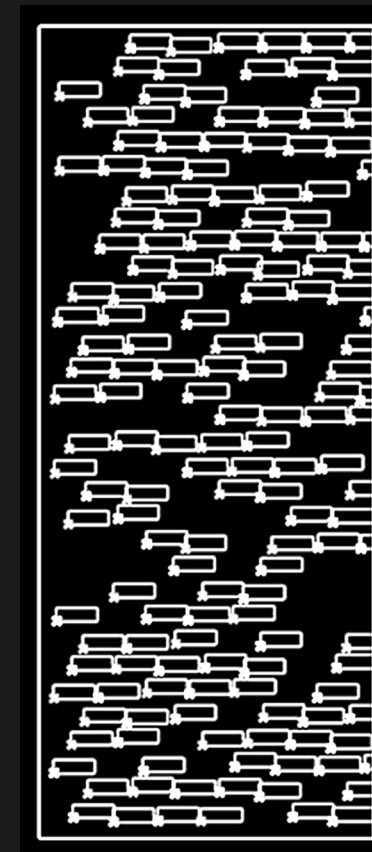
16. Hide category A for now.



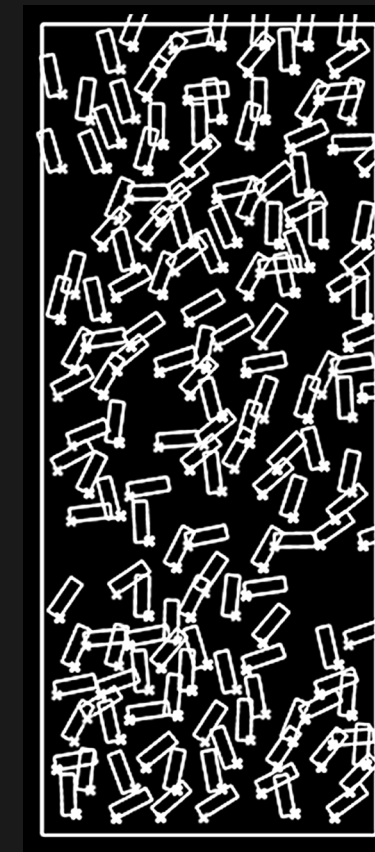
17. Gradient applied because of material categories.



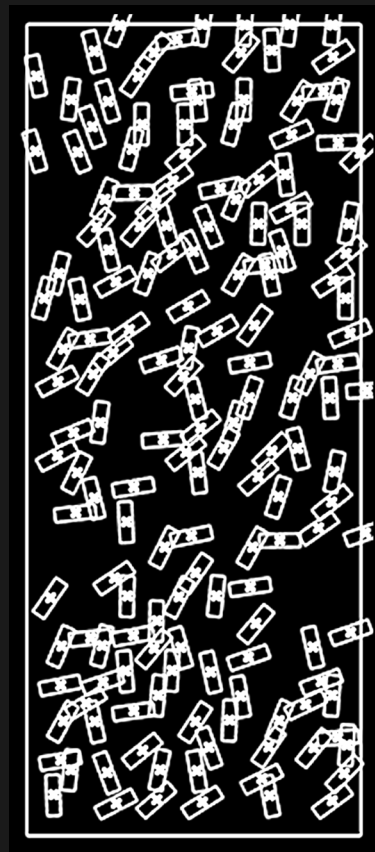
18. Random reduce category B, 70 %



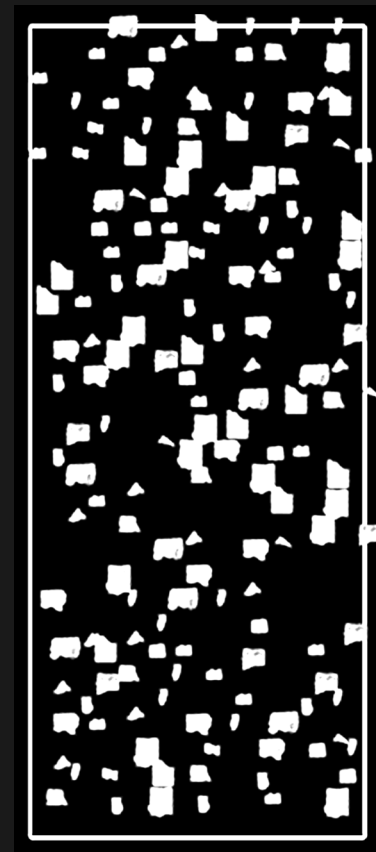
19. Placement rectangles.



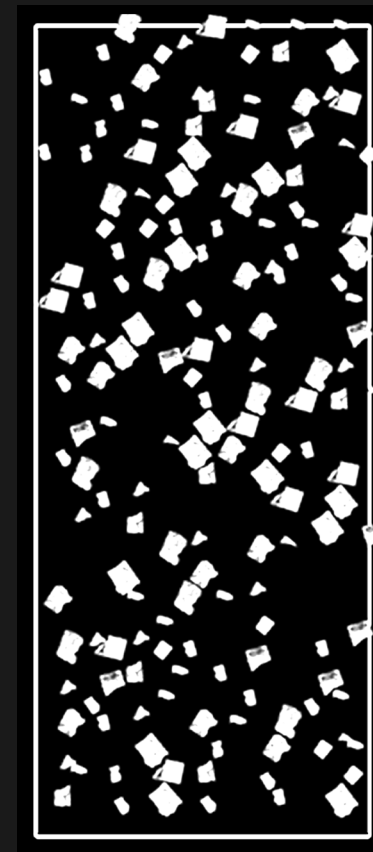
20. Random rotation.



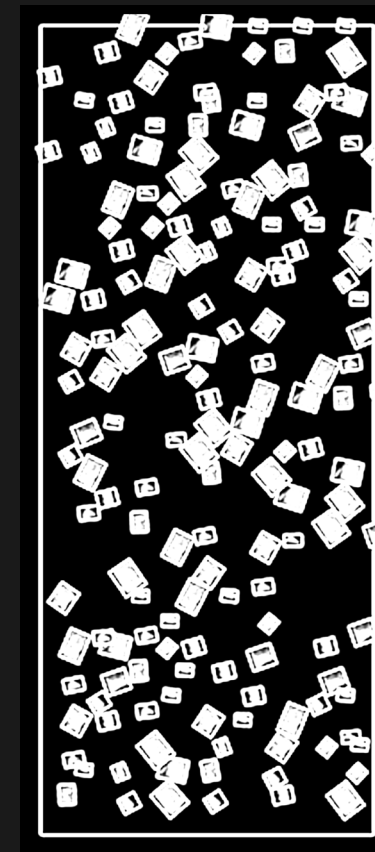
21. Center points for base points.



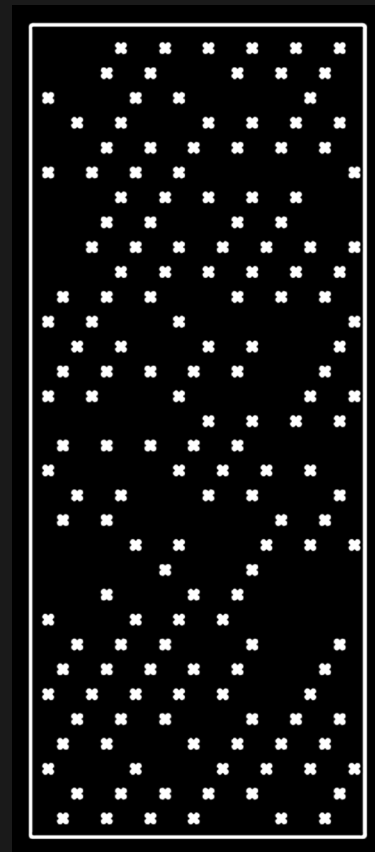
22. Random category B meshes placed at basepoints.



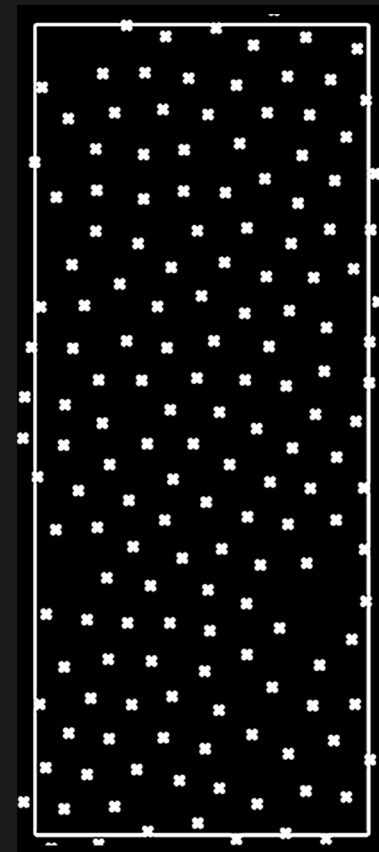
23. Rotation applied.



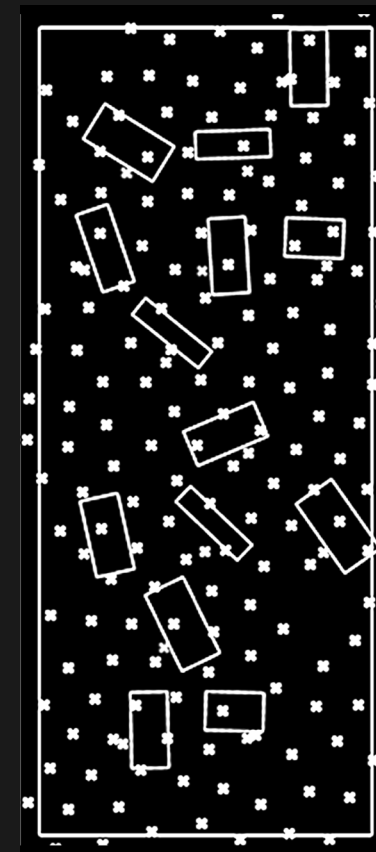
24. New rectangle edge curves for individual objects. In preparation of collision control.



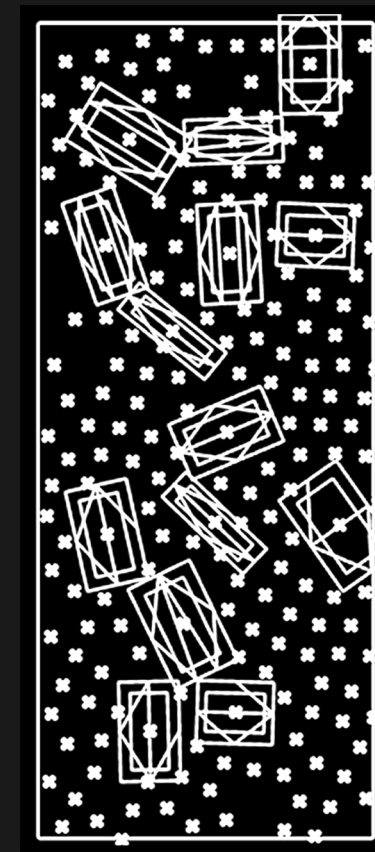
25. Starting collision control process using points. Temporarily disconnecting brick meshes. Placement points of category B.



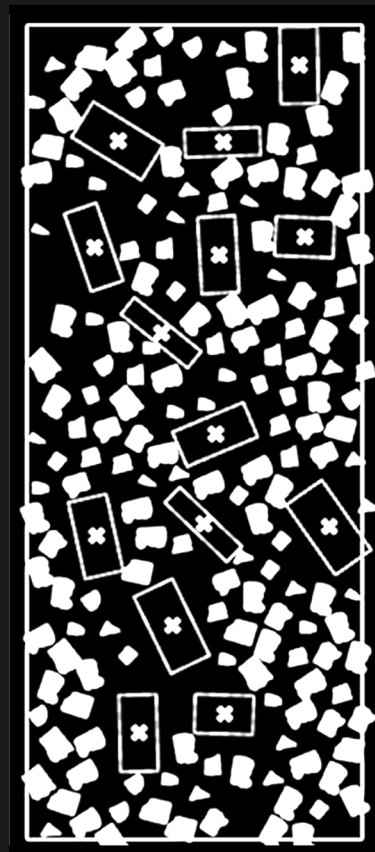
26. Using Kangaroo, gravity simulation, to ensure distance between points leading to no internal collisions in category B.



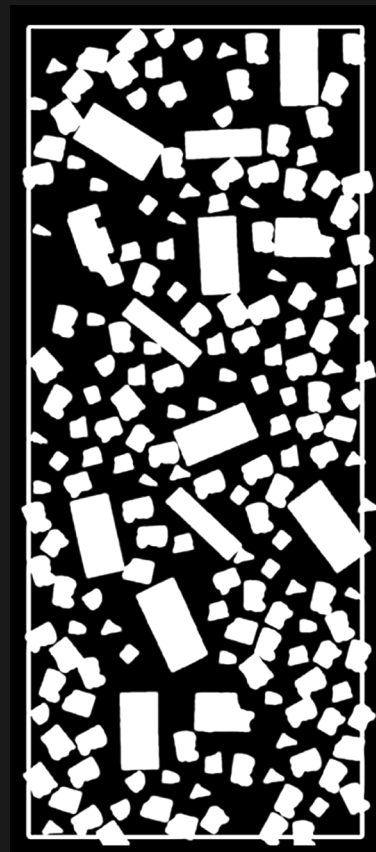
27. Placement of edge curve rectangles category A.



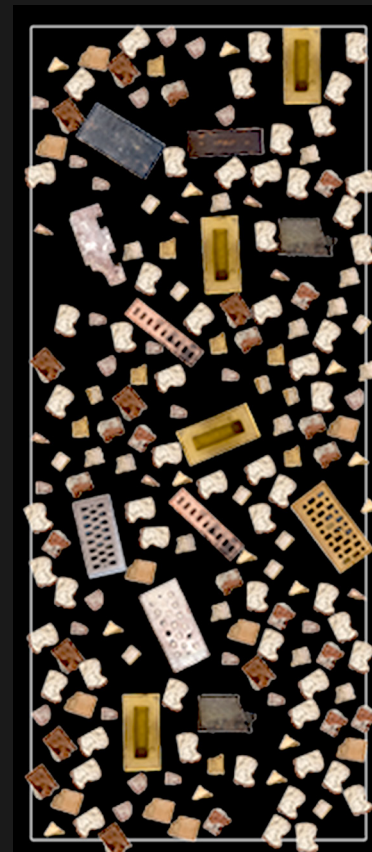
28. Creating an outer edge around rectangles. Remove category B points inside the bigger rectangles to ensure no collisions in between category A and B.



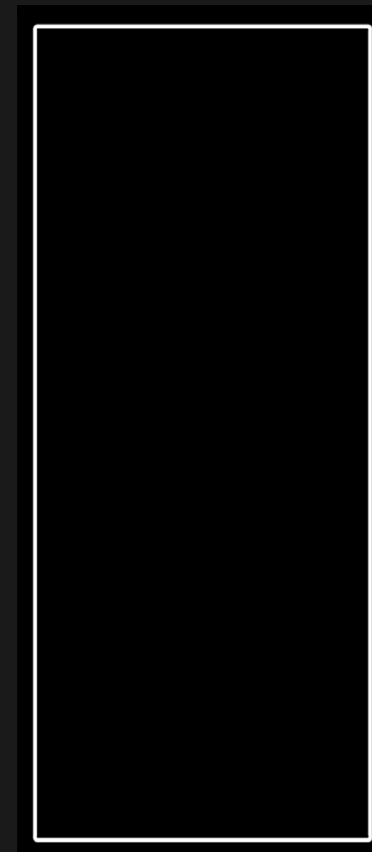
29. Re-link category B meshes.



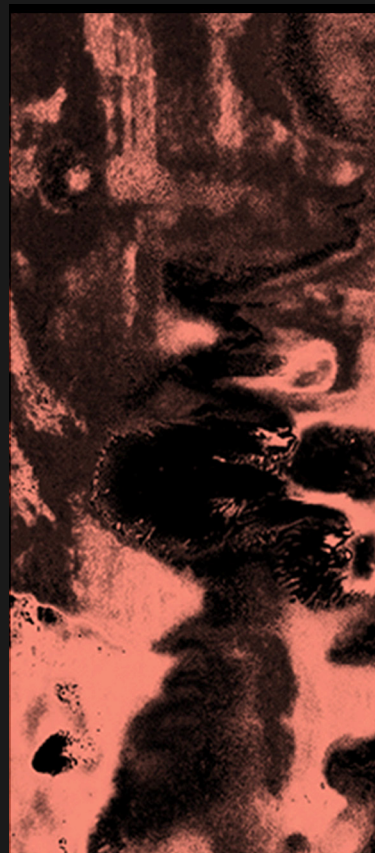
30. Re-link category A meshes.



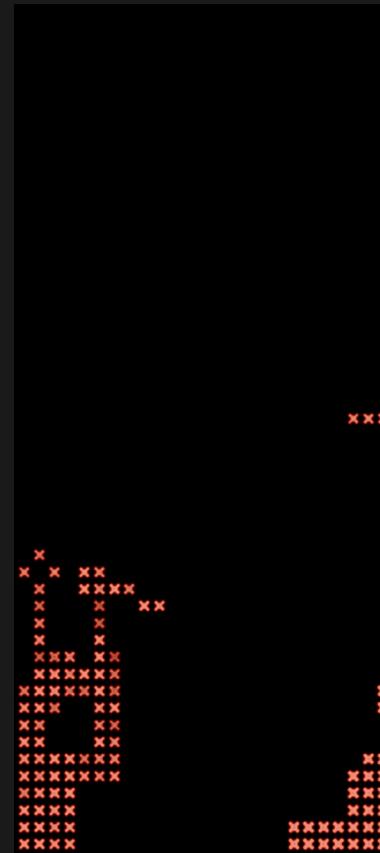
31. Baked + render display mode.



32. Continuous steps are not automated in grasshopper, but merely visualized due to time constraints.



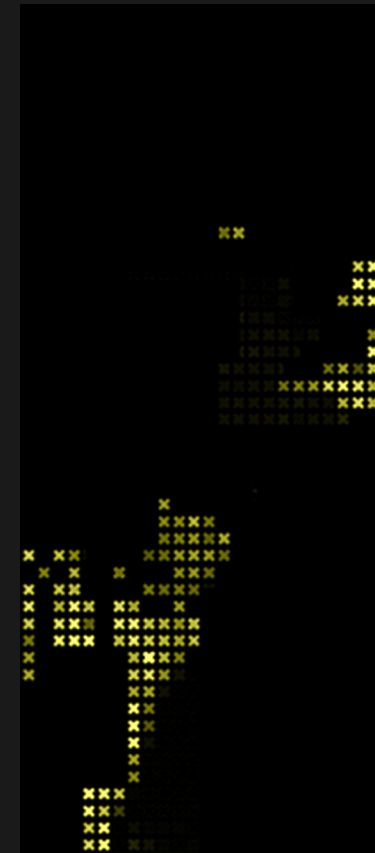
33. Fields of colour categories extracted from input pattern. Here for category 1.



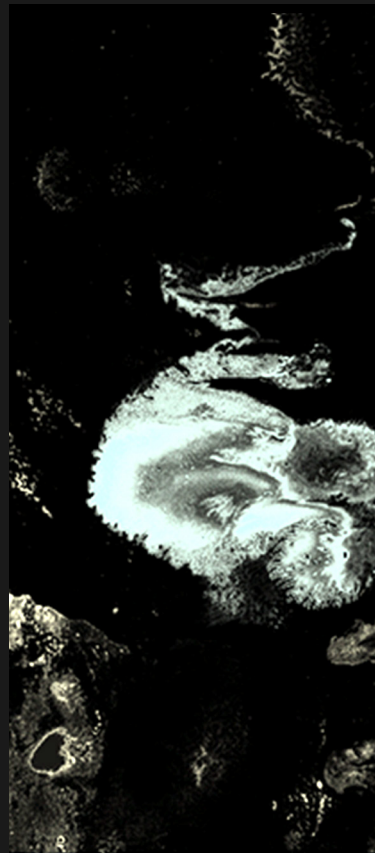
34. Corresponding points (in a tightly placed grid) detect where colour category is predominant. Here for category 1.



35. Category 3.



36. Category 3.



37. Category 4.



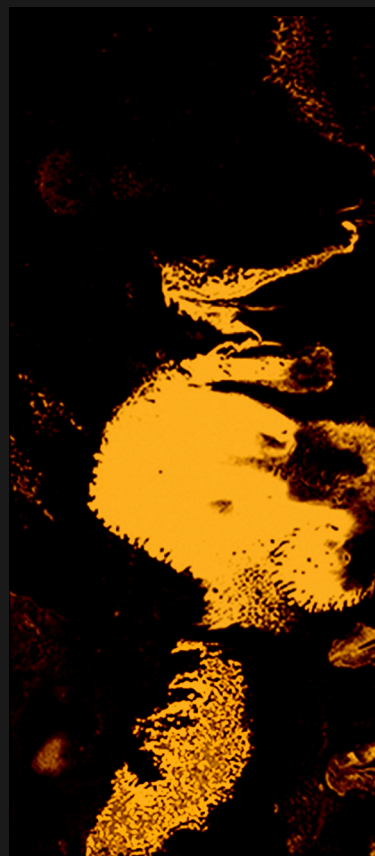
38. Category 4.



39. Category 0. (inverse display)



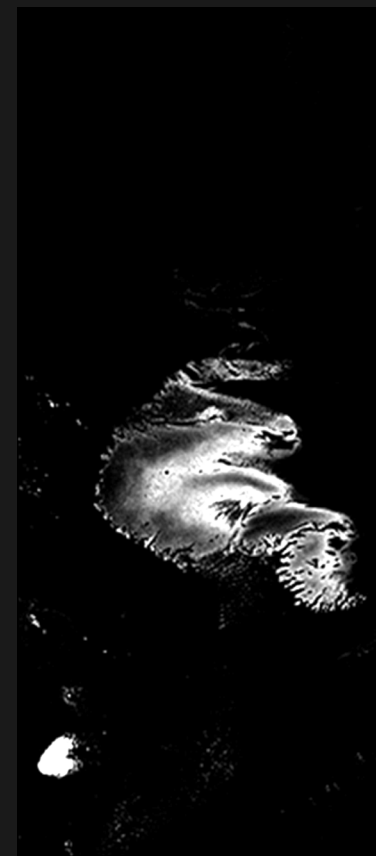
40. Category 0. (inverse display)



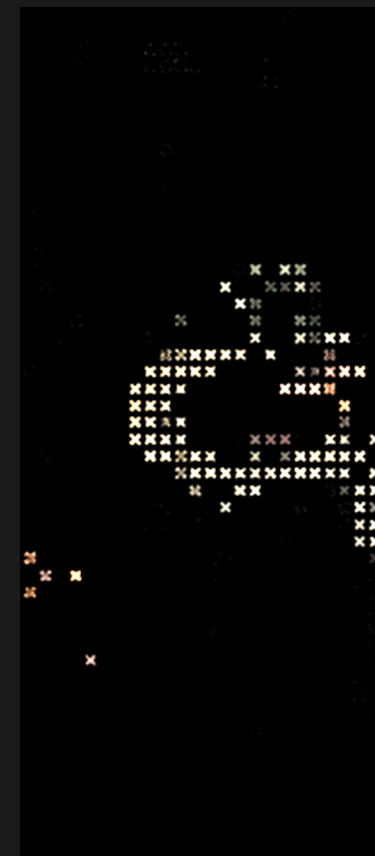
41. Category 5.



42. Category 5.



43. Category 2.



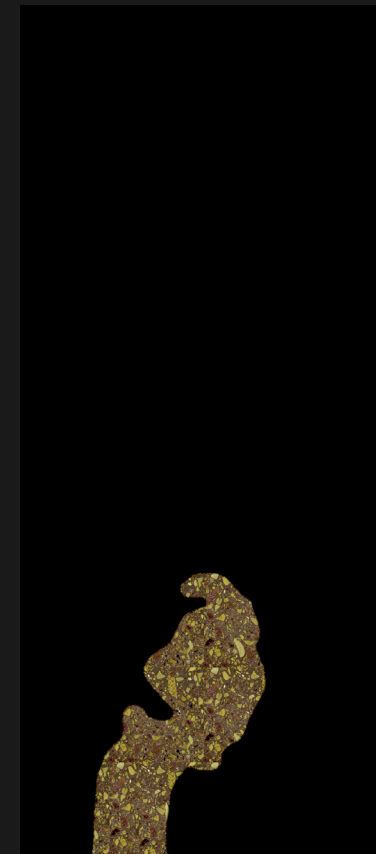
44. Category 2.



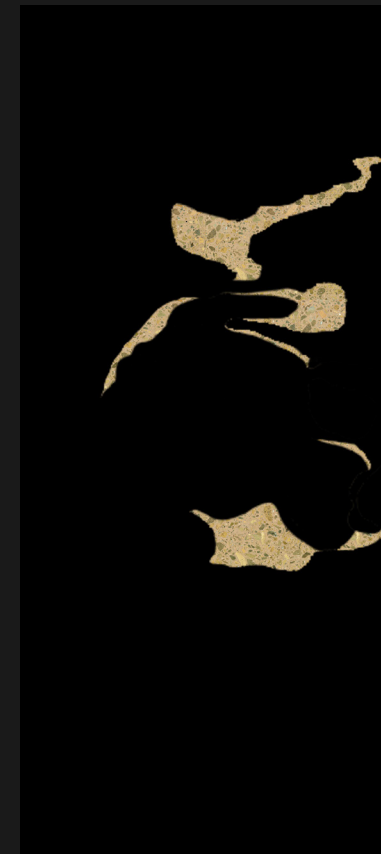
45. The tight grid of points connected to the colour categories is used to create fields.



46. Categories C-D are placed in corresponding fields. Shown here: CO_D0_E0



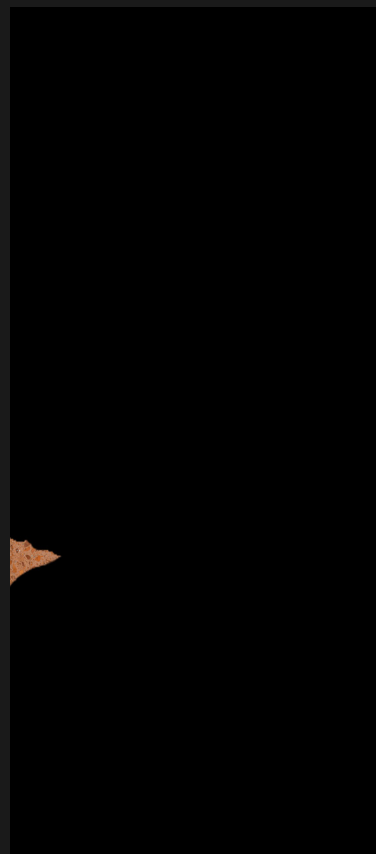
47. CO_D0_E0_C1_D1



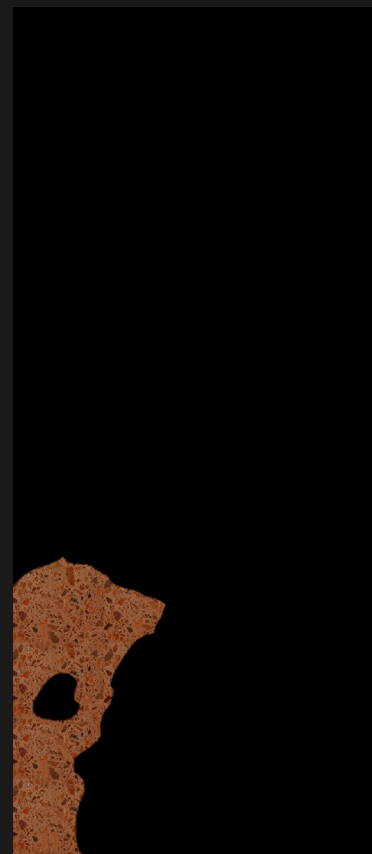
48. CO_D0_E0_C1_D1



49. C2_D2_E2



50. C5_D5_E5



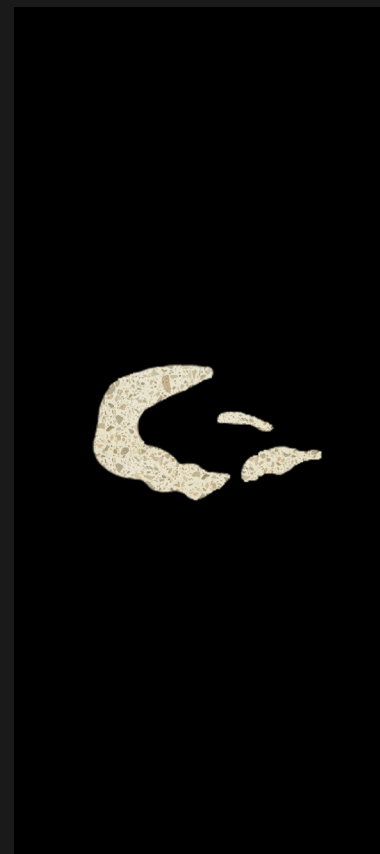
51. C5_D5_C5_D5_E5



52. C2_D2_E2_C5_C4



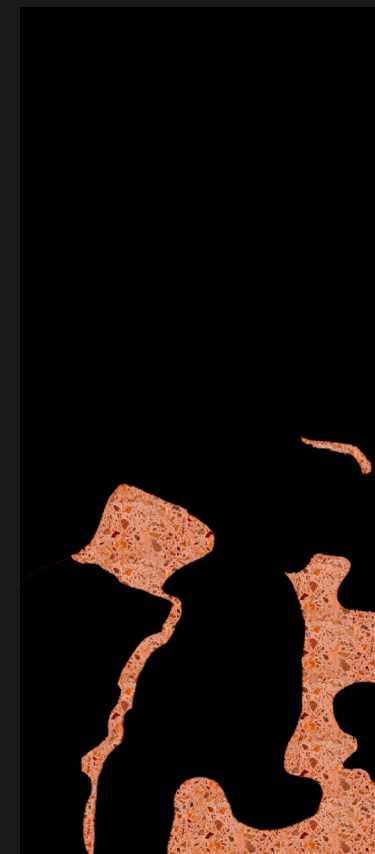
53. C4_D4_E4



54. C2_D2_C4_D4_E4



55. C0_D0_E0_C1_D1



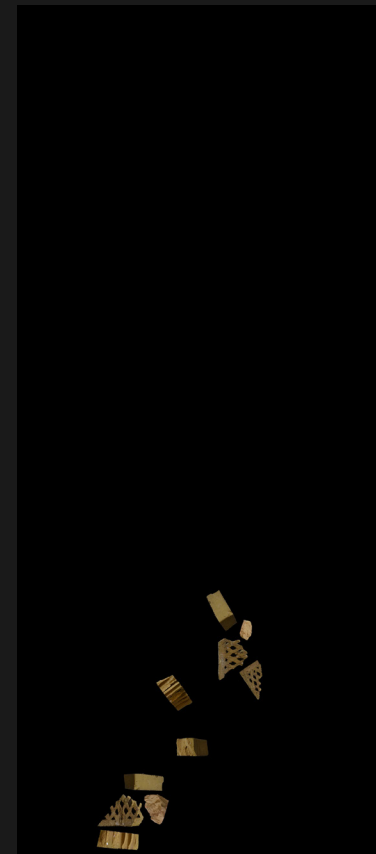
56. C1_D1_C0



57. All fields of categories of C - E combined



58. Continuing from here, category B is divided in colour categories and placed according to the same fields. Here: B0



59. B3



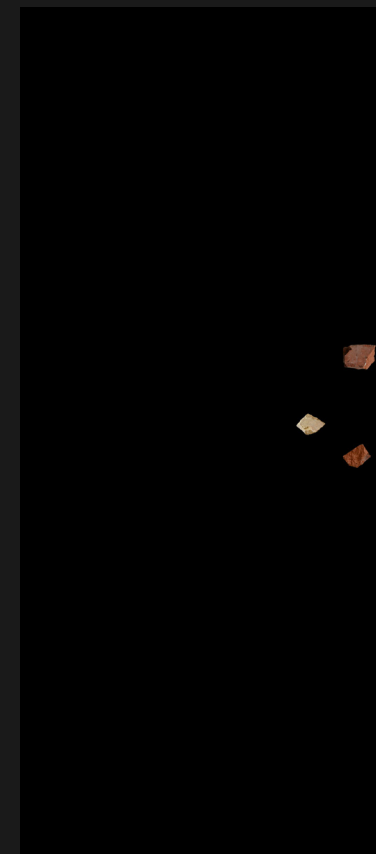
60. B2_B3



61. B2



62. B5



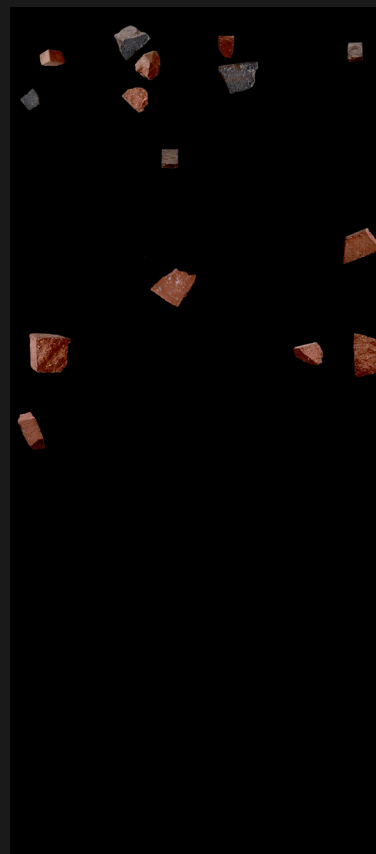
63. B5_B2



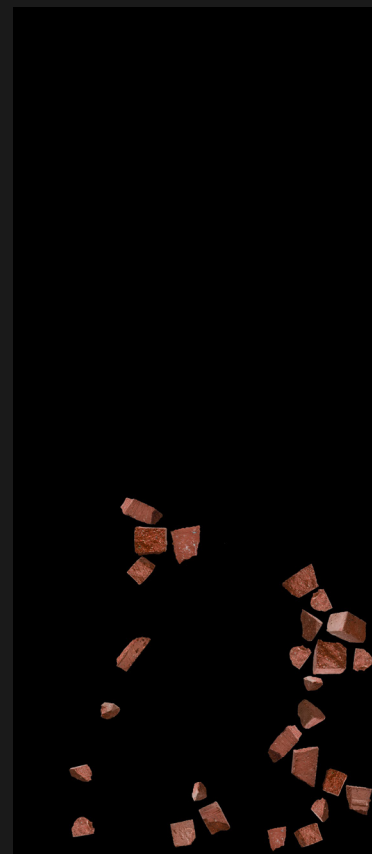
64. B4



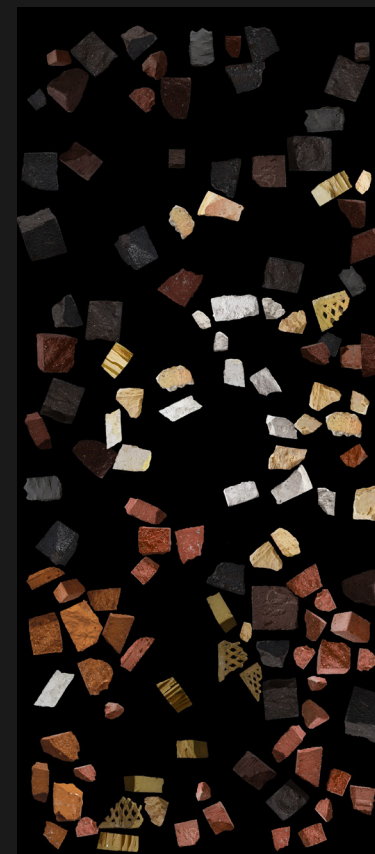
65. B2_B4



66. B0_B1



67. B1



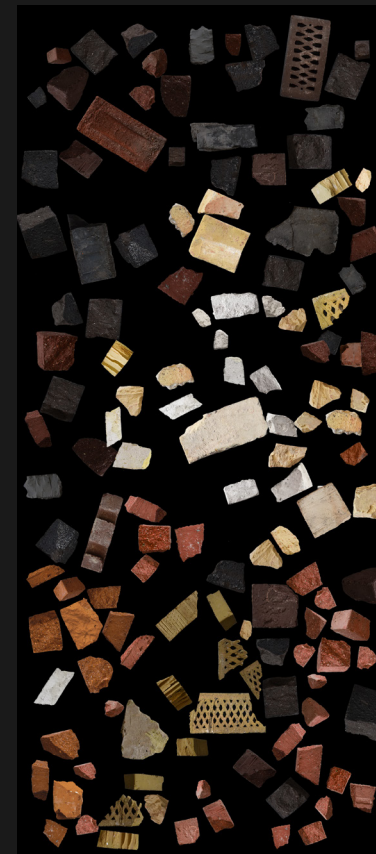
68. All of category B



69. All of categories B,C,D,E



70. Category A



71. Category A + B



72. All colour and size categories. Final digital prototype.

05. OUTPUT /
POSSIBLE PROCEDURE



Data Structures and Robotic Fabrication Strategies for Pattern Realization

The following text constitutes the second part of a two-part interview conducted on April 21, 2026, with Björn Olofsson and Mathias Haage at Lund University, Faculty of Engineering (LTH).

This section focuses on the output stage of the proposed workflow, addressing the type of data required from the pattern generation process and how such data can be translated into robotic fabrication. In particular, the discussion explores the relationship between digital pattern definitions and robotic execution, including positioning, material handling strategies, and levels of automation.

The output phase is defined by the translation of pattern generation into actionable data for robotic fabrication. A central insight from the interview is that robotic systems fundamentally operate through spatial instructions—specifically, positions and orientations within coordinate systems. Consequently, the output of a pattern generation process must be structured in a way that aligns with this logic, providing explicit geometric information for each element to be placed.

In this context, each brick or component must be associated with a coordinate frame, typically defi-

ned by a position (e.g., centroid) and an orientation. Luckily, this is already the case for the pattern generation of this thesis, as each brick is assigned a local coordinate system in Grasshopper. This structured output enables direct interfacing with robotic systems, provided that the relationship between the digital representation and the physical object—such as how a brick is grasped and oriented—is clearly defined.

The effectiveness of this translation is closely linked to the degree of structure established during the input phase. If materials have already been classified into well-de-

fined categories, the output process can operate at the level of these categories rather than individual objects. This significantly simplifies robotic execution, as the system can select any brick from a given category without requiring detailed knowledge of its unique geometry. Conversely, if higher precision or individual differentiation is required, additional sensing—such as real-time vision systems or 3D scanning—must be integrated into the fabrication process, increasing complexity.

Fabrication itself is primarily conceptualized as a pick-and-place

process, which aligns well with the capabilities of industrial robotic systems. However, the complexity of this process varies significantly depending on the structure of the material supply. If bricks are delivered in an unstructured manner (e.g., loosely arranged in containers), the primary challenge lies in the picking operation. Identifying and grasping individual bricks requires advanced sensing and adaptable gripping technologies, such as soft or multi-fingered grippers. In contrast, if materials are supplied in structured formats—such as stacked or magazine-fed systems—picking becomes significantly simpler, though at

the cost of increased upstream organization and logistics.

The discussion further distinguishes between different material categories and their implications for both data representation and fabrication processes. Larger, well-defined brick elements are suited to discrete pick-and-place operations, where precise positioning is required. In contrast, smaller fragments or granular materials (e.g., aggregated brick) may be more appropriately handled through continuous processes such as pouring or filling. This necessitates different types of output data: while distinct elements

require exact coordinates and orientations, granular materials may instead be defined by spatial regions or volumes to be filled.

Previously mentioned factors align with the thought process of the suggested pattern generation, starting from the biggest category moving towards the smallest. Indicating that another critical aspect is the sequencing of fabrication. Björn and Mathias supported the idea behind the original proposal of arranging the fragments in descending order of size, from the largest to the smallest elements. They also add that additionally, collision avoidance and accessibi-

lity must be considered, implying that the pattern itself may need to be constrained to ensure robotic feasibility.

The potential role of feedback mechanisms is also emphasized. Vision systems can be used to monitor the fabrication process, comparing the constructed result with the intended pattern and enabling adjustments in real time. This introduces the possibility of closed-loop control, where deviations are detected and corrected either automatically or with human intervention. Hybrid systems, combining robotic precision with human

collaboration, are identified as particularly relevant in contexts where aesthetic judgment and adaptability are important.

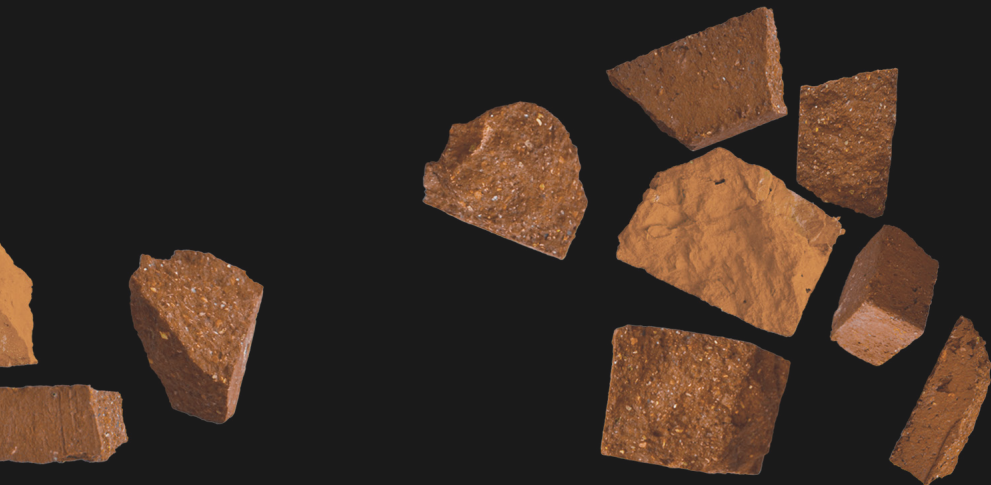
Finally, the interview outlines alternative fabrication paradigms beyond conventional pick-and-place. One such approach involves distributing material within a defined area and using robotic systems to rearrange it according to a pattern. This method is particularly suited to scenarios with limited material quantities or highly variable components, though it imposes constraints on achievable patterns. The choice of fabrication strategy is thus closely linked to

both material conditions and design intent, with different approaches favoring either precision or adaptability.

In conclusion, the output stage represents a critical interface between design and fabrication, where abstract patterns are translated into executable robotic actions. Its effectiveness depends on the alignment between data structures, material classification, and fabrication strategies, as well as on the balance between control and flexibility within the overall system.

06. MATERIAL TESTING

/PHYSICAL PROTOTYPE

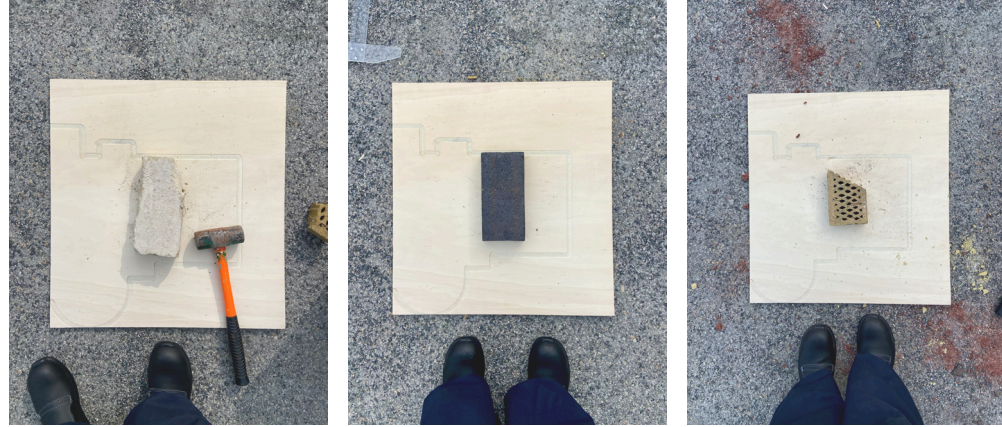




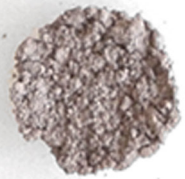
Initially, mixtures containing 50% material from the various E categories and 50% cement were tested. In addition, attempts were made to match the appearance of these samples by pigmenting the cement, since the quantity of material available from the E categories was insufficient for the production of larger prototypes

and additional material could not be generated by hand.

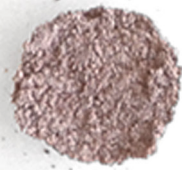
For categories B–D, where the available material was likewise limited, supplementary material was produced by manually crushing reclaimed brick with a sledgehammer.



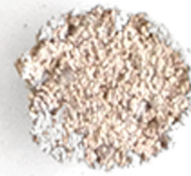




0E



1E



2E



3E



4E



5E

Results of Samples Containing
50% Category E Material and 50%
Cement

Prototype 1

This first attempt was cast horizontally in a mould. The larger fragments from Categories A and B were first arranged in a pattern with their exposed faces placed downward in the mould. Category C material was then added, followed by a mixture consisting of 45% Category D, 45% Category E, and 10% cement, which was poured into the mould and allowed to flow into the gaps between the larger fragments.

After curing, the mould was disassembled and the prototype was turned over to reveal its front surface. Initially, the intention was to

grind the surface using a diamond grinder and subsequently apply a wax finish in order to create a smooth, terrazzo-like appearance. However, once the prototype was revealed, the front surface appeared considerably cleaner than anticipated, and the existing texture provided a sense of depth and character to the material. As a result, the decision was made not to proceed with grinding the surface.





1. Categories A and B arranged in the mould.
2. Category C added.
3. Mixture of Categories D and E with cement placed according to the designed pattern.
4. A layer of Category E material and cement added on top to provide cohesion and structural stability.
5. Prototype cured within the mould.



Prototype 2

In Prototype 2, the intention was to continue casting horizontally in a mould, but unlike Prototype 1, the prototype would not be turned over after curing. Instead, the front surface would remain facing upward during casting, and the larger aggregates would be exposed by cleaning them before the binding matrix had fully hardened. Categories A and B were first arranged according to the intended pattern. A layer of Category E material combined with concrete—here replaced with pigmented concrete—was then applied to securely anchor the larger aggregates. Once this layer had cured,

material from Category C was distributed across the surface to reinforce the pattern. Subsequently, a mixture of Categories D and E with cement was poured to bind the composition together.

Before the mixture had fully hardened, the larger aggregates were exposed by carefully washing away the surface layer using water and a sponge. The prototype was then allowed to cure completely before the mould was removed.

The resulting prototype did not meet the intended design objectives. A hazy film covered the entire surface, reducing the visual



1



2



4



3



5



6



prominence of the aggregates. The material appeared flatter, lacking the depth and texture achieved in Prototype 1. Furthermore, the process proved to be more labour-intensive and time-consuming than the method used for Prototype 1. Consequently, the approach employed in Prototype 2 was deemed unsuccessful and was not pursued further.

1. Categories A and B arranged according to the intended pattern.
2. A layer of Category E material and cement mixture applied.
3. The mixture hardens.
4. Category C material added.
5. A mixture of Categories D and E with cement applied.
6. The larger stones are exposed before the mixture is fully hardened (approximately 20 minutes after application).

Prototype 3

Finally, a third and final prototype was produced. This prototype was based on the same principles as Prototype 1, but at a larger scale, allowing for a more comprehensive evaluation of the pattern's visual effect. The ceramic tile shown to the left served as a loose source of inspiration for the pattern, providing an indication of how its composition could be translated into the proposed material system, although the proportions were not replicated exactly.

Several observations emerged from this experiment. Most notably, the pattern underwent a sig-

nificant degree of abstraction, an outcome that was considered successful. The fact that the façade elements appeared markedly different when viewed from varying distances contributed to a greater sense of depth and visual richness. The surface texture remained dynamic and expressive, while the overall structural integrity of the elements proved satisfactory. Only a small number of the finer fragments located near the surface failed to bond adequately and detached when the prototype was turned over.





1. Categories A and B arranged according to the intended pattern.



2. Category C material added.

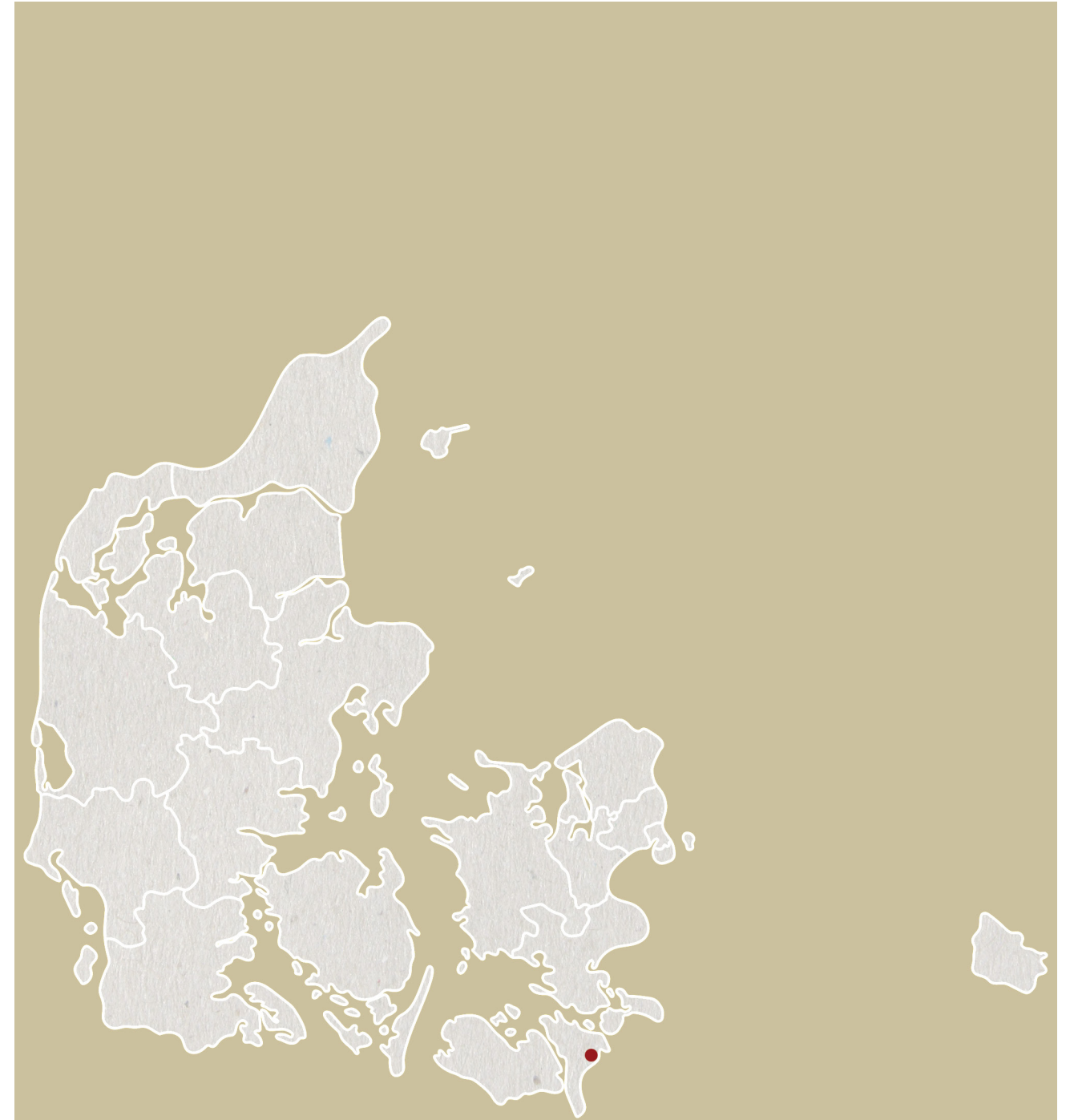


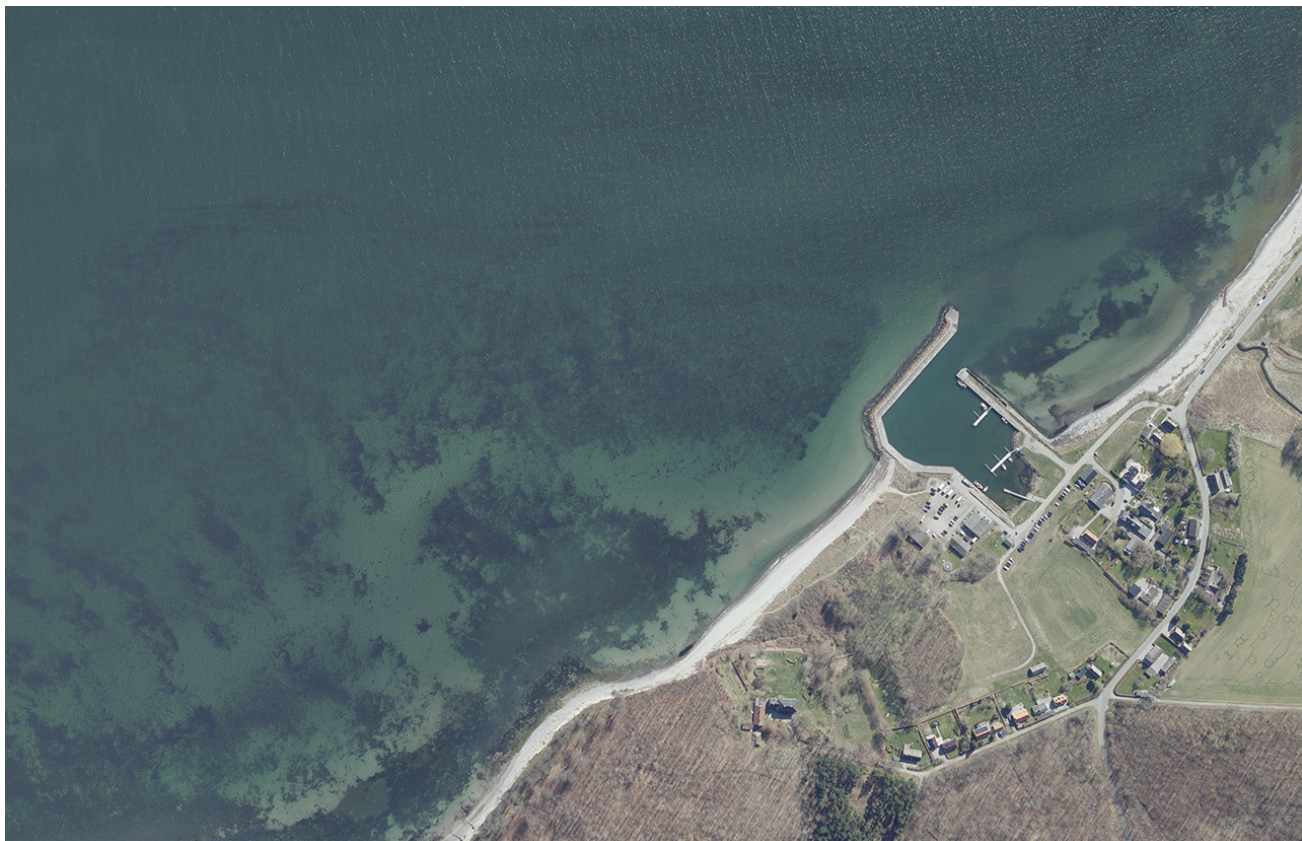
3. A mixture of Categories D and E with cement poured into the mould. An additional layer of cement was applied to level the surface and improve structural stability.



4. After curing, the mould was disassembled, the prototype was turned over, and the mould was reassembled.

[illegible]





Hæsnes, Falster. Image source: Styrelsen for Dataforsyning og Infrastruktur (2026)

Hæsnes, Falster

Hesnæs is a sleepy fishing village on the east coast of the island of Falster in Denmark. It has a very special, almost magical atmosphere. Here, far away from the hustle and bustle in what feels like the edge of the world, lies a unique place where time seems to stand still. Both in the calmness it exudes and in its architecture. The feeling of stepping back in time is predominant. Yet, it does not feel outdated.

Maybe it is the uniqueness of the architecture that made it immune to the test of time. In the late 1800s, after a major flood destroyed most of the village, the

architect Vilhelm Tvede developed a new housing design for the fishermen's houses in Hesnæs. The typology, known today as the "Hesnæs houses," introduced a unique Danish expression with half-timbered structures, straw-clad walls, thatched roofs, and horizontal bracing elements along the façade. (Historisk Atlas, 2026) Today, the town is still very much alive. The newer buildings and sheds, though outnumbered by the "Hesnæs houses," give the place a laid-back atmosphere. Because they are so modest and weathered by time and salty air - even more so than the older houses - it fe-

els almost contradictory that they are the newer additions. In every corner of the village, you can hear the soft rhythmic sound of waves rolling in.

One might raise questions as to why I chose this place as the site for this thesis. Would it not make more sense to select a location with traditional brick-infilled half-timbered houses? However, while randomly wandering through Google Maps and stumbling upon the town of Hesnæs, I immediately felt that this was where the villa was supposed to be. Maybe it was the spirit of Vilhelm Tvede's progressive thinking - something I did

not yet know about at the time - or perhaps wanting to avoid the intimidation of placing the villa next to the cross timber architecture that had directly inspired it. I do not know. But visiting Hesnæs only strengthened that feeling and confirmed my decision.





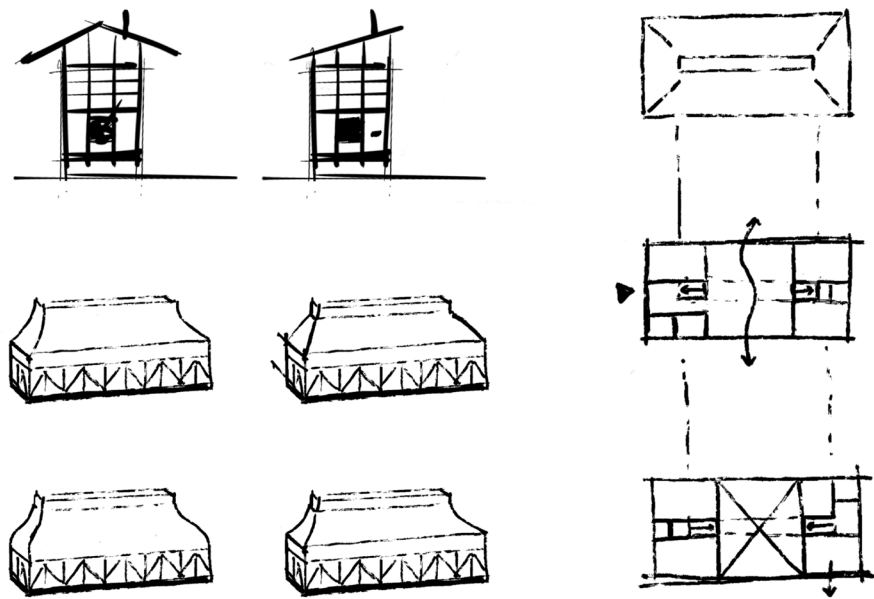




Chosen site



Chosen site. Hæsnes, Falster. Image source: Styrelsen for Dataforsyning og Infrastruktur (2026)



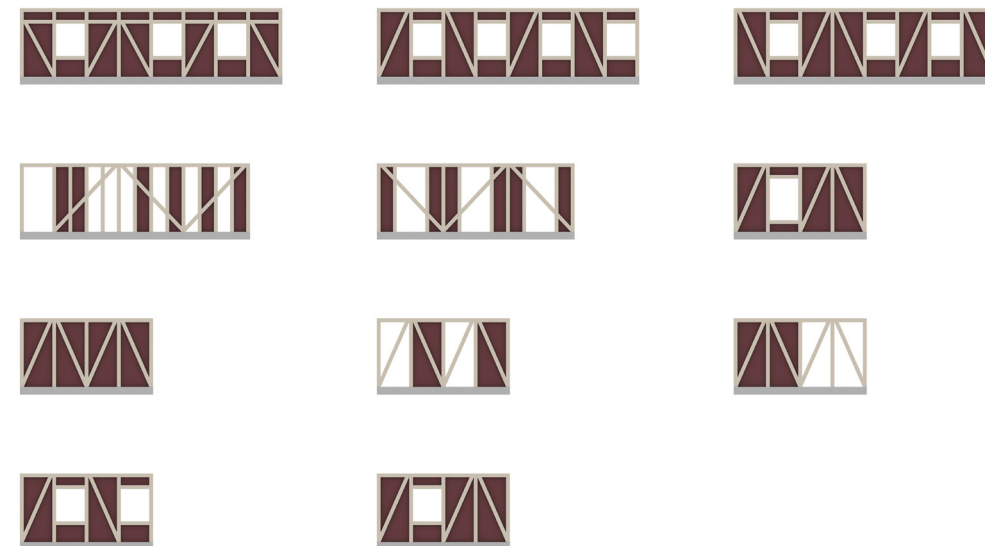
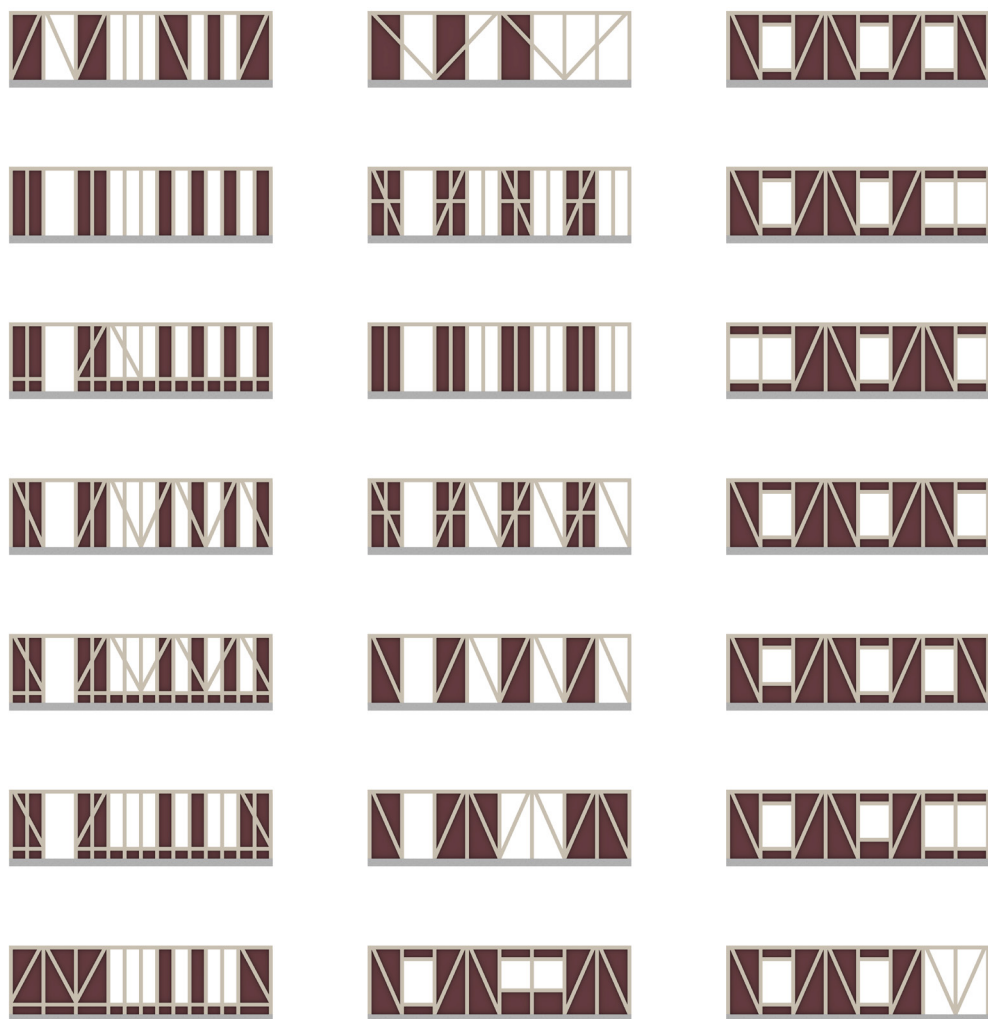
Sketching

The sketching process began with an exploration of how the building could relate to traditional construction techniques and integrate with its surroundings, while remaining free to maintain a distinct and contemporary architectural expression.

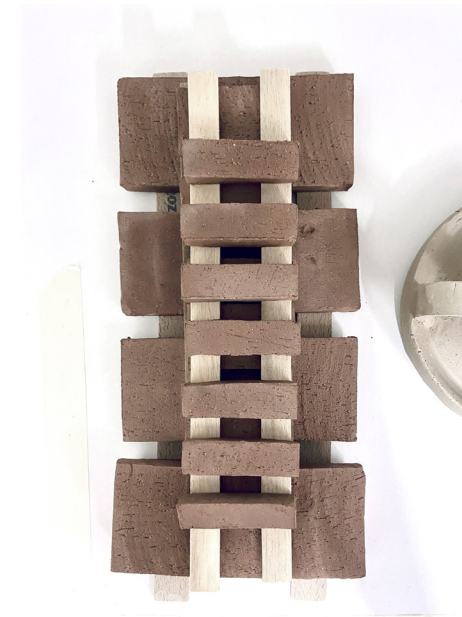
The key qualities I sought to learn from and preserve in relation to the site and its history were the use of honest, natural materials—namely

timber, straw, and brick—as well as a spatial organisation that allows daylight to flow through the social spaces across the entire building volume from north to south and an overall simple building volume.

The villa is conceived as a holiday residence for a family with two children.



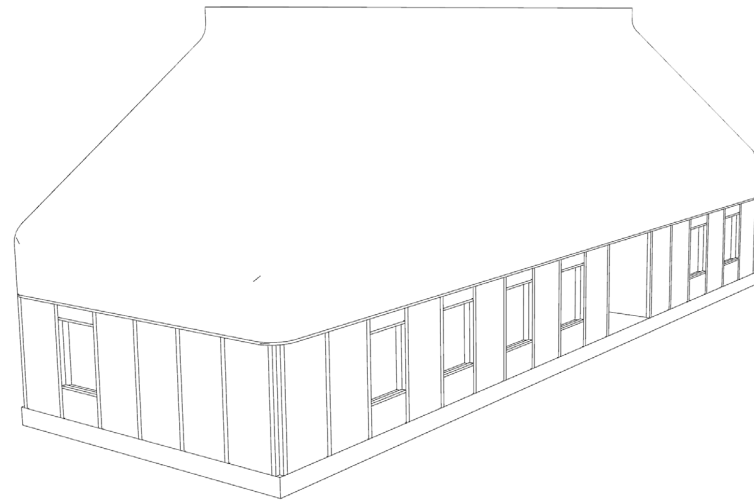
Façade sketches investigating the relationship between rhythm, the dimensions of the façade elements, timber-framing principles, and historical precedents.



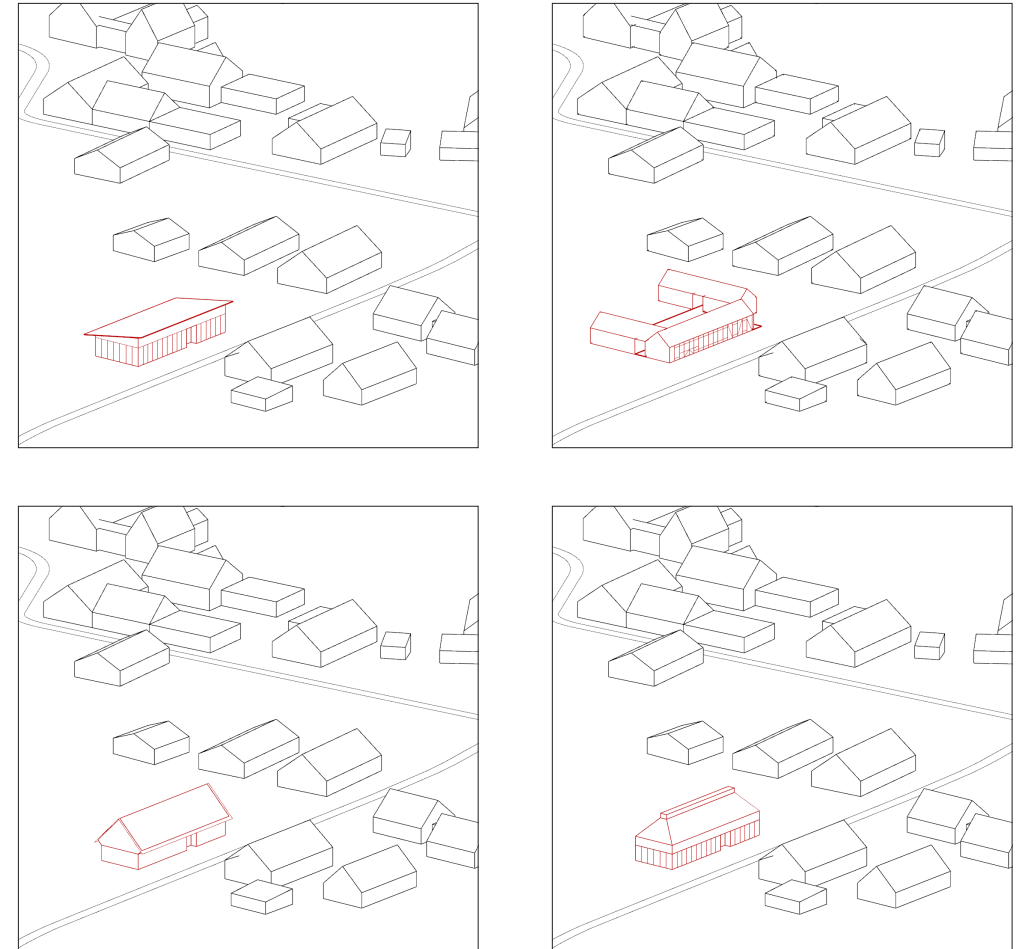
The tiles

As part of a ceramics course at Folkuniversitetet in Malmö, I rolled, fired, and glazed a series of stoneware tiles. These tiles were initially intended to serve as input images for the digital pattern-generation process. However, as the process was not fully automated, they were instead used to explore and visualise how a patterned façade might appear in an architectural context. The tiles functioned as a design and sketching tool throughout the development process and were subsequently incorporated into the final physical model.

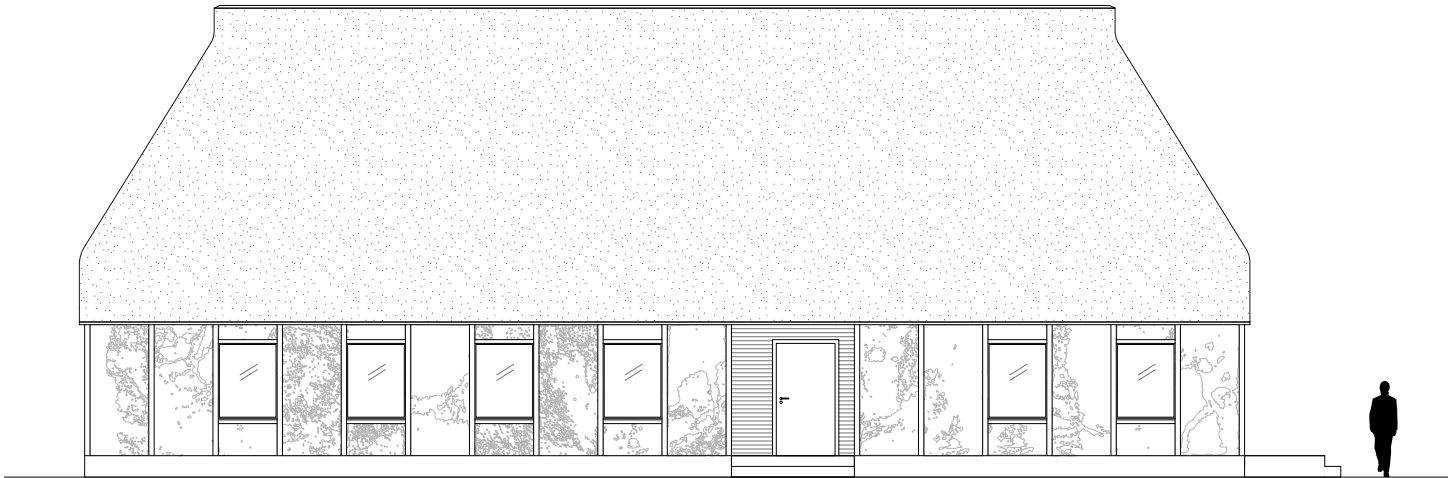
final volume



volume study



Different building volumes were tested within the context of the site.



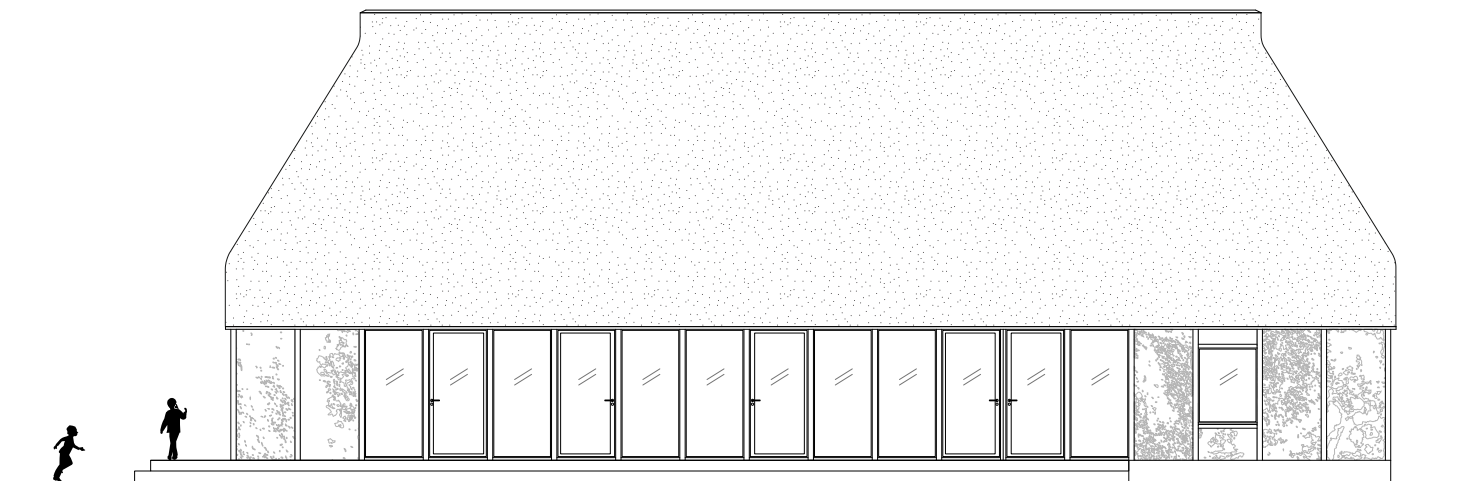
north facade



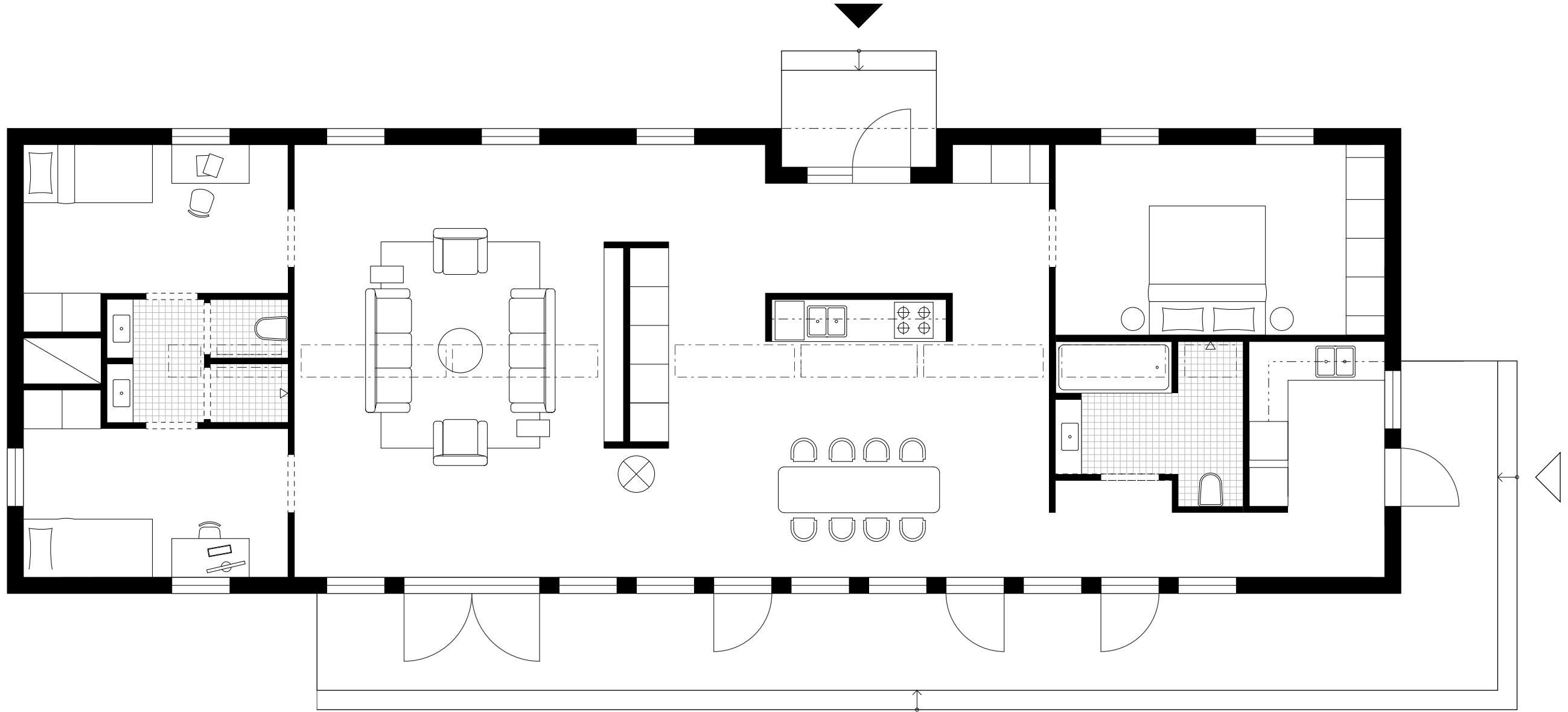
east facade



west facade



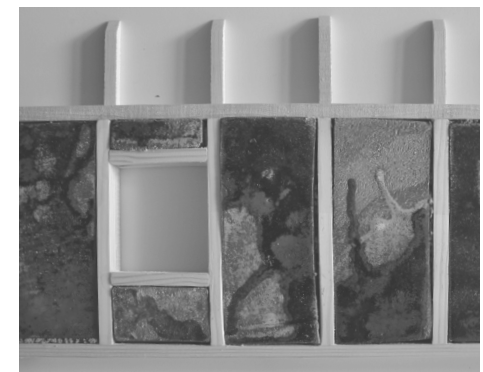
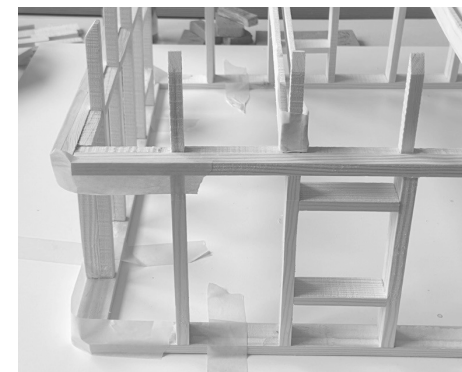
south facade





Physical model

The model was constructed as a timber post-and-beam structure, with the cast ceramic panels used as infill elements. The process required considerable reflection on assembly, structural relationships providing an understanding of load transfer and material behaviour.









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Candidates were required to submit both an AI poster and a video. I submitted a proposal presenting the basic concept of this thesis. To the left is the AI poster, inclu-

Trash is treasure

"Uniqueness is not corrected or accidental, but composed."

In my UTOPIA: NOW, waste does not exist. What we call trash is simply material without a system for its use. In this sense, trash is every man's treasure. Architecture, too, belongs to this cycle, temporary, transformed, and eventually discarded. In this sense, architecture is trash. So why not make trash architecture?

Today, reuse has become a necessity, shaped by the limits of our shared resources. Yet it often oscillates between two positions: the acceptance of the accidental patchwork, or the imposition of uniformity, forcing reclaimed materials to imitate the new. Between these two options, another possibility emerges. One where uniqueness is not corrected or accidental, but composed.

This utopia proposes a shift in priority: from control to accommodation, from standardization to recognition. Every element, cracked, uneven, discolored, is not a problem to solve, but a value to work with.

Emerging digital tools make this possible, freeing us from the bounds of standardization that have held society in a firm grip over the last century.

One possible application of this approach is presented here. Unsorted bricks in mixed conditions are gathered from recycling facilities across Denmark. They become intricate patterned facade elements, where each piece contributes with its own character. The bricks are sorted robotically using 3D scanning, RGB data, and machine learning into categories of color and size. Some are crushed into aggregates of 0–8 mm and 4–16 mm, also sorted by color. An in-

put image is fed into Grasshopper, where an image tracer translates it into data. The script maps this data onto the categorized bricks, placing the largest elements first and filling in with smaller ones. The result is a coded arrangement executed through robotic fabrication, casting patterned infill masonry elements.

The input image is completely free for artistic expression. It defines a direction, a desire, a gesture. The system interprets it. In that translation, something shifts. Control is neither lost nor absolute. Abstraction becomes desirable. A dialogue between human intention and machine logic, producing abstrac-

tion, imperfection, and unexpected beauty. Architecture regains something it has partly lost. Not control, but expression.

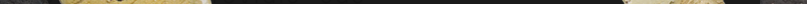
What emerges is a different kind of order. One that does not erase variation, but builds with it. Rooted in what is available, shaped by where it is, and open to interpretation. This is not a vision of the future. The tools needed to create this system already exist.

UTOPIA: NOW is not about new materials or distant futures. It is about learning to see what already exists, to refuse to waste it, and instead to treasure its individuality.

08. CONCLUSION

A collection of various colored and shaped fragments of ancient pottery or stone, including reddish-brown, yellowish, and dark grey pieces, scattered on a black background.

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 ignisimpos. en
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Discussion

This thesis began with a material reality: the accumulation of broken and irregular brick fragments within contemporary systems of demolition and reuse. What initially appeared as discarded material gradually revealed itself as an architectural resource carrying traces of previous construction, weathering, and use. Rather than treating this heterogeneity as a problem to be corrected, the project explored how computational design methods could organise variation into new architectural expressions rooted in reuse, locality, and material memory.

One recurring reflection throughout the process has been the extent to which digital tools inevitably shape architectural expression. In computational workflows, rules, parameters, and classification systems influence not only fabrication, but also the aesthetic language that emerges. This raises an important question: if contemporary digital systems are capable of handling far greater levels of complexity and variation than previous industrial methods, how should architects engage with these possibilities, and where does human intention remain within increasingly system-driven processes?

Historically, irregularities in craft were often understood as traces of human presence and local material conditions. During the twentieth century, however, industrialisation and standardisation gradually reduced much of this variation in favour of efficiency, repetition, and predictability. Within this context, the digital tools explored in this thesis are not understood as replacements for traditional craft, but rather as possible means of reintroducing expression, variation, and material individuality into contemporary architectural production.

At the same time, the project has highlighted a tension between control and openness. The more precisely a system is defined, the greater the risk that architectural expression becomes constrained by the logic of the tool itself. The challenge therefore lies not only in exploring what digital technologies are capable of producing, but also in questioning why these systems should be used and what kind of architectural qualities they support.

The role of the architect consequently shifts from designing completely fixed outcomes toward

designing relationships, rules, and conditions through which variation can emerge. In this sense, computation becomes less about achieving perfection and more about enabling negotiation between human intention, material irregularity, and machine logic.

What emerges is not a return to historical craft, nor a celebration of technological control, but a hybrid condition in which imperfection, ambiguity, and material memory remain active parts of architectural expression.

Further research

This thesis should be understood as an exploratory framework rather than a finished proposal, and several aspects would benefit from further development.

A key direction is robotic fabrication. While the workflow was developed digitally, future research could focus on full-scale testing to understand how irregular brick fragments behave in real robotic processes. This includes challenges related to handling, positioning, tolerances, and sequencing in physical assembly.

The pattern generation system

also offers further potential. A fully automated setup in grasshopper would allow the testing of different input images. Along with variations in the proportion of size and colour categories based on material availability, could be tested to study how these parameters influence the resulting architectural expression. This could also support a more adaptive system where material stock directly informs design outcomes.

Another area of interest is increasing the level of computational “intelligence” in the pattern generation process in terms of placement logic, moving beyond ran-

domness toward more relational or rule-based interactions between individual fragments.

Finally, the material research and physical prototyping could be expanded, particularly regarding binder composition. Further investigation into reducing or replacing the current 5-10% cement in the mix with more sustainable alternatives such as clay-based systems could significantly impact the environmental performance of the material system.

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