WHAT MATTERs

REUSING DEBRIS TO REBUILD COMMUNITY

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Architecture graduation report
MSc Graduation Studio Extreme Architecture AR4EA010

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PREFACE

This graduation report was produced as part of the graduation project at the Faculty of Architecture and the Built Environment at TU Delft, within the Extreme Architecture studio, during the academic year 2025–2026.

I would like to thank my graduation studio mentor, Job Schroën for his guidance throughout the design process and for the inspiring studio excursion to London. His enthusiasm, dedication, and passion for architecture have been a great source of inspiration throughout this project. I also would like to thank my research mentor, Alessandra Navarro, for her critical feedback and guidance during the project. Her support helped me to sharpen the research questions and deepen my understanding of the relationship between climate, construction, and architectural design.

Finally, I would like to thank the people close to me for their support, patience, and encouragement throughout this process.

Because I am dyslexic, I used AI tools for language editing and translation support to check grammar and phrasing. All ideas, reflections, design decisions, and content were developed by me and carefully reviewed before submission.

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READING GUIDE

This graduation report is supported by an accompanying research paper that examines gabion-based building envelope systems (appendix B), climate-responsive performance criteria, and post-conflict construction debris in Homs. The research paper provides the analytical framework for this graduation project.

This report builds upon those findings and translates them into a broader architectural proposal. Analytical results are not repeated in full, but are selectively referenced where they inform key design decisions, the development of the building system, and the final architectural design.

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CONTENT

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INTRODUCTION

This chapter introduces the project by outlining the post-conflict context of Homs, the architectural relevance of reusing construction debris, and the design questions that guide the graduation project. It also defines the scope of the project and its position in relation to the accompanying research paper.

PROBLEM STATEMENT

UN-Habitat (2022a) identifies Homs as one of the Syrian cities most severely affected by the conflict. A large share of the housing stock is moderately or severely damaged, resulting in widespread partial inhabitation rather than complete abandonment of residential areas. The same report notes that debris is still present and continues to affect everyday life, causing difficulties related to accessibility, safety, and general living conditions.

Rubble is not only a spatial obstacle but also a material condition associated with risk. Zwijnenburg and te Pas (2015) describe that construction leftovers are often mixed with household and medical waste and may contain materials such as asbestos, which are harmful to health. As a result, rubble is primarily addressed as a hazard that requires removal rather than as a potential construction resource. In practice, post-conflict debris is primarily treated as waste to be cleared and dumped, rather than being reintegrated as a resource into local reconstruction processes (UN-Habitat, 2022b).

Furthermore, Syria is characterised by hot, dry summers combined with limited annual precipitation (Naaouf & Torma, 2023). As Okba (2005) explains, the building envelope is the layer that connects inside and outside, which is particularly relevant in hot and dry climates. Post-conflict debris management approaches primarily focus on clearance, sorting, and centralised recycling. Kallab and Kaskas (2024) describe step-by-step approaches centred on risk prevention and industrial reuse, while architectural reuse is not explicitly addressed within these policy frameworks. This creates a gap between rubble clearance as a logistical practice and the architectural question of how inhabitation can be supported under ongoing material and climatic constraints.

For the research phase of this project, gabion systems were used as a focused point of departure. Gabions consist of wire cages filled with stone and are primarily applied in infrastructural contexts, where their mass, porosity, and relatively simple assembly are valued (Uray, 2022). Within this project, these characteristics made them relevant as a research lens for exploring whether post-conflict debris could be engaged architecturally at the scale of the building envelope. The project does not treat gabions as a final solution in themselves; rather, the insights gained through this research are translated into a broader architectural investigation of how debris can be transformed into a climate-responsive building system in Homs.

Figure 1 Crisis Impacts in Homs Old city
Note. From "From Homs city urban recovery profile 2022" by UN-Habitat (2022).

RELEVANCE & MOTIVATION

The relevance of this graduation project lies in its architectural positioning within existing post-conflict recovery approaches. While construction debris in post-conflict situations has often been examined in terms of clearance, material recycling, and engineering-based reuse options, these studies have primarily addressed debris at the technical or policy level. Architectural engagement with construction debris as a design material, particularly at the scale of building envelope systems, remains limited.

This gap limits architectural understanding of how building envelopes can respond to simultaneous material constraints and climatic demands in post-conflict settings. In hot and dry climates, where building performance is strongly shaped by envelope design, gabion-based systems form a relevant point of departure for examining how material reuse can be aligned with climate-responsive architecture.

At the same time, post-conflict rebuilding extends beyond technical and material concerns alone. It is also a spatial and social process. This project moves beyond the question of architectural material reuse by examining how design can also support rebuilding processes, learning, and local participation. Its relevance lies not only in reconsidering debris as a climate-responsive building resource, but also in exploring how its transformation into a building system can support both spatial reconstruction and community rebuilding in Homs.

The objective of this graduation report is to explore how selected, non-hazardous construction debris can be transformed into a building system within an architectural proposal for post-conflict Homs. In this report and the accompanying research paper, the term climate-responsive refers to an analytical focus on the relationship between architecture, material, and climate, without implying proven or quantified performance. Rather than approaching debris primarily as a waste management or engineering challenge, the report positions it as a material condition relevant to architectural design at the building scale.

This graduation project is driven by conditions in post-conflict environments where a hot and dry climate, demands on building performance, and large quantities of construction debris coexist. These conditions call for architectural approaches that address material availability, climate, construction, and processes of rebuilding in relation to one another. As a result, the project adopts a design-oriented research approach, in which the architectural programme, climatic response, and building system are developed in relation to each other. The goal is not to provide a final solution, but to explore how debris can support both spatial reconstruction and community rebuilding in Homs.

THE DEBRIS OF HOMS EQUALS 25 YEARS OF A CITY'S WASTE.

(UN-Habitat, 2022b)

DESIGN AND RESEARCH QUESTIONS & SCOPE

This graduation report is guided by the following main design question:
'How can post-conflict debris be transformed into a building system that supports climate-responsive architecture and community rebuilding in Homs?'

The graduation report addresses this question through three sub-questions:
DQ1. What kind of architectural programme can support rebuilding processes in post-conflict Homs?
DQ2. How can this programme respond to the climatic, cultural, and spatial conditions of Homs?
DQ3. How can post-conflict debris be transformed into a building system that supports this architectural response, both materially and structurally?

These questions guide the design research and translate analytical insights into spatial and material design decisions.
The paper addressed the following research question:
How can construction debris be reused as climate-responsive gabion-based building envelope systems in Homs?

This research question was explored through three analytical sub-questions addressing the architectural use of gabion systems, envelope-scale climate-responsive performance, and the material conditions of post-conflict debris in Homs. The findings of the research paper inform the theoretical framework of the graduation project and provide the analytical basis for the architectural development of the design proposal.

This section defines the scope of the graduation project. This graduation project examines the post-conflict context of Homs, Syria, at the building scale, with a specific focus on how selected, non-hazardous construction debris can be applied within an architectural building system, within a programme aimed at supporting rebuilding processes through making and learning. The scope is restricted to the architectural scale of the building and its material and climatic response, where material selection, climatic performance, and habitation are most closely related. The project focuses only on selected non-hazardous construction debris that can be safely reused. It does not address the identification, removal, or treatment of hazardous substances. Asbestos-related constraints are discussed separately in the appendix to clarify this boundary, but they do not form part of the architectural investigation. The research focuses on climate-adaptive principles suitable for hot and arid climates and investigates their application in architectural design.

Questions related to large-scale urban reconstruction, debris management, and broader economic or policy frameworks fall outside the scope of this project. Simulations, measurements, and optimisation studies are also excluded. Climate-responsive performance is addressed qualitatively rather than quantitatively. The project does not aim to produce a universally applicable solution, but develops a design-oriented architectural proposal for the context of Homs. Hazardous materials, including asbestos, are acknowledged only as a boundary condition and are addressed separately in the appendix C.

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APPROACH

This chapter explains the methodological approach of the graduation project. It outlines how research and design were developed in parallel, how the research paper informed the project, and which methods, tools, and theoretical foundations guided the design process.

DESIGN-RESEARCH STRATEGY & PLANNING

This graduation project adopts a design-oriented architectural research approach in which research and design are developed in parallel and inform one another throughout the project. Rather than separating analysis and design into distinct phases, analytical insights are used as active input for spatial and material design decisions at the building scale.

The graduation project builds directly on the research paper that forms part of this graduation project. That paper examined gabion-based envelope systems, climate-responsive performance criteria for hot–dry climates, and the material conditions of post-conflict construction debris in Homs. In the graduation report, these findings are not repeated in full, but function as a conceptual and theoretical framework that guides the subsequent design exploration.

Design development proceeds through parallel and sequential studies in which programme, climatic response, and building system are developed in relation to one another. While the material and climatic logic of the building system functions as a primary architectural basis, spatial organisation and programmatic requirements are continuously tested in relation to it. This is seen in material, climatic, and spatial studies that interact repeatedly to evaluate spatial connection, climatic exposure, and architectural consistency.

The project's research tools include sketches, schematics, moodboards, and physical models. Physical models at the material and façade scale are used to investigate various material configurations, including differences in stone size, packing density, layering, and thickness. These studies are exploratory and focus on spatial, material, and atmospheric qualities. Material studies are conducted using actual brick and concrete debris. By fragmenting masonry and concrete elements, the project investigates how heterogeneous debris behaves within different assemblies and how material openness, thickness, and porosity can be modulated. Climatic considerations are addressed through climate analysis, precedent research, and conceptual studies of sun paths and prevailing wind directions, without the use of simulations or optimisation tools. These observations inform the positioning and differentiation of architectural responses rather than determining a single optimal solution.

The graduation project is structured across four assessment moments (A1–A4), in which research and design develop in parallel. Analytical research outcomes from the research paper are gradually translated into design principles, material studies, and spatial design decisions, as illustrated in Figure 3. The research paper was developed during the first phase of the graduation project and was brought to a working conclusion around A2. From A2 onwards, its findings were translated into design criteria, programme development, and architectural design decisions. As the project approaches A3, the focus shifts towards spatial integration, building-system development, and the consolidation of the design proposal.

Planning graduation project

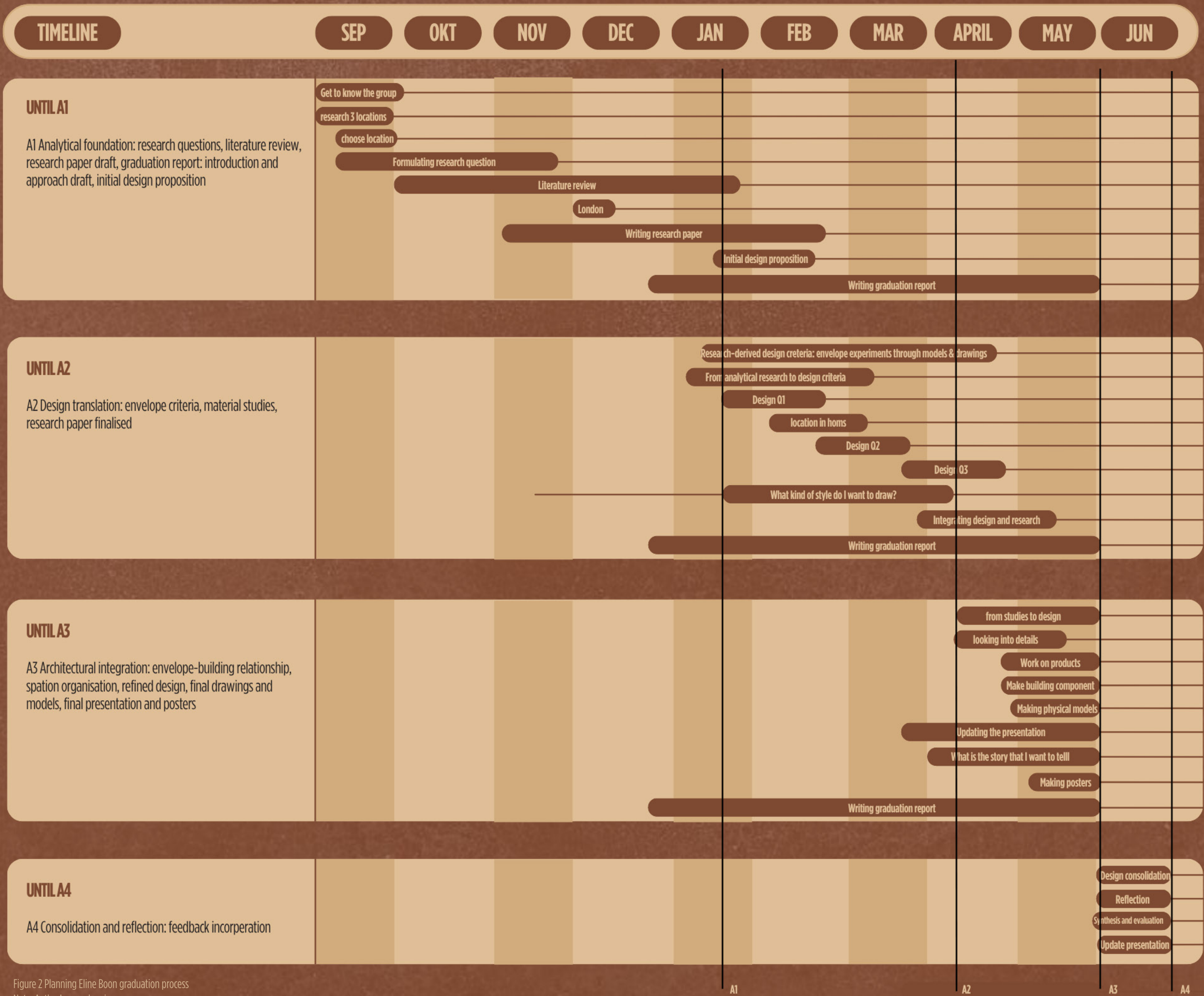


Figure 2 Planning Eline Boon graduation process
Note. Author's own drawing.

THEORETICAL FRAMEWORK

This section draws on the theoretical framework established in the accompanying research paper. Rather than repeating the research in full, it uses its findings as a theoretical point of departure for the graduation project. Figure 3 situates the project within the urban context of Homs, indicating the distribution of neighbourhoods affected by conflict-related damage.

Architectural construction logic of gabions

Gabion systems consist of modular wire cages filled with stone or mineral fragments and are traditionally applied in infrastructural contexts, where they are used for erosion control and structural stability (Shabanova et al., 2024; Uray, 2022). The material and mesh configuration of a typical gabion basket is illustrated in Figure 4.

The research identified two primary architectural configurations: load-bearing systems and non-loadbearing systems. Load-bearing envelopes rely on monolithic stacking and interlocking connections to ensure global stability, although such systems are generally restricted to low-rise applications (Samayoa et al., 2018). Representative load-bearing architectural configurations are illustrated in Figure 5.

In contrast, non-loadbearing envelopes are structurally decoupled from the building's primary frame (Fortier et al., n.d.). This separation allows the gabion layer to function independently of structural stability requirements, making variations in material porosity, packing density, and thickness possible that would be less suitable in load-bearing applications. The relationship between the primary structural frame and the gabion envelope is illustrated in Figure 6. These two configurations imply fundamentally different envelope logics.

In load-bearing applications, the gabion wall acts as a porous gravity structure, deriving stability from mass and friction rather than tensile strength. As a result, such systems remain limited in height and do not function as closed climate envelopes in their standard form. Additional enclosure layers are therefore required to achieve weather-tightness.

In non-loadbearing applications, the gabion envelope operates as a permeable outer layer positioned in front of a separate weather-tight inner envelope. This configuration allows air, moisture, and light to pass through the stone-filled cage, while climatic control is ensured by the inner envelope (see Figure 6). The distinction between these two systems directly informs how gabion-based envelopes can be understood architecturally and integrated within a broader building strategy.

Within the graduation project, these findings are not treated as a final solution in themselves, but as a theoretical basis for the development of a broader architectural building system.

Figure 3 The targeted Neighborhoods in Homs
Note. From *From Homs city urban recovery profile 2022* by UN-Habitat (2022).

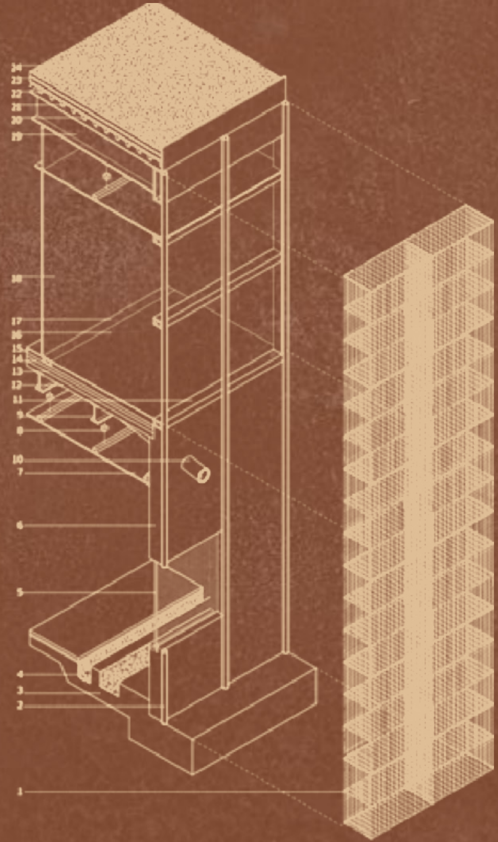


Figure 6 Non-loadbearing gabion façade detached from primary structural frame.
Note. Diagram from "R | Dominus Winery Herzog & De Meuron | Archisinthesection," retrieved from https://sglarchbezalel.wixsite.com/archisinthesection/dominuswinery

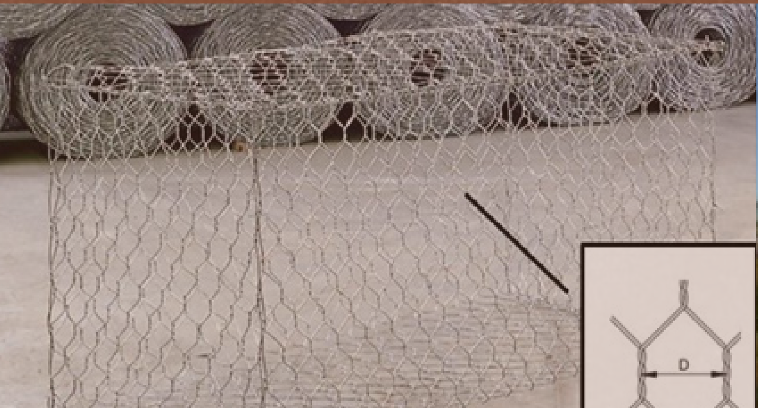


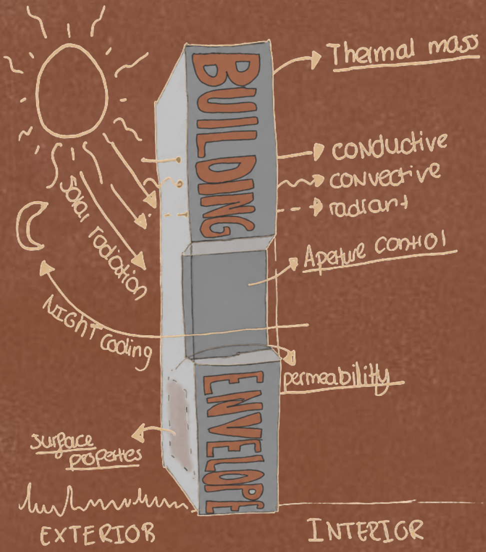
Figure 4 Gabion basket
Note. From *Gabion structures and retaining walls design criteria* by E. Uray (2022).

Figure 5 Gabion-box wall construction in architectural applications.
Note. From "Seismic Behavior of One-Storey Gabion-Box Walls Buildings" by J. Samayoa et al. (2018),

THEORETICAL FRAMEWORK

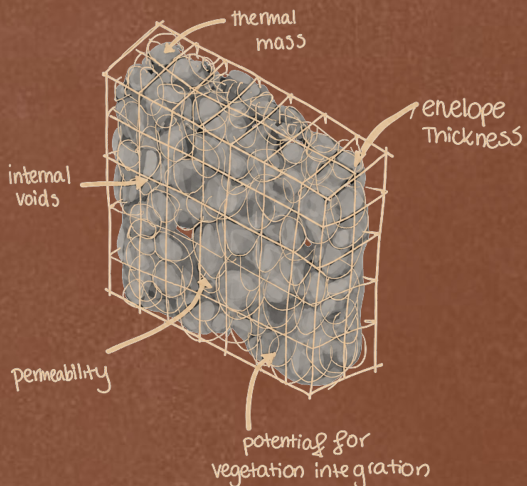
Climate-responsive performance criteria

In the hot and dry climate of Syria, the building envelope mediates severe thermal exchange through the control of conductive, convective, and radiant heat transfer (Naaouf & Torma, 2023; Okba, 2005). Three qualitative performance criteria were established: thermal regulation, solar control, and permeability (Okba, 2005; Elnabawi et al., 2024). These envelope-scale performance dimensions are schematically illustrated in Figure 7. Gabion assemblies respond to these through substantial material mass, with an apparent density often exceeding 17.5 kN/m3 (Shabanova et al., 2024). This mass provides a thermal buffer and temporal heat delay, while the porous internal structure enables air movement and heat dissipation (Okba, 2005; Samayoa et al., 2018). The material configuration and internal structure of a gabion-based envelope are illustrated in Figure 8 Furthermore, the internal structure may gradually consolidate over time, which may enable incidental vegetation integration as a secondary effect (Shabanova et al., 2024).



THERMAL REGULATION

Figure 7 Schematic representation of envelope-scale performance dimensions in hot–dry.
Note. Author's own drawing.



GABION QUALITIES

Figure 8 Schematic representation of material-related characteristics of a gabion-based envelope
Note. Author's own drawing.

SUN PROTECTION AND LIGHT PERFORATION

Figure 9 Envelope thickness and material openness in non-loadbearing gabion envelope configurations.
Note. Author's own drawing.

THEORETICAL FRAMEWORK

Alignment with construction debris in Homs

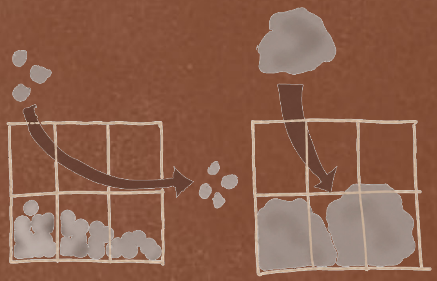
The residual debris inventory in Homs is dominated by reinforced concrete, plain concrete, and cement bricks (Zydia et al., n.d.). The quantitative composition of post-conflict construction debris in Homs is summarised in Table 1. The analytical alignment of these materials with gabion systems depends on fragment size, packing density, and resistance to degradation (UN-Habitat, 2022). To ensure retention, fragments must exceed the mesh opening by at least 1.3 times (Shabanova et al., 2024). Figure 10 schematically illustrates how fragment size and packing behaviour influence material retention within gabion assemblies. Large, angular concrete and masonry fragments show strong alignment with thermal mass and permeability requirements (Ghimire et al., 2024; Shabanova et al., 2024). In contrast, pulverised materials and fine particulates are less suitable, because they restrict permeability and do not exceed the required scale criteria (UN-Habitat, 2022). Finally, soluble inclusions, such as damaged mortar, have limited durability and may cause structural settling when exposed to moisture (Shabanova et al., 2024). Figure 11 schematically illustrates the relative alignment of debris materials with envelope-scale performance criteria.

Together, these theoretical findings provide the basis for translating post-conflict debris into an architectural building system that responds to both climatic conditions and rebuilding processes in Homs.

Building Material	Material inventory (Kg/m²)	Materila stok (ton)	Damaged (ton)
Plain concrete	365.89	16588499	1141425
Reinforced Concrete	457.49	20741459	1427182
Steel	27.33	1239092	85260
Cement Bricks	377.37	17108740	1177222
Mortar	64.95	2944446	202602
Clay	122.76	5565473	382950

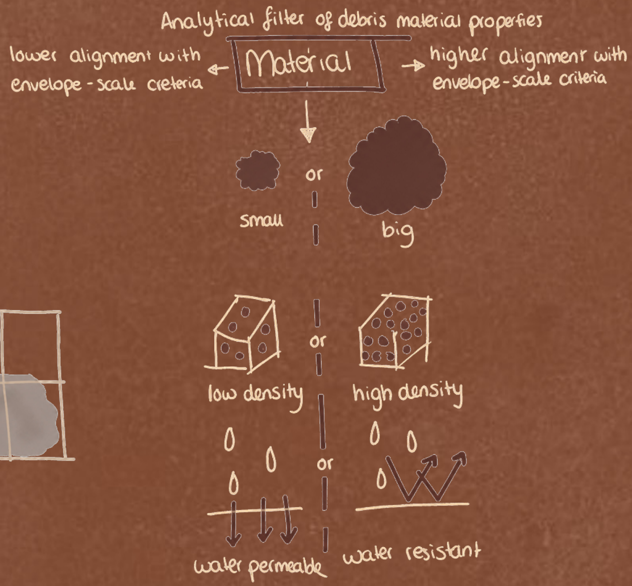
MATERIAL INVENTORY

Table 1
Material inventory, material stock and the damaged materials in Homs
Note. From "Material Inventory Analysis of Residential Buildings in Homs, Syria for Rehabilitation" by Zydia et al. (n.d.).



SIZE & RETENTION

Figure 10 Schematic representation of fragment size and packing behaviour in relation to gabion mesh retention.
Note. Author's own drawing.



ALIGNMENT

Figure 11 Analytical filter relating debris material properties to envelope-scale perfo
Note. Author's own drawing.

‘How can post-conflict debris be transformed into a building system that supports climate-responsive architecture and community rebuilding in Homs?’

06

RESULTS: ARCHITECTURAL SYNTHESIS

This chapter presents the results of the graduation project. It discusses how the different design decisions were developed and how they relate to the main design question and sub-questions. Rather than presenting the design as a fixed outcome, this chapter shows how programme, climate, material, and building system were gradually brought together in the design process.

DESIGN QUESTION: 1 PROGRAMME

To determine what kind of architectural programme could support rebuilding processes in post-conflict Homs, three early programme scenarios were explored. Each scenario tested a different relationship between return, recovery, and neighbourhood life, and examined how these social conditions could be translated into spatial organisation. Together, these studies clarified which programme direction most strongly connected material reuse, collective rebuilding, and architectural potential.

Scenario 01: Neighbourhood health post / clinic
The first scenario explored a neighbourhood health post or clinic as a response to the immediate physical and mental needs of returning residents. It investigated how care, privacy, protection, and neighbourhood presence could be translated architecturally through enclosed spaces, gradual thresholds, and protected outdoor areas. While this scenario addressed an urgent social need and introduced relevant spatial themes, it remained relatively closed and specialised in use. For that reason, it was not developed further as the main programme direction, although its spatial qualities informed later design decisions.

Scenario 02: Transitional housing / next-life housing
The second scenario explored transitional housing as a response to the need for temporary living space during rebuilding. This study examined how domestic life, collective use, and long-term neighbourhood recovery could be combined within a quickly buildable structure using local material conditions. It also tested how cultural references such as courtyards, liwan-like transitions, and semi-open thresholds could inform the spatial organisation. Although this scenario generated useful insights into privacy, collectivity, and shared outdoor space, it remained primarily focused on living rather than on making or rebuilding. Nevertheless, several spatial principles from this study were carried forward into the later design development.

Scenario 03: Debris envelope hub / cultural memory centre
The third scenario explored a programme centred on making, learning, collecting, and rebuilding. It tested the idea of a place where debris is not only remembered, but also transformed into a new architectural and social process. This study examined how making spaces, learning spaces, and public functions could be combined, and how the transformation of material could be made visible rather than concealed. Of the three scenarios, this one most strongly connected the project's material, architectural, and social ambitions. It therefore formed the basis for the final programme direction, offering the clearest link between debris reuse, climate-responsive architecture, and community rebuilding in Homs.

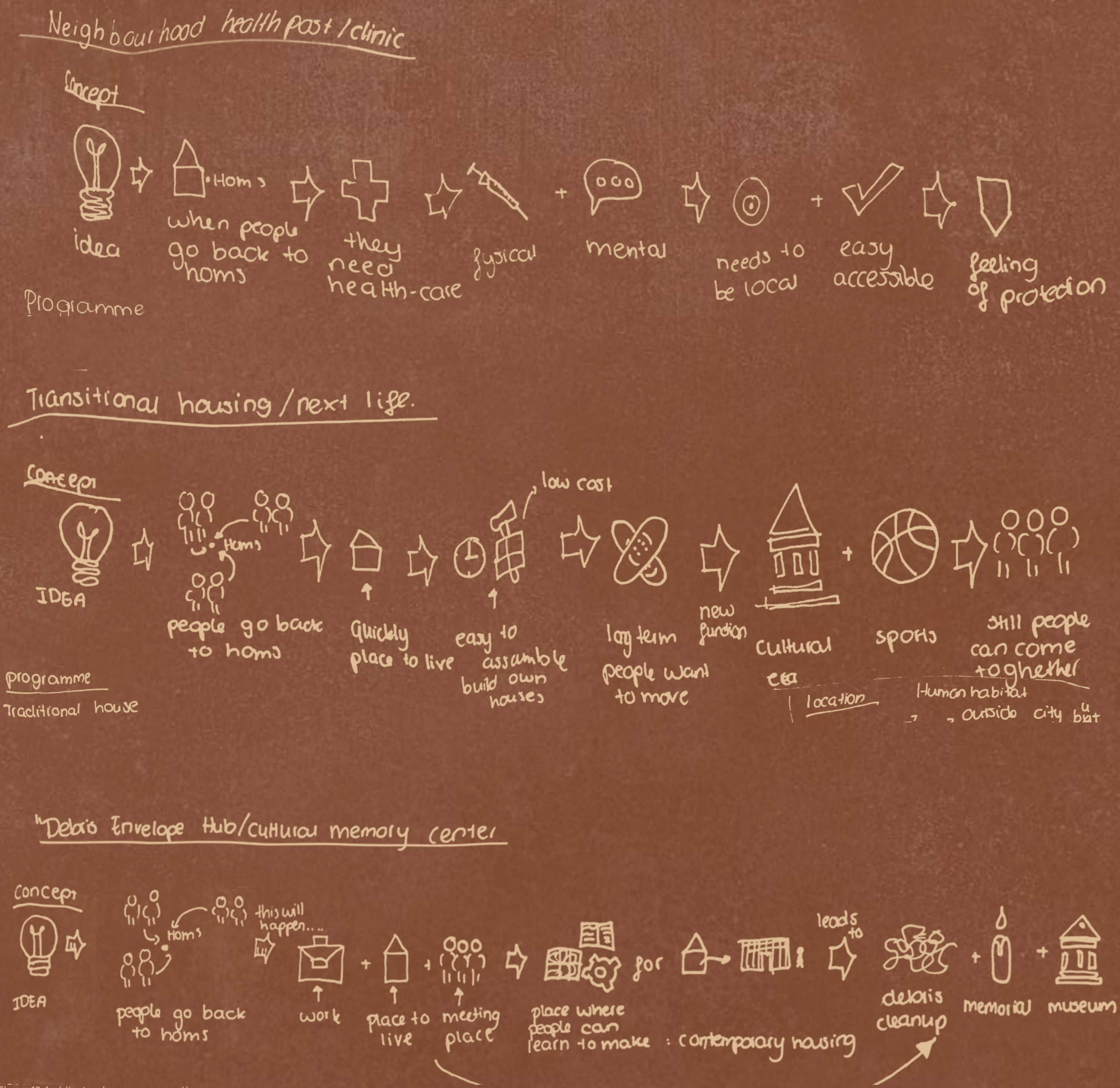


Figure 12 Architectural programme options
Note. Author's own drawing.

DESIGN QUESTION: 1

This programme direction was then developed further by relating debris reuse not only to construction, but also to broader rebuilding processes. The project links post-conflict debris not only to a material problem, but also to a social process of rebuilding. Reusing debris requires labour, knowledge, and local involvement, and therefore creates opportunities for skill development, participation, and ownership. Within this logic, the architectural question is no longer only how to build again, but what kind of space can support this process.

Within this project, the makerspace is understood as a place where debris becomes a driver for making, learning, and rebuilding. It is therefore not approached as a generic workshop model, but as a spatial framework that connects material transformation, skill development, and community participation.

Figure 13 Programme direction
Note. Author's own drawing.

DEBRIS -> PROCESS -> PEOPLE -> COMMUNITY

DESIGN QUESTION: 1

Within the project, the makerspace is organised around the process of producing gabion-based building elements. The programme therefore includes workspaces for mesh making and assembly, rubble sorting, filling and stacking, and the exploration of patterns and form. In this way, making is directly connected to material transformation, learning, and rebuilding.

Figure 14 workshop spaces
Note. Author’s own drawing.

DESIGN QUESTION: 1

The site was first selected because it is located in a heavily damaged part of Homs, where debris is directly available and rebuilding remains urgent. Its central and accessible position also supports its role as a public and neighbourhood-oriented programme. The plan by Humane Urbanism (2022) proposes a reconstruction strategy for this area, including the rebuilding of the school on the square and the introduction of a cultural facility. The project builds on this vision by introducing a makerspace that can connect to these proposed interventions and strengthen the social and educational role of the area. In this way, the site supports both the practical ambition of material reuse and the wider social role of rebuilding.

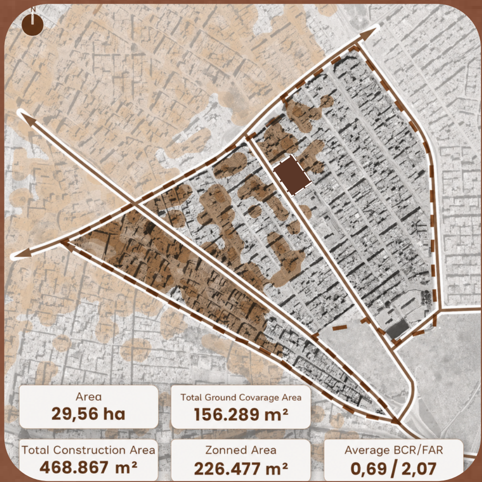


Figure 15 urban setting
Note. Adapted from Humane Urbanism (2022)

Figure 16 neighbourhood Karm Shamsham
Note. Adapted from Humane Urbanism (2022)

Figure 17 Karm Shamsham centre
Note. Adapted from Google Maps (z.d.)

MASS FORMATION

OPEN SPACE SYSTEM

FUNCTIONAL DISTRIBUTION

TRANSPORTATION SYSTEM

Figure 18 Site analysis
Note. Author's own drawing.

DESIGN QUESTION: 1

The concept is based on broken stone, where fragments are brought back together to create a connected architectural form with space in between.

This creates a spatial structure in which making, learning, and meeting can take place around a shared collective core. The form therefore does not only express fragmentation and reconstruction, but also supports accessibility, visibility, and interaction. In this way, the project relates to spatial principles that are relevant in the context of Homs, such as courtyard-like meeting spaces, bazaar-like passage, and layered thresholds between public, semi-public, and more private areas. These principles are not copied literally, but translated into a contemporary architectural form that supports both climate-responsive design and community rebuilding.

Figure 19 Concept drawing
Note. Author's own drawing.

SPATIAL ELEMENTS IN SYRIAN URBAN CULTURE

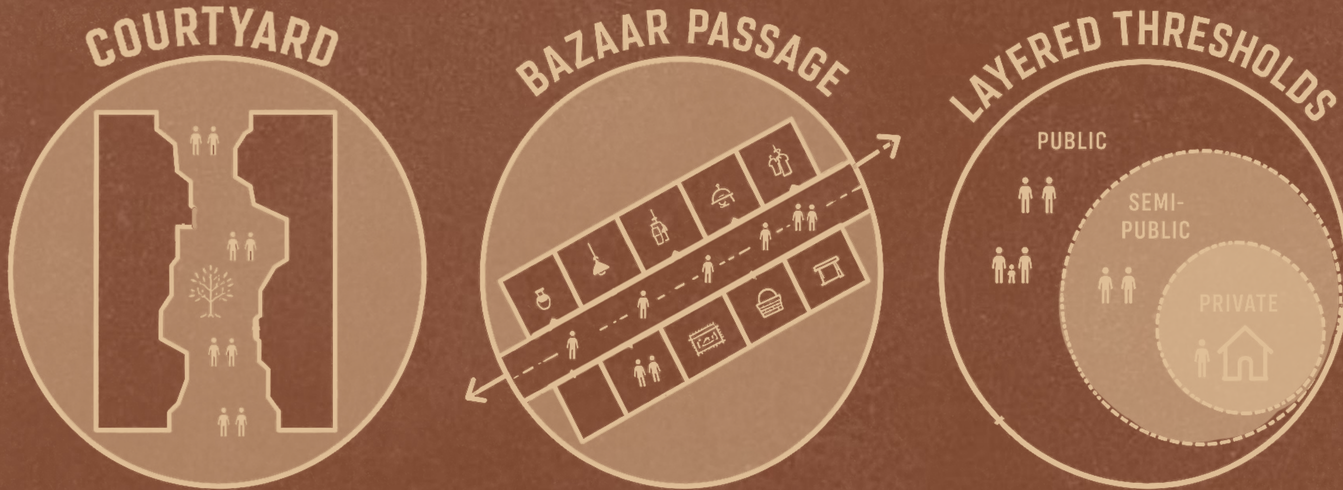


Figure 20 Concept drawing syria
Note. Author's own drawing.

DESIGN QUESTION: 2 CONDITIONS

To answer the second design question, the project investigates how the selected programme can respond to the climatic, cultural, and spatial conditions of Homs. Rather than treating these conditions separately, they are approached as interconnected design drivers that influence the building envelope, spatial organisation, and public character of the project.

The wind studies examined how air movement could be supported in a hot and dry climate through porosity, sectional openings, and a central airflow space.

The sun studies focused on solar exposure, shading, depth, and thermal buffering, leading to the use of overhangs, shaded thresholds, and protected exterior spaces.

The urban studies addressed access, visibility, and public presence, informing a more open building edge that engages the neighbourhood while balancing accessibility with protection and enclosure.

The cultural studies focused on courtyard logic, layered thresholds, and liwan-like transitions. Rather than being copied literally, these references were translated into a contemporary architectural language that supports both privacy and collective use. Together, these studies informed the project's climatic, spatial, and social design logic.

Figure 21 Extreme scenarios
Note. Author's own drawing.

DESIGN QUESTION: 3
DEBRIS IN BUILDING

Building on the accompanying research paper, the project first explored gabion systems through physical model studies in order to investigate how debris could be used architecturally. These studies compared debris as raw material, gabion infill, and both non-loadbearing and loadbearing applications. The comparison showed that non-loadbearing systems offer greater flexibility in porosity, depth, and material composition, while also functioning effectively as a climate buffer. This became an important design decision, as it allowed the gabion layer to act as a self-supporting outer envelope rather than as the project's primary structural system.

Figure 22 physical model 1
Note. Author's own drawing.

DESIGN QUESTION: 3

To understand how gabion-based construction could be developed beyond flat enclosure, the project also explored how openings and arches could be assembled within the system. This sequence shows how mesh, support, filling, and stabilisation work together to create a buildable arched element. The arch was not only studied as a construction problem, but also as an architectural one, since arched openings are widely present in Syrian architecture and often associated with public and collective buildings. In this way, the study tested how a culturally familiar element could be reinterpreted within the material logic of the project.

Figure 23 Assembly of the arches
Note. Author's own drawing.

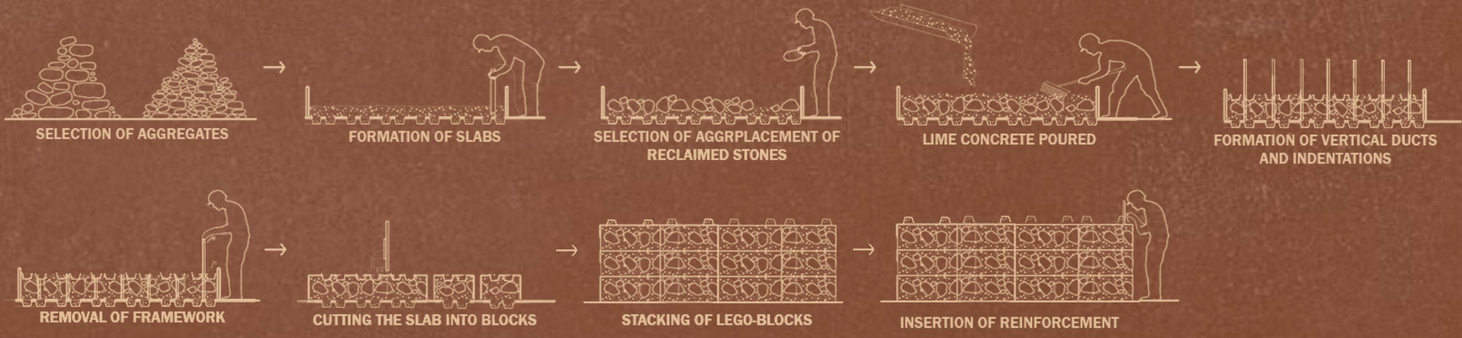
DESIGN QUESTION: 3

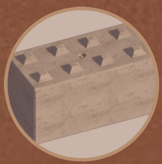
A reference project by HARQUITECTES (n.d.) was studied to understand how demolition material can be integrated into an architectural construction system. It showed how reused material can move from a raw condition to an applied building logic in which construction, spatial organisation, and architectural expression are developed together. For this graduation project, the reference was not adopted directly, but used to clarify how debris could be translated into a broader and more buildable architectural system.

Figure 24 Social housing 2104
Note. From HARQUITECTES (n.d.).

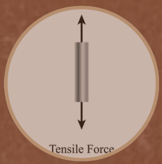
DESIGN QUESTION: 3

The project then translated this logic into its own architectural system by developing a more modular and adaptable construction method. In this proposal, debris is combined with concrete in a block-based system that allows for greater precision, repetition, and structural control. The interlocking “lego block” logic also supports disassembly and potential reuse, while FRP reinforcement improves the structural reliability of the system in a seismically active region.

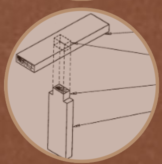




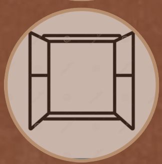
Interlocking block geometry to improve mechanical stability



Vertical FRP reinforcement for tensile strength



FRP anchored in foundation and top ring beam



Reinforcement placed at corners, openings, and ±1m intervals

Figure 25 Assembly of lego blocks + FRP bars
Note. Author's own drawing.

DESIGN QUESTION: 3

Together with my fellow student Laura, I developed a prototype of the blocks shown in the images. This prototype was used to test the material behaviour, assembly logic, and spatial expression of the proposed system.

Figure 26 physical model
Note. Author's own drawing.

ARCHITECTURAL SYNTHESIS OF THE PROJECT

The following drawings present the architectural synthesis of the project. They show how my design principles, developed from the design questions, have been further translated into the final proposal. These principles, such as debris as a building system, making as a public process, climate as a form driver, the courtyard, layered thresholds, and a heavy base with a lighter upper layer, are brought together here as architectural decisions. Together, the drawings show how programme, material, climate, and site strategy come together in one spatial proposal for a makerspace and rebuilding hub in Homs.

Figure 27 Render
Note. Author's own drawing.

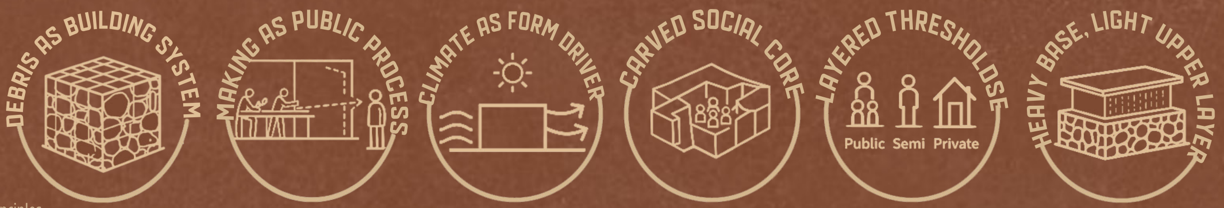


Figure 28 Design principles
Note. Author's own drawing.

FLOORPLAN 1:100 (SCALED)

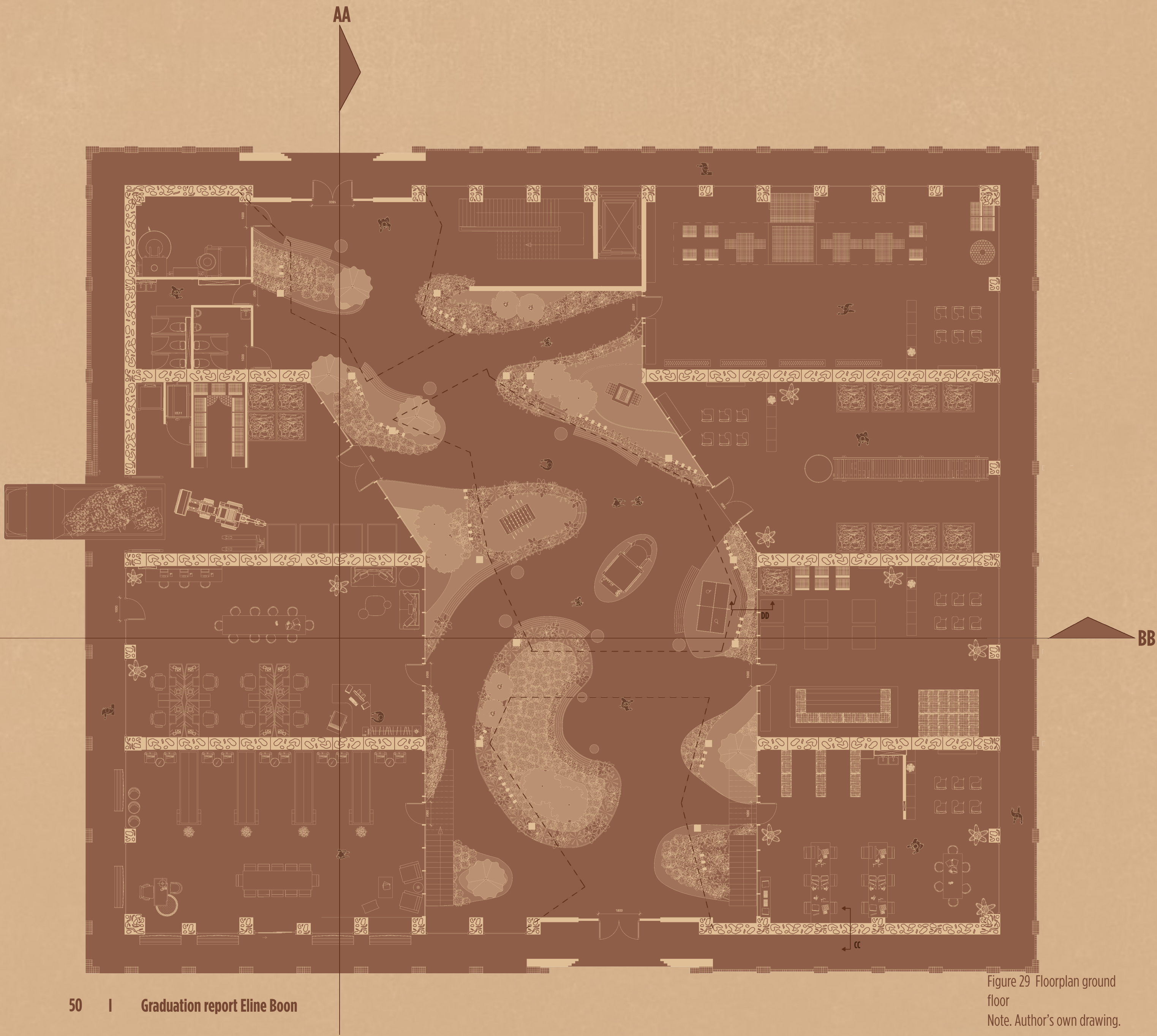
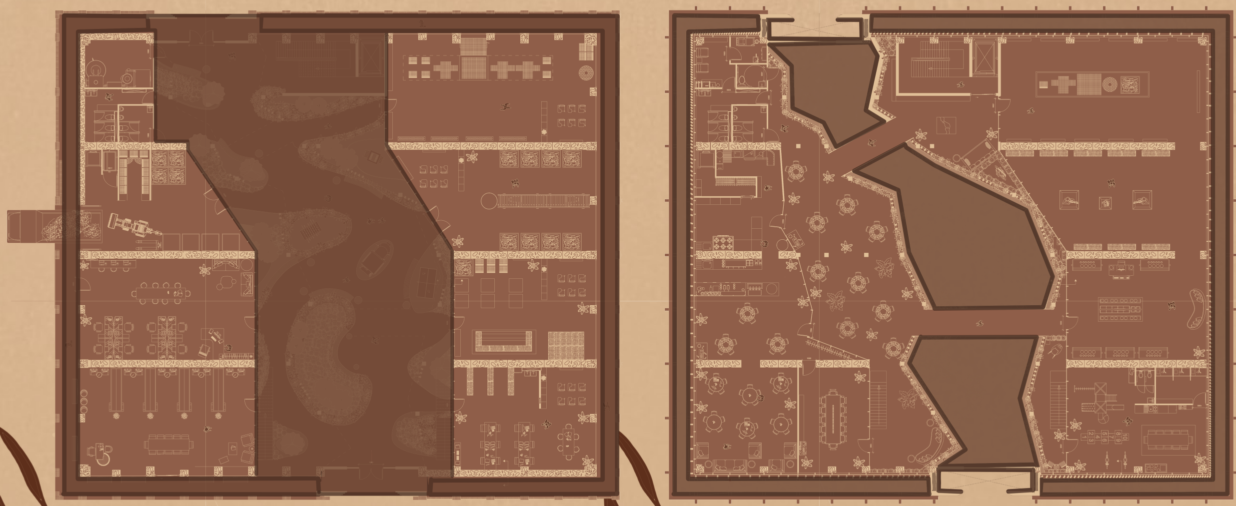


Figure 29 Floorplan ground floor
Note. Author's own drawing.

Figure 30 Floorplan first floor
Note. Author's own drawing.

FLOORPLAN DIAGRAMS

S H A D O W



W I N D & S U N

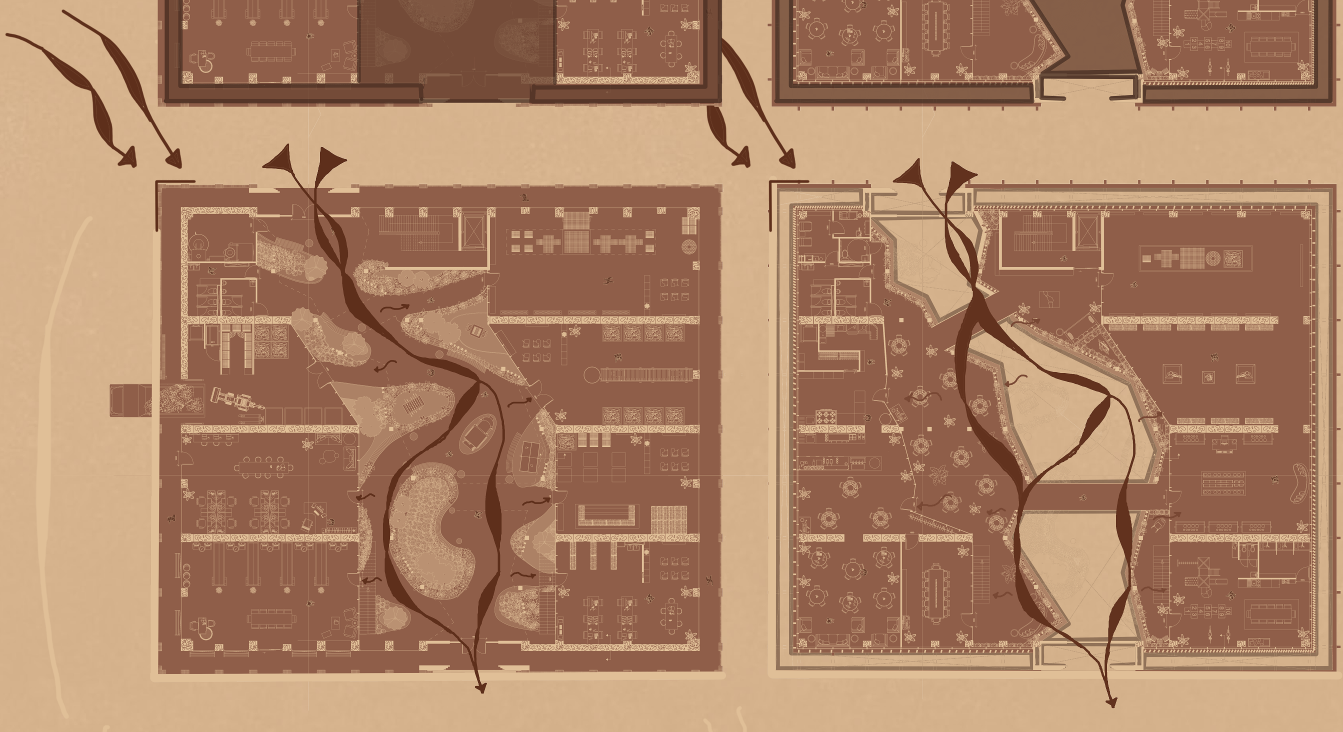


Figure 31 Floorplan diagrams shadow and wind & sun
Note. Author's own drawing.

Description:

The floorplan diagrams show how movement and climate become part of the spatial experience. The route moves through, around, and above the building, allowing visitors to see the process of making while connecting the different programme zones. At the same time, the building forms a canyon-like space that guides wind through the project and creates shaded areas through overhangs and horizontal elements. In this way, circulation, making, learning, viewing, and climate are brought together within one spatial strategy.

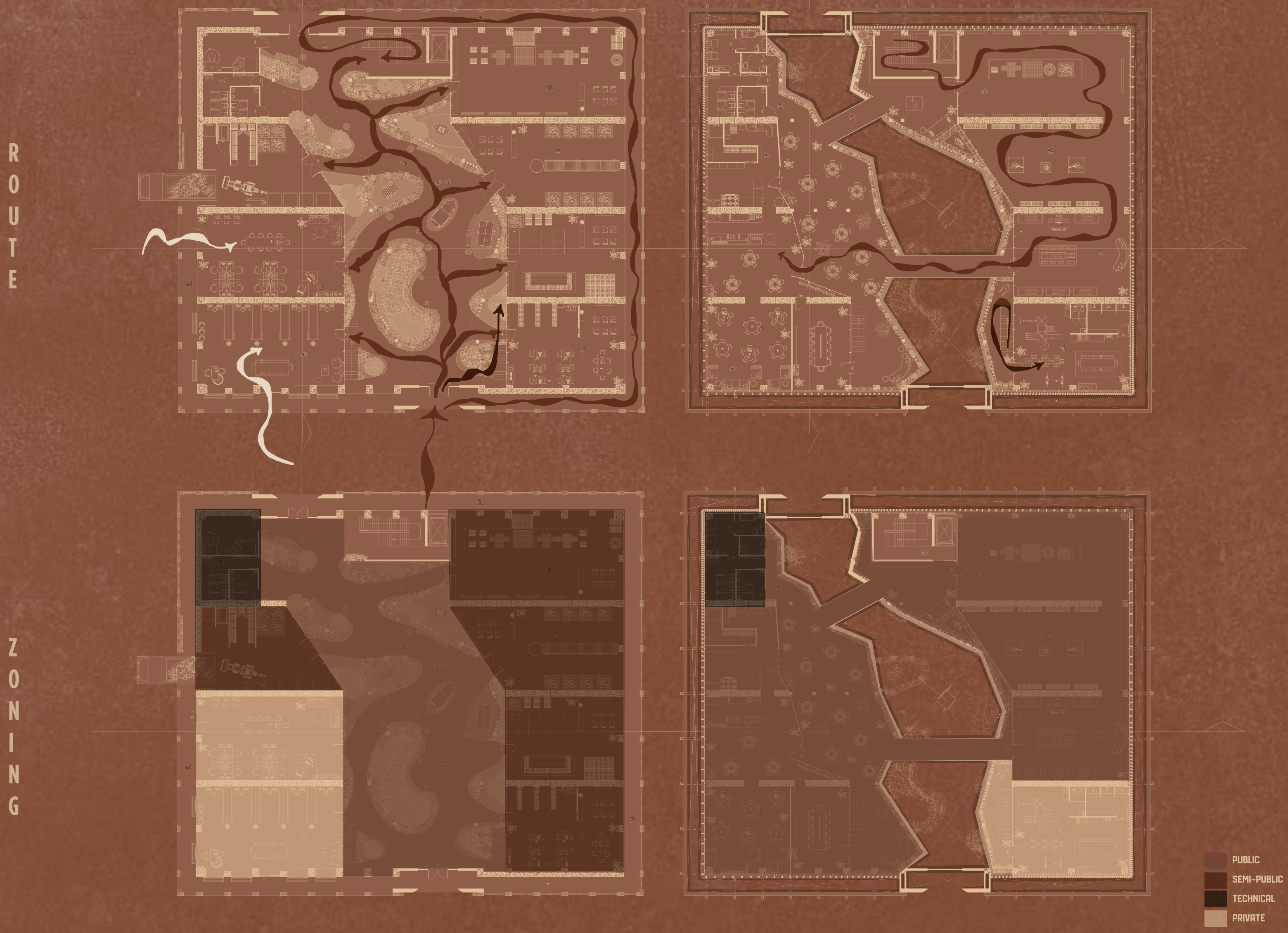


Figure 32 Floorplan diagrams route and zoning
Note. Author's own drawing.

FLOORPLAN 1:100 (SCALED)

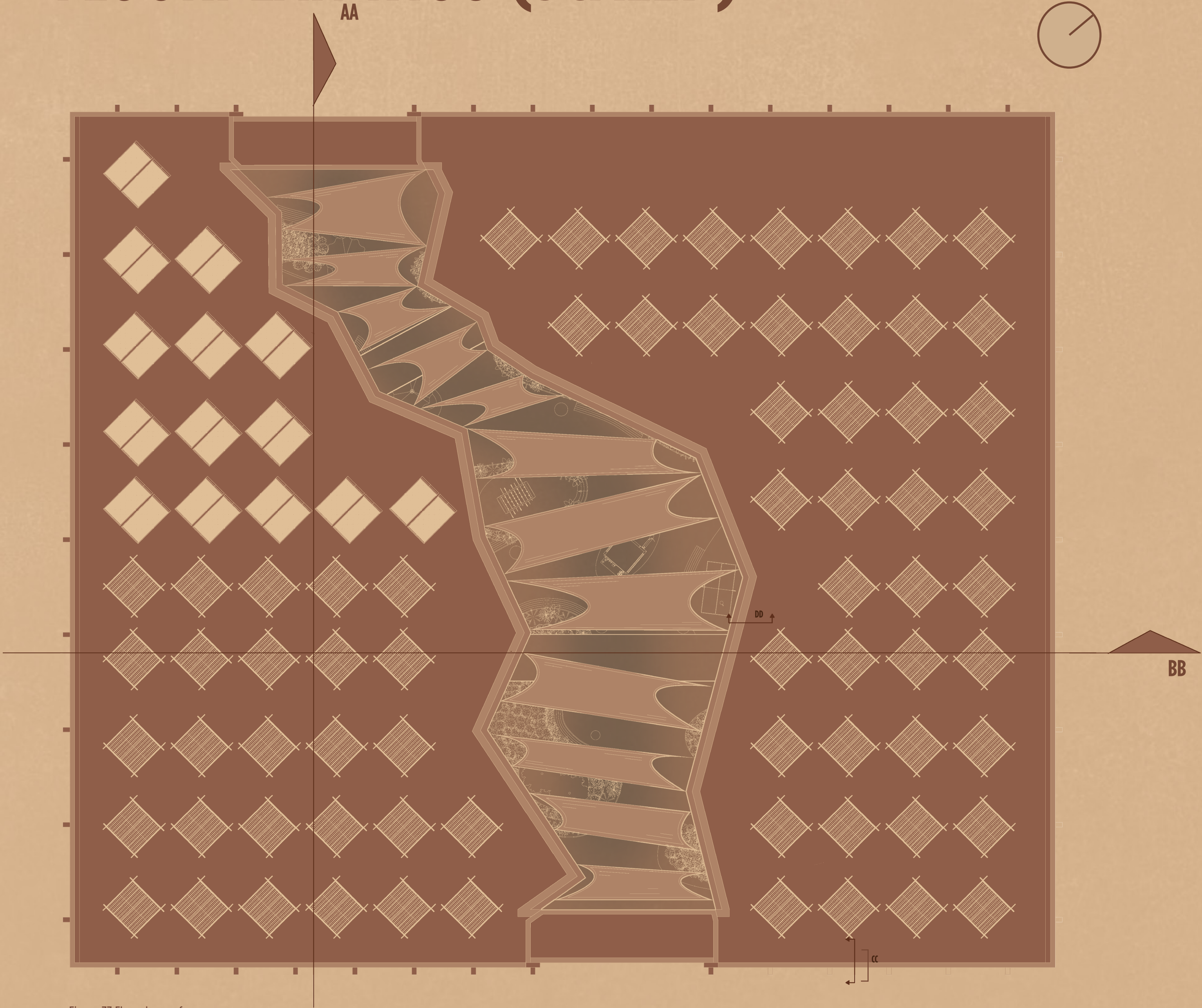


Figure 33 Floorplan roof
Note. Author's own drawing.

URBAN PLAN 1:500 (SCALED)

Figure 34 in the site
Note. Author's own drawing.

Description:

The roof plan illustrates how active and passive climate strategies are integrated into the architectural design. Solar panels are placed on the south-facing roof surfaces, and solar water heating near the technical room supports the floor heating system. The fabric shading elements add shade to the canyon and improve outdoor comfort. In the urban plan, the school is connected to the project through a green zone, creating a clear link between learning, making, and community life..

SITE LEGEND 1:500
01 EMPLOYEE PARKING
02 GREEN ZONE WITH SCULPTURES
03 AMPHITHEATRE
04 MAINTENANCE ZONE / GARBAGE
05 VEGETATION ZONE FOR CAFÉ
06 SHADED AREA TO READ BOOK
07 PICNIC ZONE
08 PARKING VISITORS
09 SHADED AREA WITH PLAY ELEMENTS AND LEARNING
10 SMALL OUTDOOR CLASSROOM
11 SCHOOL

ELEVATIONS 1:100 (SCALED)

Figure 35 in the site South-East facade
Note. Author's own drawing.

ELEVATIONS 1:100 (SCALED)

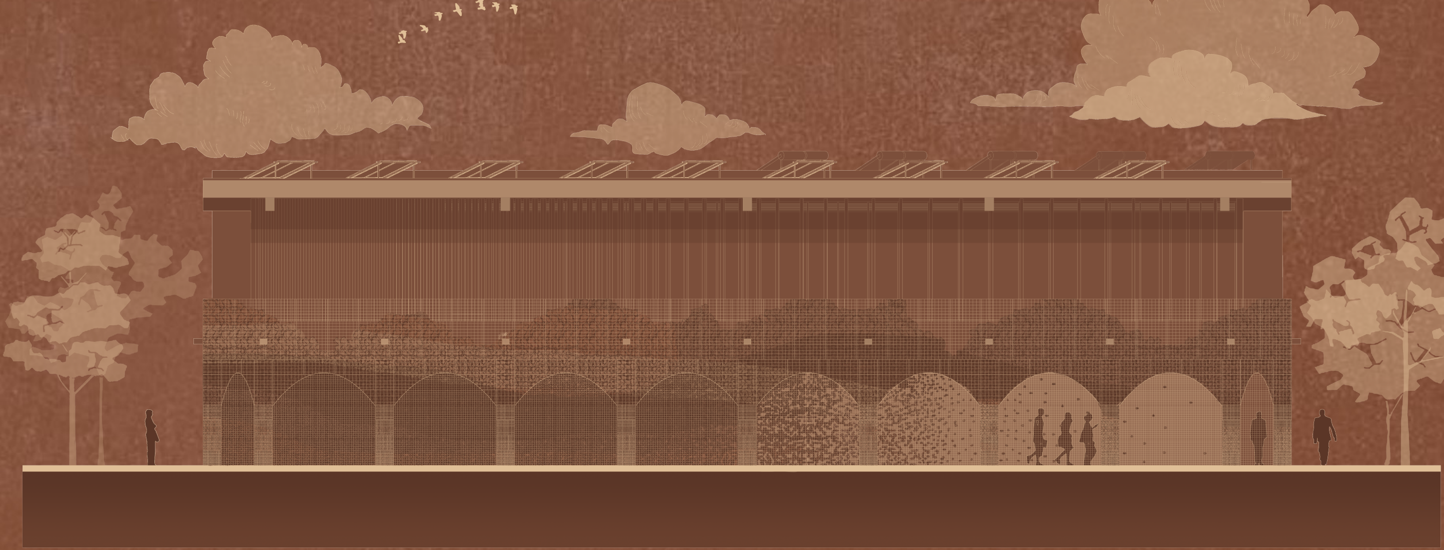


Figure 36 in the site North-East facade
Note. Author's own drawing.

Figure 37 in the site South-West facade
Note. Author's own drawing.

Description:

The elevations respond to climate and movement. The main entrance is shaped as a large liwan, creating a shaded transition between outside and inside. The east and west facades are more closed to protect against direct sunlight, while the second layer of louvers filters the sun and becomes more open towards the north and south. Along the north-east passage, the mesh layer creates a semi-transparent edge, giving glimpses of the making process and inviting people to enter the building.

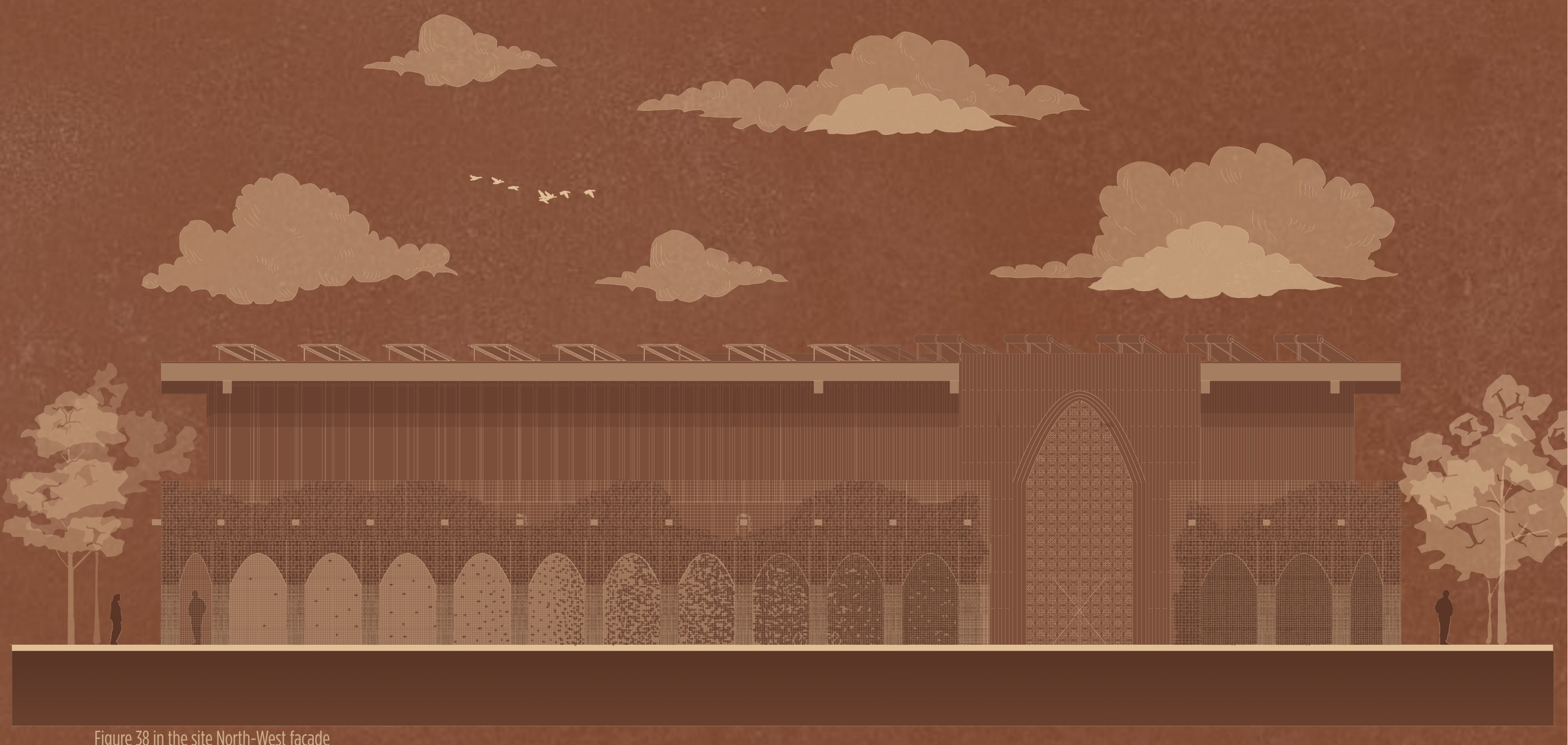


Figure 38 in the site North-West facade
Note. Author's own drawin

SECTION 1:100 (SCALED) AA

Figure 39 section 1
Note. Author's own drawing.

Description:

This section cuts through the long side of the building and shows the canyon-like interior space. The central void brings light, greenery, and movement into the project, while the programme is placed on both sides of this shared space. In the middle, the espresso bar creates an informal place to pause, meet, and gather in the shade, showing how the building is organised not only around making and learning, but also around encounter and everyday social life.

SECTION 2 1: 100 (SCALED) BB

Figure 40 section 2
Note. Author's own drawing.

Description:

This second section focuses on the first floor and terrace. It shows how the upper level becomes lighter and more open, while remaining connected to the canyon space below. The terrace adds an additional shared space for informal use and viewing.

STRUCTURE 1:200 (SCALED)

Figure 41 Kielsteg floor
Note. Author's own drawing.

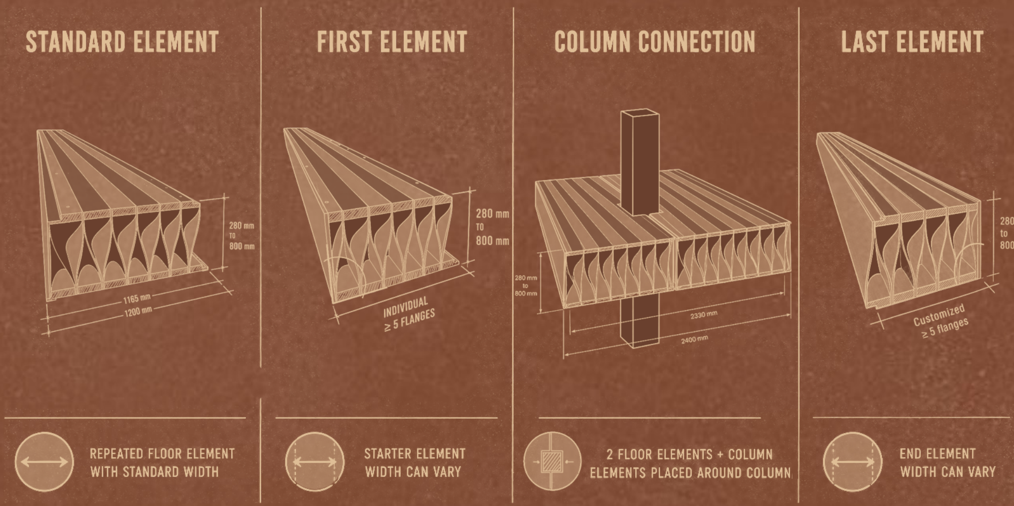


Figure 42 Diagrams floor
Note. Author's own drawing.

Description:

For the floor structure, a Kielsteg system was selected because it allows large spans and cantilevers while using less material. This reduces the need for columns and creates more open and flexible spaces for the programme. It is combined with the interlocking debris blocks, which form the main load-bearing structure, while the gabion walls remain self-supporting and function mainly as enclosure, shading layer, and climate buffer.

FOUNDATION STRUCTURE 1:100 (SCALED)

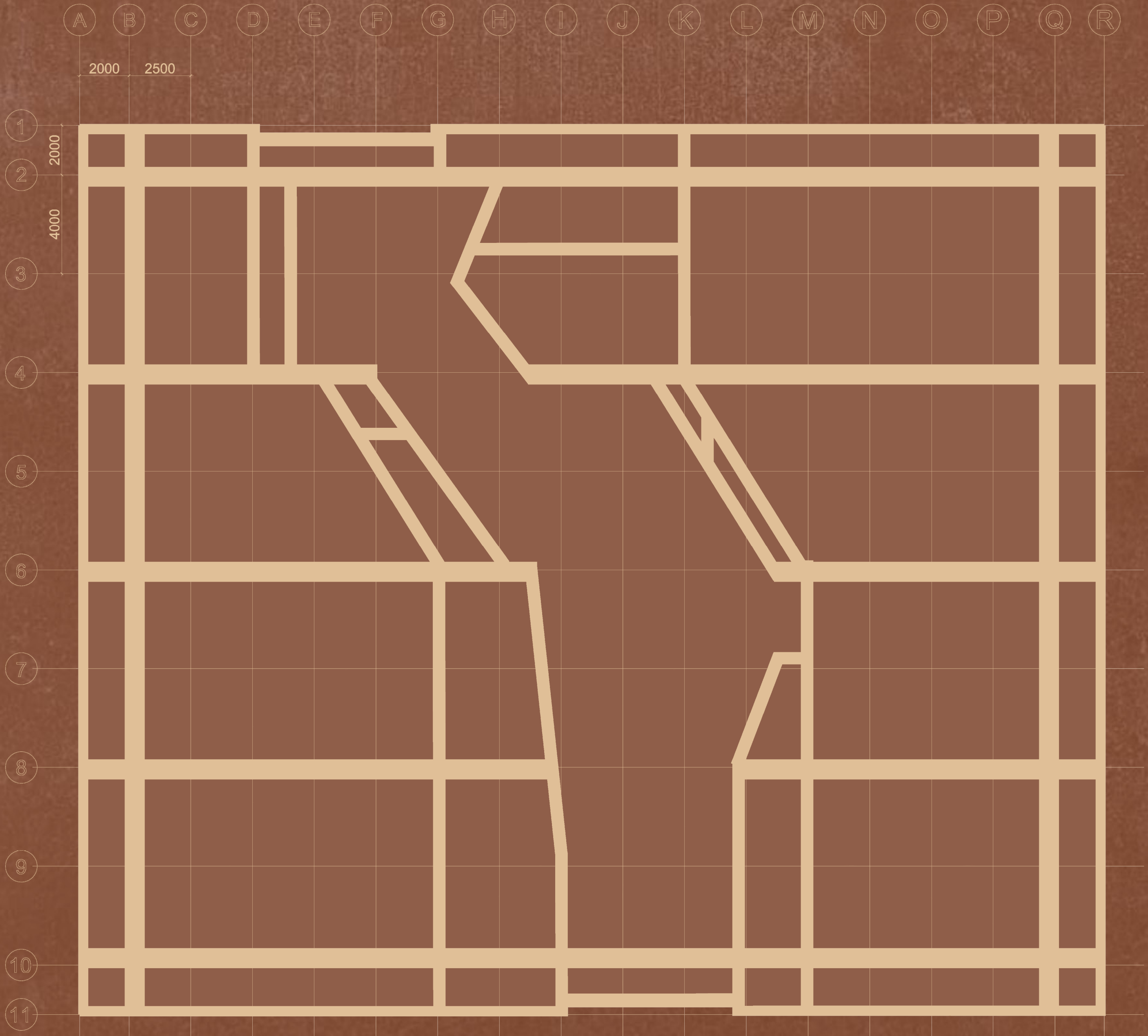


Figure 43 Structure foundation
Note. Author's own drawing.

FIRST FLOOR STRUCTURE 1:100 (SCALED)

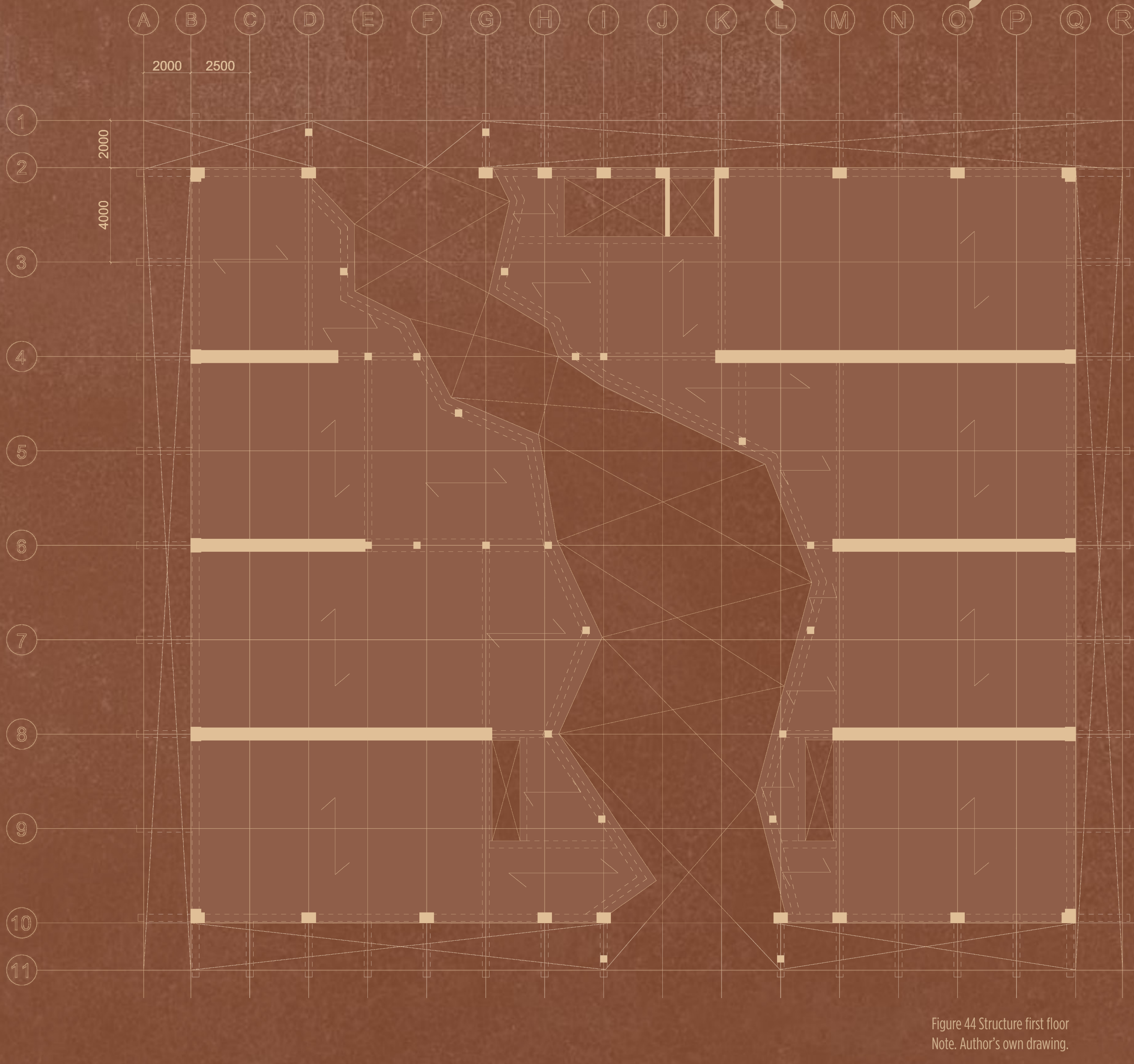


Figure 44 Structure first floor
Note. Author's own drawing.

ROOF 1:100 (SCALED)

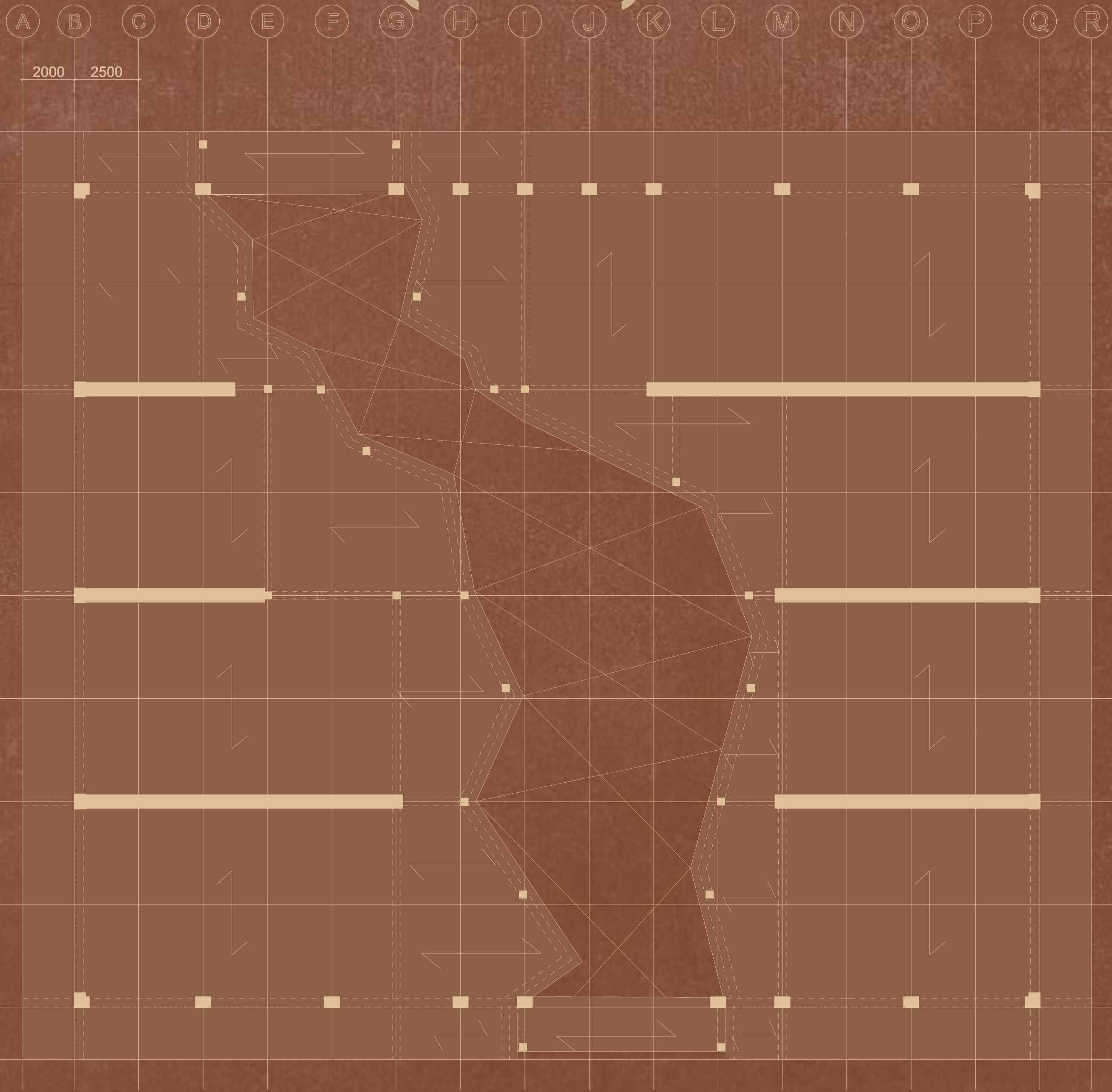


Figure 45 Structure roof
Note. Author's own drawing.

1:20 SECTION

Description:

The first 1:20 facade fragment shows the build-up of the outer envelope. From outside to inside, it shows the gabion skin, intermediate cavity, and inner layer. It also shows the interlocking debris blocks, which form the main load-bearing layer and connect the material research to the architectural expression of the building.

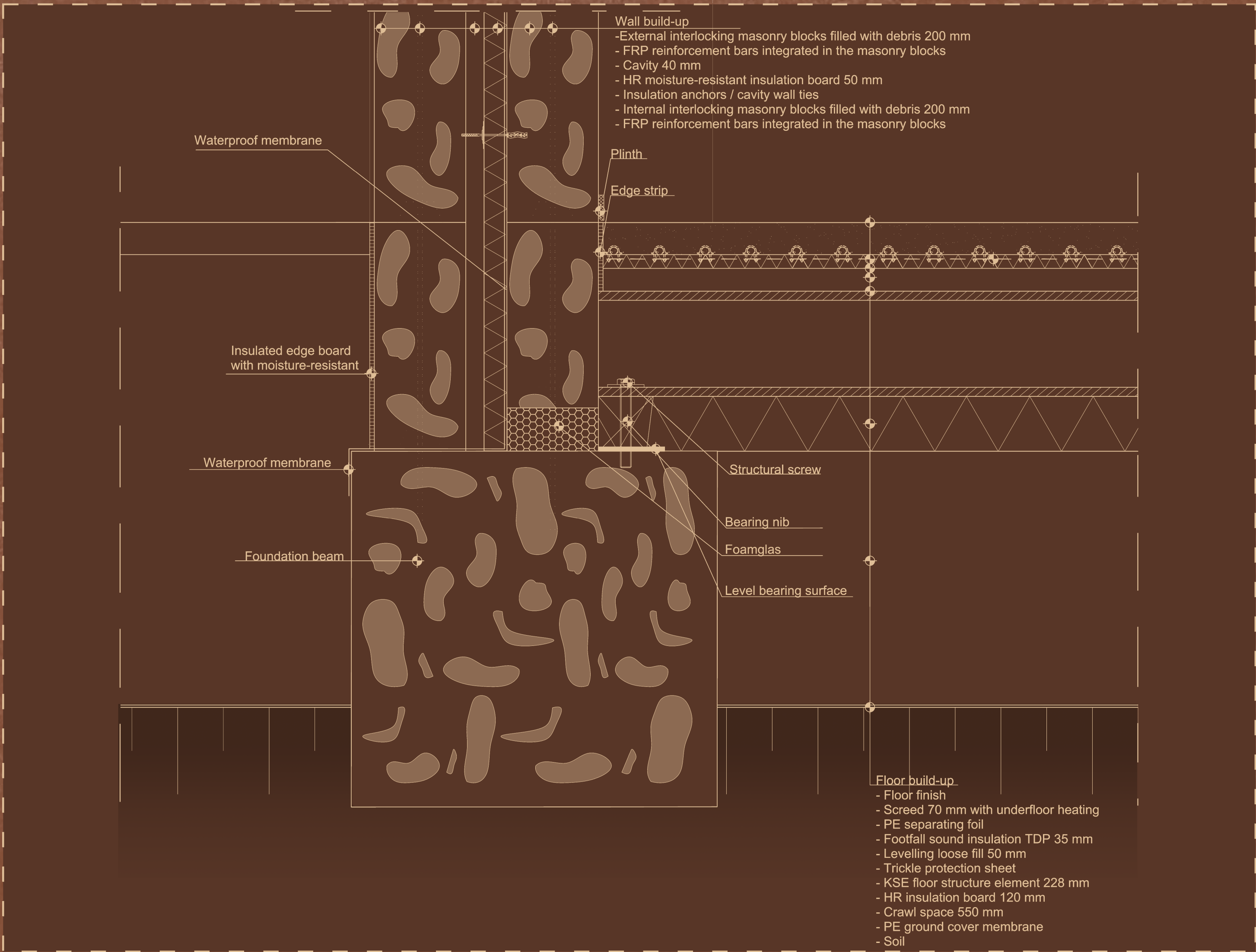
Figure 46 section 1:20 A
Note. Author's own drawing

Description:

The second 1:20 facade fragment is taken inside the canyon. It shows the contrast between the heavier, protective outer envelope and the lighter interior atmosphere. The canyon side becomes more open and connected to the shared inner space, where light, movement, greenery, and visibility create a softer atmosphere compared to the outside of the building.

Figure 47 section 1:20 B
Note. Author's own drawing.

DETAILS 1:5 1:5 (SCALED)

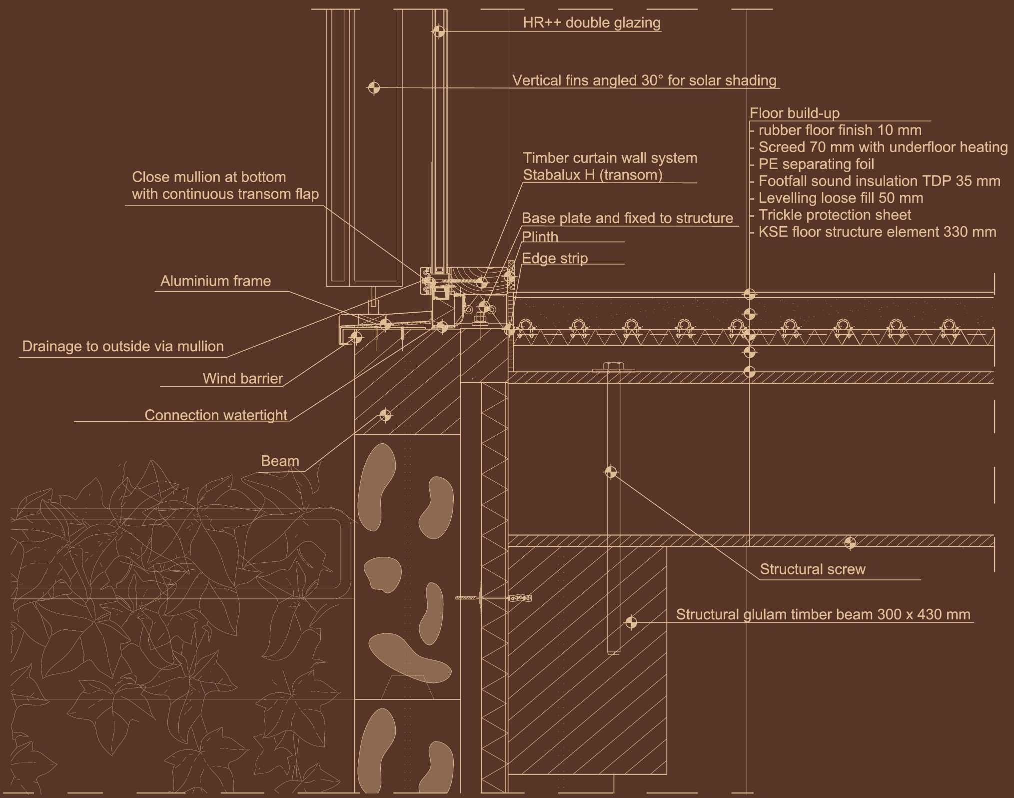


Description:

Detail 1 shows how the interlocking “lego” blocks connect to the foundation. It also shows the use of foam glass insulation, which is more expensive, but possible here because the floor is placed next to the wall. This means the floor can still be replaced in the future if needed.

Figure 48 detail 1

Note. Author’s own drawing.

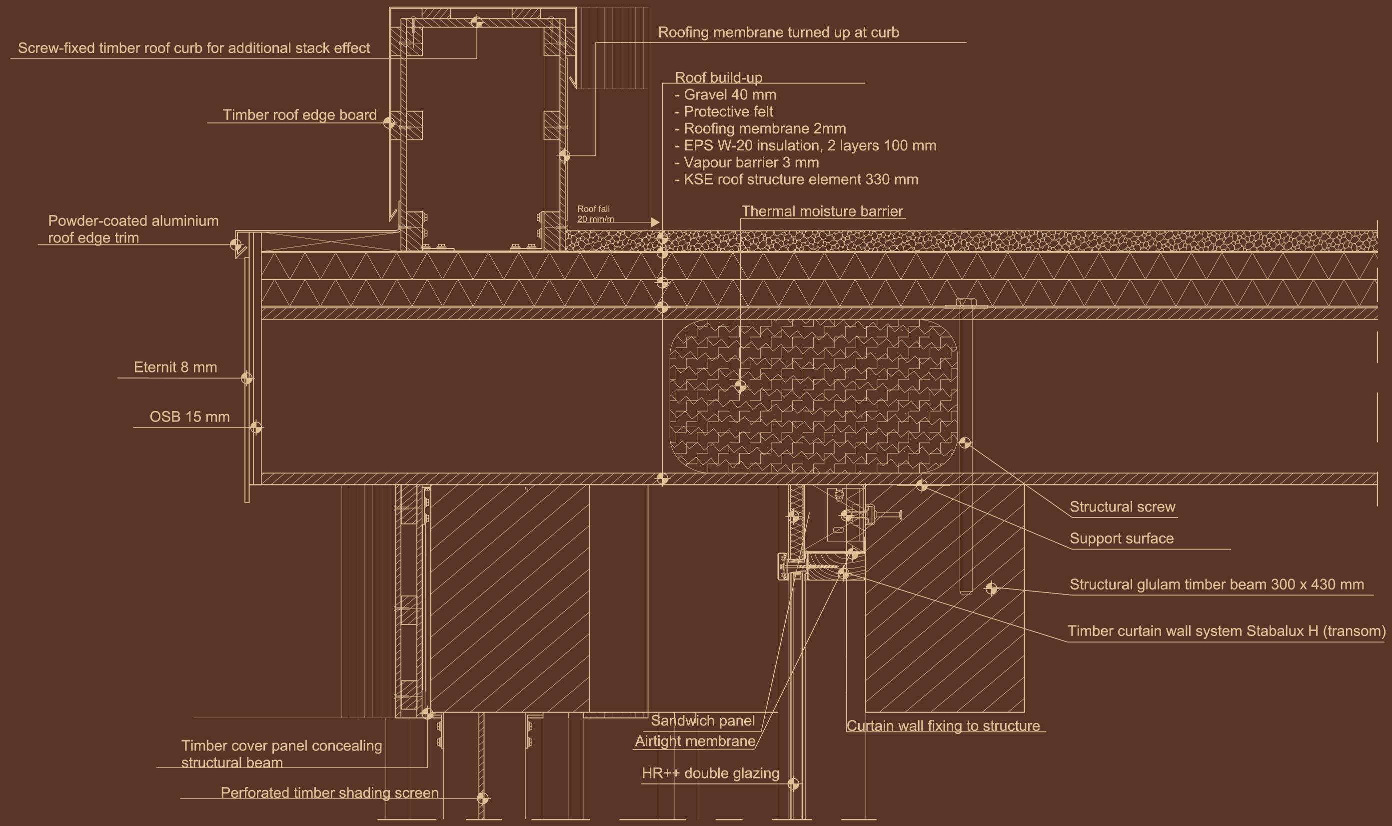


Description:

Detail 2 shows how the curtain wall connects to the blocks and to the timber beam on which the Kielsteg floor is supported. It also shows the louvres as part of the facade build-up. Together, these elements clarify how the lighter upper layer is assembled.

Figure 49 detail 2
Note. Author's own drawing.

DETAILS 1:5 (SCALED)



Description:

Detail 3 shows the roof build-up, including the raised part of the roof. It also shows how the thermal moisture barrier is integrated within the roof assembly. This detail clarifies the climatic and technical build-up of the roof.

Figure 50 detail 3
Note. Author's own drawing.

CLIMATE

Description

This climate section brings together the passive and active climate strategies of the building. On the roof, solar panels generate energy, while solar water heating supports the floor heating system during winter.

In the canyon, fabric shading and vegetation create shade and help lower the perceived temperature, making the central space more comfortable during hot periods. The thick walls provide thermal mass, storing heat during the day and releasing it more slowly.

The building also uses the canyon to guide airflow. Low openings on one side and higher openings on the other side allow air to move through the building. During the day, this airflow can be limited to keep the cooler air inside the shaded canyon. In the evening, the openings can be adjusted to create cross ventilation and release warm air.

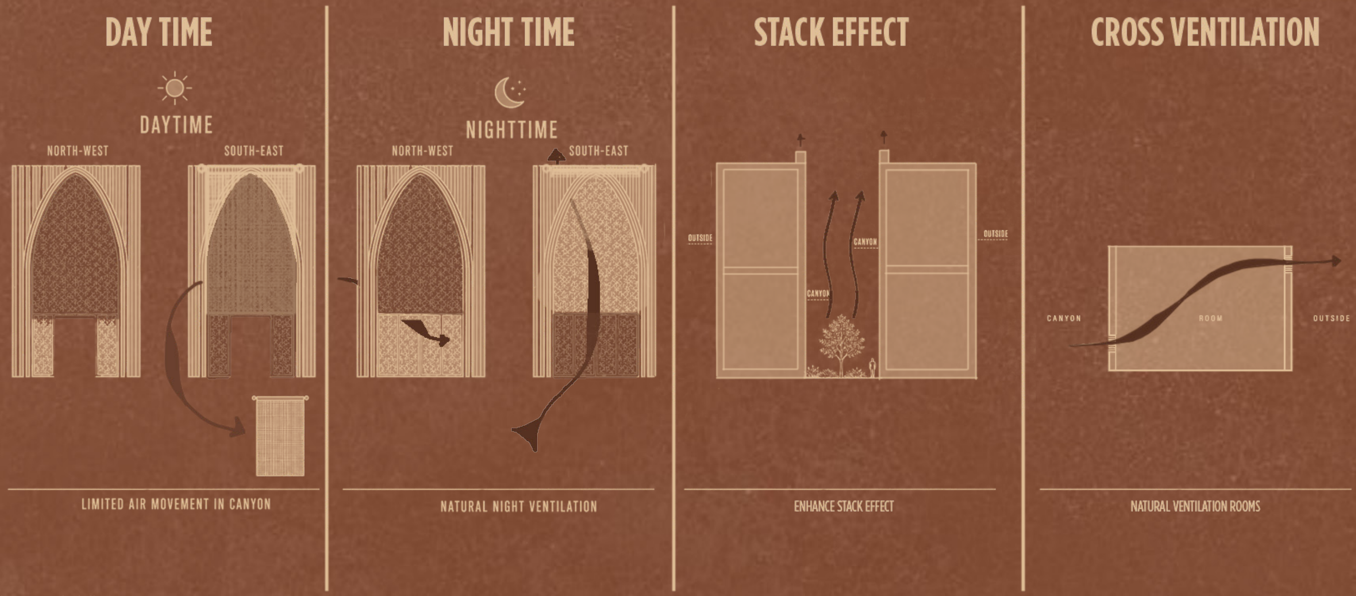
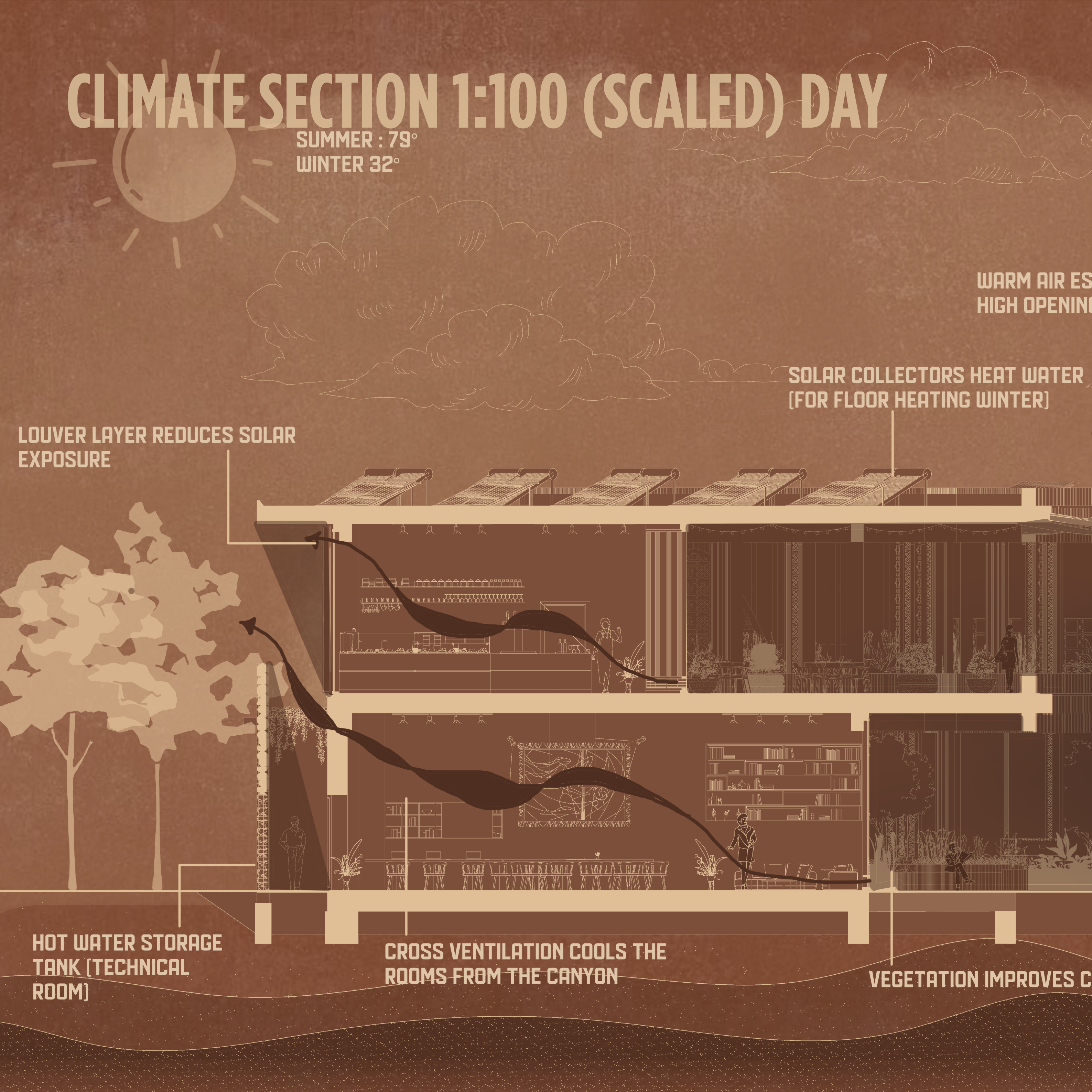


Figure 51 wind diagram
Note. Author's own drawing.

CLIMATE SECTION 1:100 (SCALED) DAY



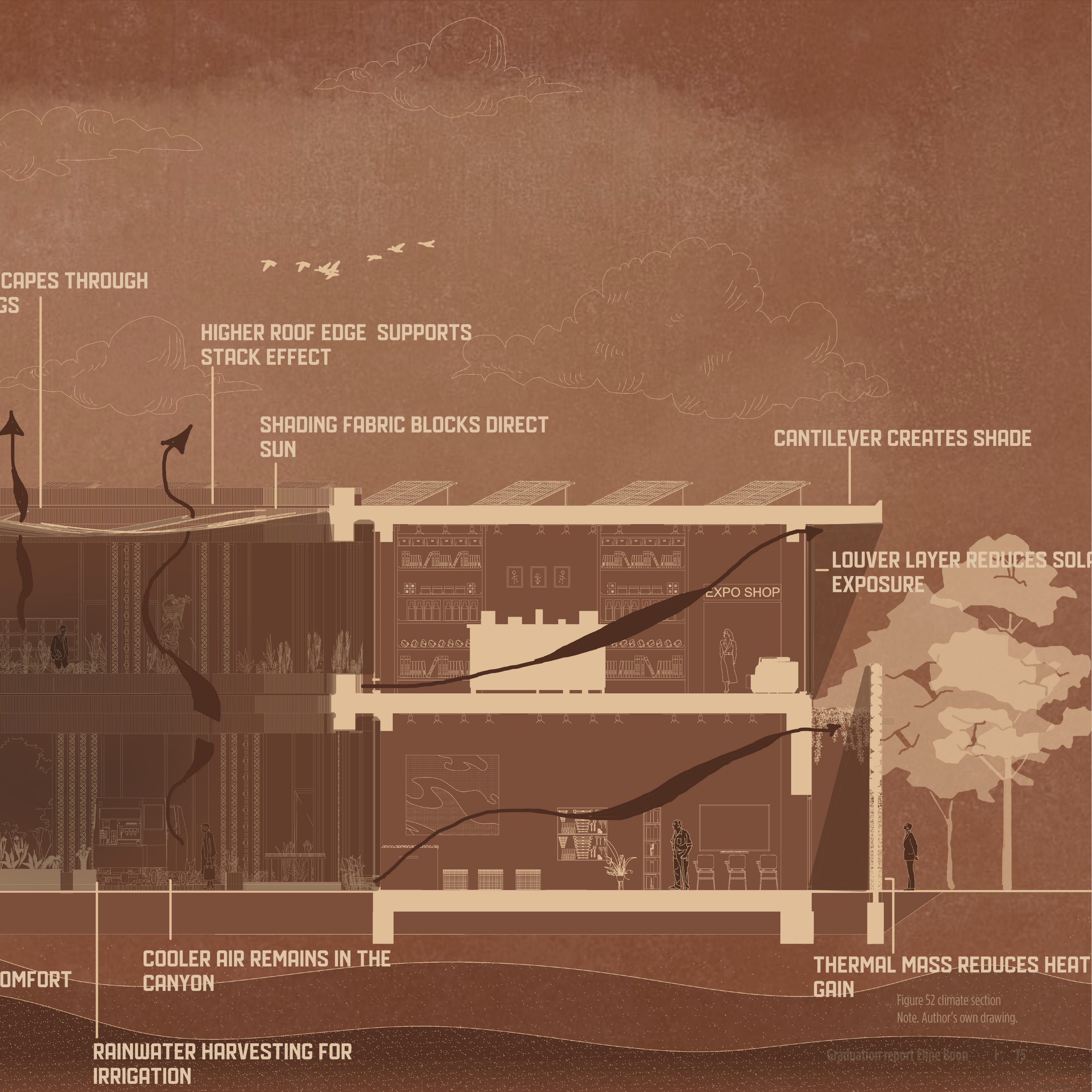
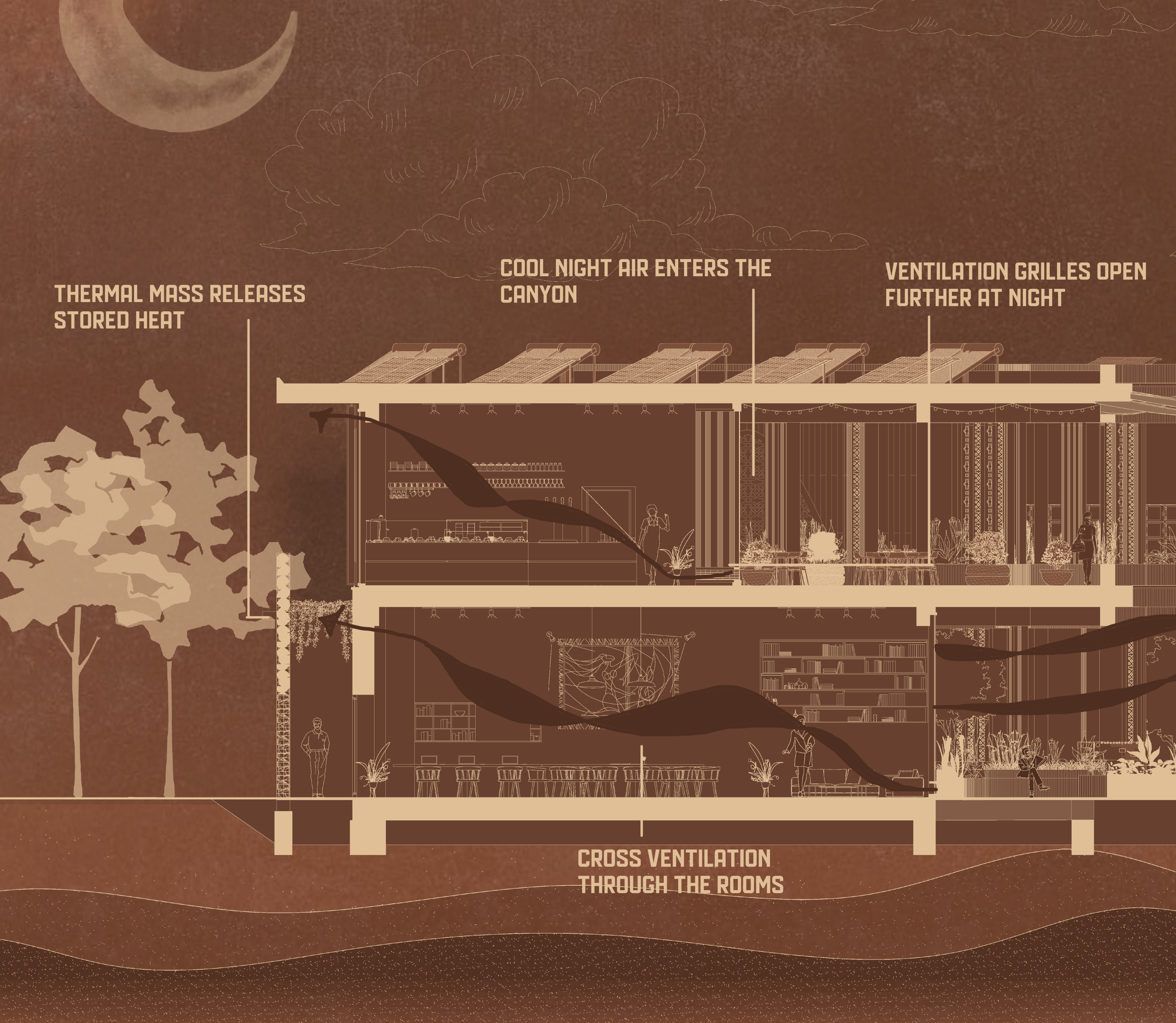


Figure 52 climate section
Note. Author's own drawing.

CLIMATE SECTION 1:100 (SCALED) NIGHT



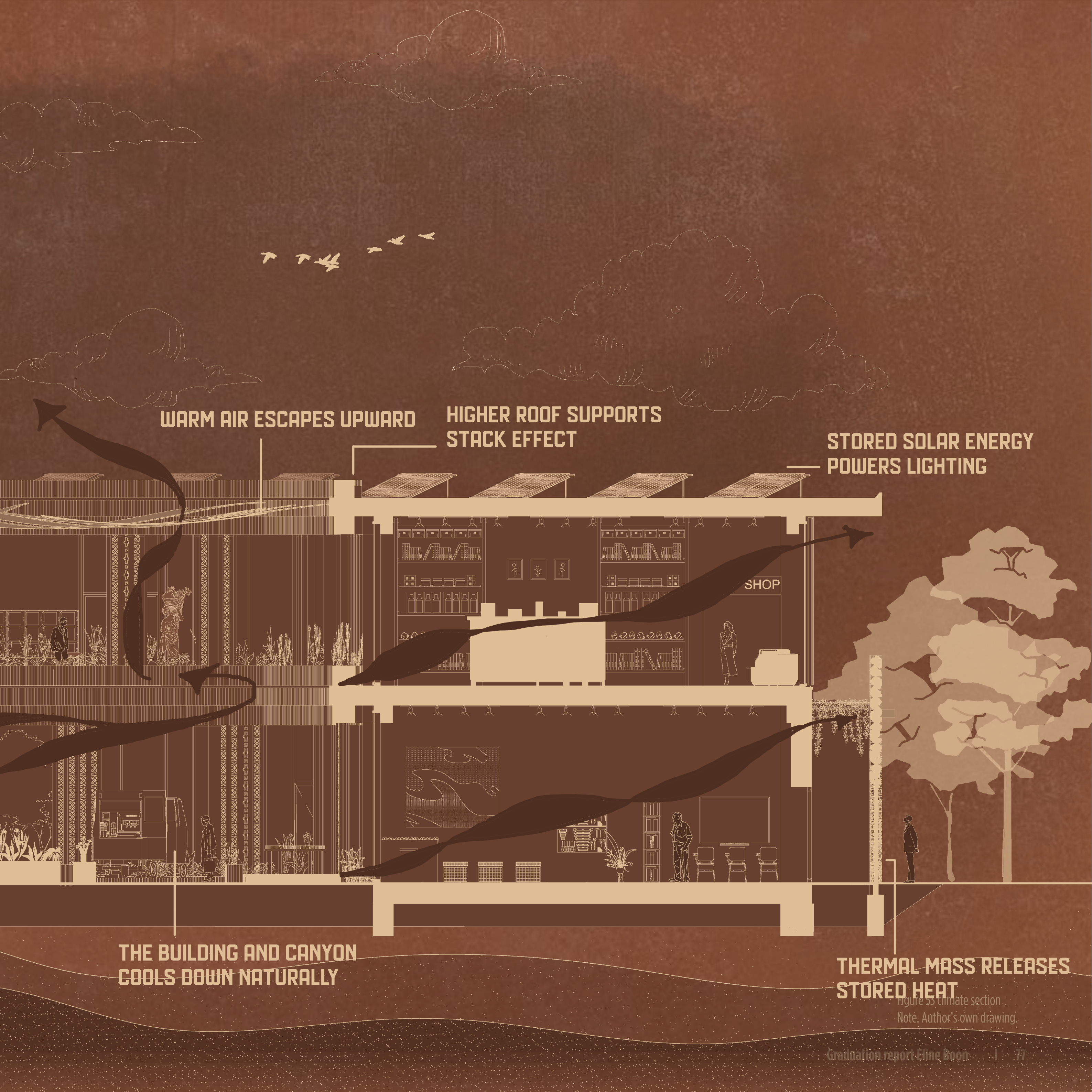


Figure 53 climate section
Note. Author's own drawing.

FUTURE

Description:

In the future, when the space is no longer mainly needed for rebuilding, it can adapt to other neighbourhood functions. The workshops can become small businesses, learning spaces, or community rooms. This allows the building to remain useful after reconstruction and continue supporting local life in Homs.

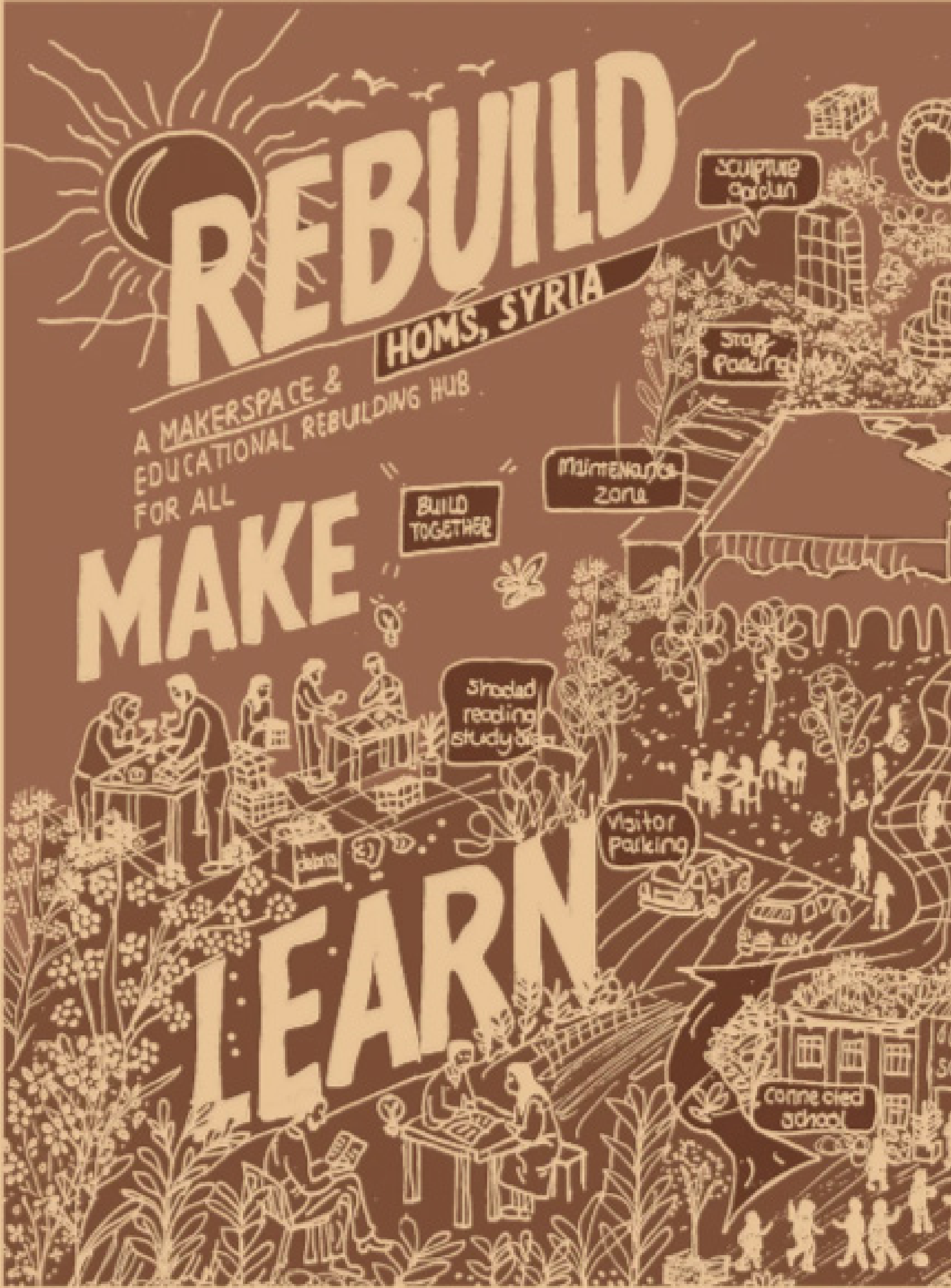


Figure 54 vision
Note. Author's own drawing.

Figure 55 Future
Note. Author's own drawing

Figure 56 impression
Note. Author’s own drawing.

Figure 57 impression.
Author's own drawing.

Figure 58 impression
Note. Author's own drawing.

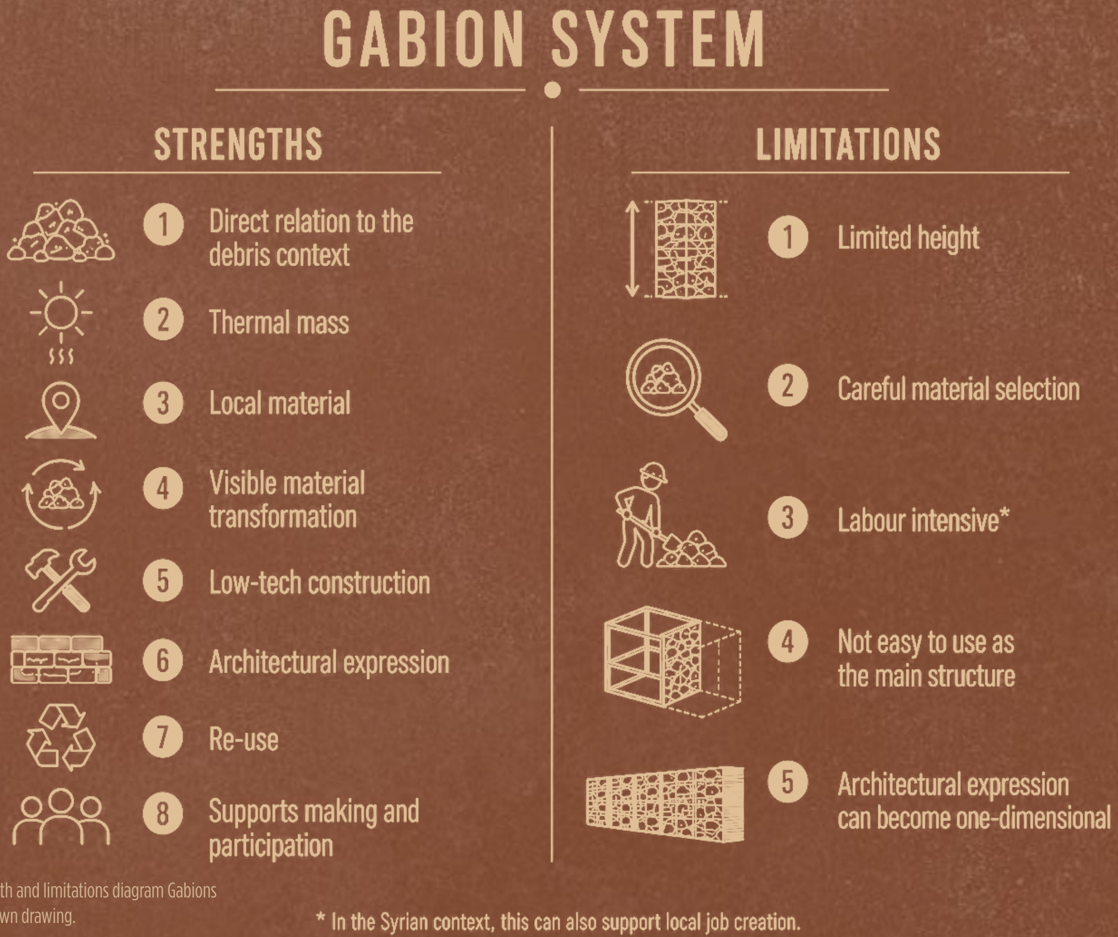


Figure 59 Strength and limitations diagram Gabions
Note. Author's own drawing.

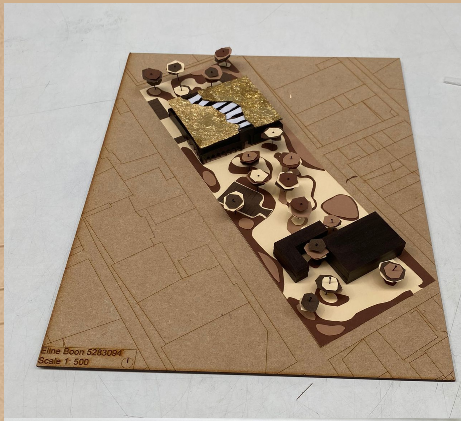
Description

Looking back at the project, I would still choose gabions, but I would define their role much earlier and more precisely. Their main strength lies in their direct relation to the debris context of Homs, as well as in their thermal mass, porosity, and climatic buffering capacity. At the same time, their limitations became more apparent when they were considered beyond that role, because in the final project they proved most convincing as a self-supporting outer climate buffer rather than as the dominant system of the whole building.

Figure 60 Strength and limitations diagram Kielsteg
Note. Author's own drawing.

Description

Looking back at the project, I would still choose the Kielsteg floor system because it responded well to the form of the building, particularly in relation to the larger cantilevers and the lighter upper level. At the same time, it does not fully align with the broader low-tech and locally grounded logic of the project, since it is a more engineered system that would likely need to be sourced from Europe. If further development were possible, it would be valuable to investigate whether a similar spatial effect could be achieved through a more low-tech and locally feasible alternative.



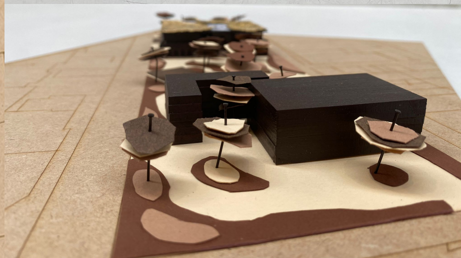



Figure 61 Model 2 site
Note. Author's own drawing.

Figure 62 Model 3 kijkdoos
Note. Author's own drawing.

07

CONCLUSION AND DISCUSSION

This chapter concludes the graduation project by reflecting on how the final design responds to the main design question and architectural ambitions formulated in the introduction. It also discusses the wider implications of the project and reflects on the design process, methods, and tools used.

CONCLUSION

This graduation project addresses the question of how post-conflict debris can be transformed into a building system that supports climate-responsive architecture and community rebuilding in Homs. It does so first by developing a makerspace programme that connects making, learning, and rebuilding, then by translating the climatic, cultural, and spatial conditions of Homs into architectural design principles, and finally by transforming debris into a modular building system supported by a self-supporting gabion climate buffer. Together, these steps show that debris can move from a condition of waste to a material, spatial, and social resource within an architectural proposal for Homs.

The project therefore demonstrates that the architectural reuse of post-conflict debris is not only a technical question of material application, but also a spatial and social question of how rebuilding can be organised over time. Its main contribution lies in showing how debris can support climate-responsive design through mass, porosity, shading, and airflow, while also enabling a programme centred on participation, skill development, and collective use. In this way, the project answers the first design question through the development of a makerspace as a programme for rebuilding, the second through the translation of climatic, cultural, and spatial conditions into architectural principles, and the third through the development of a modular and layered building system in which debris becomes part of both the structural and climatic logic of the proposal.

Rather than proposing a fixed or universal solution, the project presents an adaptable architectural framework for the context of Homs. It shows that rebuilding with debris is not only about constructing a building, but also about creating a process in which material reuse, local participation, and future transformation are brought together.

The project therefore positions debris not as a leftover of destruction, but as a starting point for new forms of architecture, learning, and community rebuilding.

IMPLICATIONS AND RECOMMENDATIONS

The implications of this project lie in the way it repositions post-conflict debris within architecture. Rather than treating debris only as waste or as a technical recycling problem, the project shows that it can also become part of a broader process of architectural and social rebuilding. In this way, debris is not only approached as a material resource, but also as something that can influence programme, spatial organisation, and collective use. The project therefore suggests that rebuilding in Homs can be supported through architectural proposals that connect material reuse, climate-responsive design, and community participation within one framework.

At the same time, the project remains exploratory and qualitative. The proposed building system would require further development through structural testing, climate-performance studies, and prototyping at a larger scale. Its practical application also depends on the safe selection, sorting, and preparation of non-hazardous debris, as well as on local construction capacities and material availability. If future research develops more effective ways of identifying, separating, and preparing non-hazardous debris from mixed post-conflict waste streams, the available material resource could increase significantly. This would make debris-based building systems more feasible and more widely applicable in Homs. Future research could therefore focus not only on the structural behaviour of the modular block system and the long-term climatic performance of the layered envelope, but also on methods for expanding the safely reusable material stock.

As an architectural recommendation, the project suggests that future rebuilding strategies should not separate material reuse from social recovery. Instead, they could consider how spaces for making, learning, and collective participation can become part of reconstruction itself. In that sense, the project does not propose a final solution, but offers a framework for thinking about debris not as the endpoint of destruction, but as the starting point of new architectural and social possibilities.

REFLECTION

Within the Extreme Architecture studio, the project positions itself at the intersection of climate response, material reuse, and post-conflict rebuilding. A central challenge in this graduation project was the transition from research to design. The accompanying research paper provided a strong analytical basis, but remained relatively technical and focused on gabion systems, climate-responsive performance, and debris as material. As a result, one of the main difficulties in the design process was to translate these analytical findings into an architectural proposal that also addressed people, use, and community rebuilding. This became particularly important in the development of the programme, since the project had to move beyond a technical material study and become a design that could support making, learning, and social interaction in Homs.

Another challenge was the selection and development of the programme itself. Determining what kind of space could meaningfully engage with gabion logic, material reuse, and rebuilding processes was not straightforward. The programme scenarios helped to clarify this, but also showed how difficult it was to connect the technical and material logic of the research to a convincing architectural and spatial proposal. In addition, the specific expression of gabion-based construction raised questions of form, atmosphere, and architectural quality. This required continuous testing of how material logic, cultural references, and spatial organisation could be brought together in a coherent design.

The design-oriented research approach proved valuable because it allowed analytical insights to be tested directly through material, spatial, and climatic studies. At the same time, the transition from technical research to architectural design remained one of its main challenges. The project was particularly valuable as a learning process in relation to material research. Through the exploration of gabions, debris fragments, prototype studies, and facade fragments, the project developed a much deeper understanding of how debris can be used architecturally. It also showed how material investigations can actively shape design decisions rather than remaining purely technical. At the same time, the project led to a stronger awareness of the cultural and urban context of Homs. Because much of the city has been destroyed, it was often difficult to build a complete understanding of the site and its architectural references. This meant that the design process had to work with limited information and carefully selected sources, which also became an important part of the project's methodological reality.

An important boundary in the project concerned hazardous debris. Rather than proposing the direct reuse of all post-conflict waste, the project focused only on selected non-hazardous debris and treated hazardous materials as a clear limit of the architectural investigation. If further development were possible, the project would benefit from more extensive work on both urban integration and technical testing. At the urban scale, the proposal could be developed further in relation to the wider reconstruction of the neighbourhood and its future role within the city. At the technical scale, the modular block system would require further prototyping and structural testing, including the behaviour of the interlocking system under load and in seismic conditions. Additional physical prototypes could also clarify how the system performs in practice and how its architectural expression develops through construction. In this sense, the project should be understood not as a finished solution, but as a design-oriented framework that opens up further architectural, technical, and urban questions.

08

APPENDIX

This appendix contains supplementary material related to the graduation project. It includes the accompanying research paper, additional technical information, and supporting documents referred to in the report.

APPENDIX A: DATA MANAGEMENT

DATA MANAGEMENT CHECKLIST

Instruction

This checklist is relevant for all graduation projects of the Master AUBS. The form is intended to highlight common aspects of graduation projects that require particular attention with regard to planning the research and data management. Relevant information and supplementary sources regarding each question are provided below each question.

With this checklist, the faculty wants to avoid that students unexpectedly find themselves in complex and stressful situations, in which ethical or privacy matters and/or other laws and regulations become an issue. In projects involving humans, certain types of data processing increase the risks to the human participants: planning such projects requires additional evaluations and advice from university staff before ethical approval can be received and the project can begin. In the case of a graduation project, obtaining additional advice or permits may delay the project with an extra education period or semester. To avoid this, it is recommended that students set up a graduation project with a low level of risk. Therefore, all students have to check their risk, by completing this checklist before their A1.

The first section of the checklist (A) should be completed by all students, together with their supervisor, during the planning of the graduation project, before the A1. It does not need to be submitted to anyone for review or approval. Please consider questions 1 to 3 carefully in relation to the intended graduation project, and answer with 'yes' or 'no'.

The second section of the checklist (B) should only be completed if the graduation project involves working with data from human participants. In that case, the student and their supervisor must apply for and receive ethical approval from the Human Research Ethics Committee (HREC) before the project can begin (see the paragraph 'Explanation and follow-up' after the questions). The student can submit the application to the HREC, but the supervisor is responsible for making sure that the project is compliant with relevant privacy regulations and ethical policies.

Section A. General considerations	yes	no
1. Is the graduation project conducted as part of an internship (at a company), or as part of a research project at TU Delft? If a student's graduation project is conducted at a company or as part of a research project at the university, questions of data ownership and intellectual property rights need to be addressed in a written graduation or internship agreement before the project begins. Students and their supervisor should consult the Intellectual Property Rights of Students webpage. Additional information can also be found in the Extended Personal Research Data Workflow.		✓
2. Does the project involve conducting (part of) the research outside the Netherlands? Students who intend to travel abroad (even to other EU countries) for study, exchange, research, internship, or graduation project purposes need to follow the Travel Safety Protocol. This includes attending a mandatory Travel Safety Training Session: see the Disclaimer.		✓
3. Will the research involve processing data from humans, such as running a survey, conducting interviews or workshops, collecting data through social media or internet forums, or re-using existing datasets about humans provided by a third party? (If 'yes', see follow-up questions 4 to 13 in Checklist B.) Students who work with data from human participants must complete the next section and apply for and receive ethical approval from the Human Research Ethics Committee (HREC) before conducting the research.		✓

APPENDIX B: RESEARCH PAPER

GABION-BASED BUILDING ENVELOPE SYSTEMS

An Architectural Analysis of Construction Debris Reuse and Climate-Responsive Performance in Post-Conflict Homs

Eline Boon 5283094
January 2026
Architecture Research Paper
MSc Graduation Studio Extreme Architecture
AR4EA010

Main supervisor: Job Schroën
Second supervisor: Alessandra Navarro

PREFACE

This research paper was produced as part of the graduation project at the
Faculty of Architecture and the Built Environment 2025/2026 in de studio Extreme Architecture at TU Delft.

I would like to thank my graduation studio mentor, Job Schroën for his guidance throughout the design process, and for the inspiring studio excursion to London. I also thank my research mentor Alessandra Navarro for taking the time to critically refine the research questions and for her guidance during the analytical phase of the project.

CONTENT

1. ABSTRACT

Keywords: Homs, Syria, Post-conflict reconstruction, Construction debris reuse, Gabion-based building envelopes, Climate-responsive design, Building envelope and Thermal mass

This research investigates the architectural potential of post-conflict construction debris in Homs, Syria, by examining its reuse within climate-responsive, gabion-based building envelope systems. In the context of widespread urban destruction and a severe hot–dry climate, building debris is currently addressed primarily as a hazard or waste management challenge rather than as an architectural design resource. Adopting a design-oriented analytical approach, the study examines the translation of gabion systems from infrastructural origins to the scale of the building envelope.

The research establishes three key performance criteria for building envelopes in Homs: thermal regulation, solar control, and permeability. The findings indicate that non-loadbearing gabion configurations offer the largest degree of architectural flexibility, as structural detachment allows for modifications in material packing and porosity without sacrificing main stability. The material inventory of Homs, dominated by reinforced concrete and cement bricks, shows a strong functional alignment with these criteria. Large, angular fragments that meet granulometric requirements and sufficient apparent density are suitable for providing thermal mass and stability, while pulverized materials and soluble inclusions represent a mismatch due to reduced permeability and durability.

The research is analytical rather than propositional, establishing a foundation for future design exploration rather than providing final solutions. Key limitations include the qualitative nature of the performance assessment and the exclusion of hazardous materials. The study positions construction debris as an architectural resource with potential for climate-adaptive reconstruction in post-conflict environments.

2. INTRODUCTION

UN-Habitat (2022) identifies Homs as one of the Syrian cities most severely affected by the conflict. Damage assessments show that a large share of the housing stock is moderately or severely damaged, resulting in widespread partial inhabitation rather than complete abandonment of residential areas. The same report also mentions that the presence of construction debris across different areas causes difficulties for inhabitants in terms of accessibility, safety, and living conditions.

Zwijnenburg & te Pas (2015) presents conflict-related rubble as a highly complex material with many issues attached to it. The report specifically states that construction leftovers are often mixed with household and medical waste, and may contain materials such as asbestos, which are harmful to health. As a result, rubble is primarily addressed as a hazard rather than as a building resource. Naaouf and Torma (2023) outline Syria as a region characterised by hot, dry and sunny summers combined with limited annual precipitation. The authors indicate that more than 60% of the country receives less than 250 mm of rainfall per year, while summer temperatures are consistently high.

Figure A1 Crisis Impacts in Homs Old city
Note. From *From Homs city urban recovery profile 2022* by UN-Habitat (2022).

In such hot and dry climates, the building envelope becomes especially important as it mediates thermal exchange between interior and exterior environments. As Okba (2005) explains, the building envelope is the layer that connects inside and outside, controlling heat gain, ventilation, and thermal exchange. Building envelope design consequently becomes a major factor of thermal comfort in areas where solar radiation is high and summer temperatures are severe. Therefore, the functional requirements of the envelope are significantly affected by environmental conditions, together with energy efficiency concerns.

According to Kallab and Kaskas (2024), one of the most common approaches to post-conflict construction and demolition waste management consists of step-by-step processes focused on clearance, sorting, and centralized recycling. Risk prevention and industrial reuse are the main focuses of these regulations; however, architectural reuse is not explicitly addressed within the policy frameworks.

Historically, gabion-based systems have been developed and applied primarily within infrastructural and hydraulic engineering contexts, such as retaining structures, erosion control, and water management (Shabanova et al., 2024; Uray, 2022). Typical infrastructural applications are illustrated in Figure A2 (Uray, 2022). Within these applications, gabions are valued for their material mass, permeability, adaptability to uneven ground conditions, and relatively simple construction logic (Chikute & Sonar, 2019; Uray, 2022).

These infrastructural characteristics are not inherently architectural, yet they define material and spatial properties that become relevant at the scale of the building envelope. This research departs from the infrastructural origin of gabion systems: where existing literature predominantly focuses on structural stability and failure modes (Chikute & Sonar, 2019; Shabanova et al., 2024) and repositions them within an architectural framework. Here, material characteristics are examined in relation to climate-responsive envelope performance rather than structural ground retention or infrastructural stability.

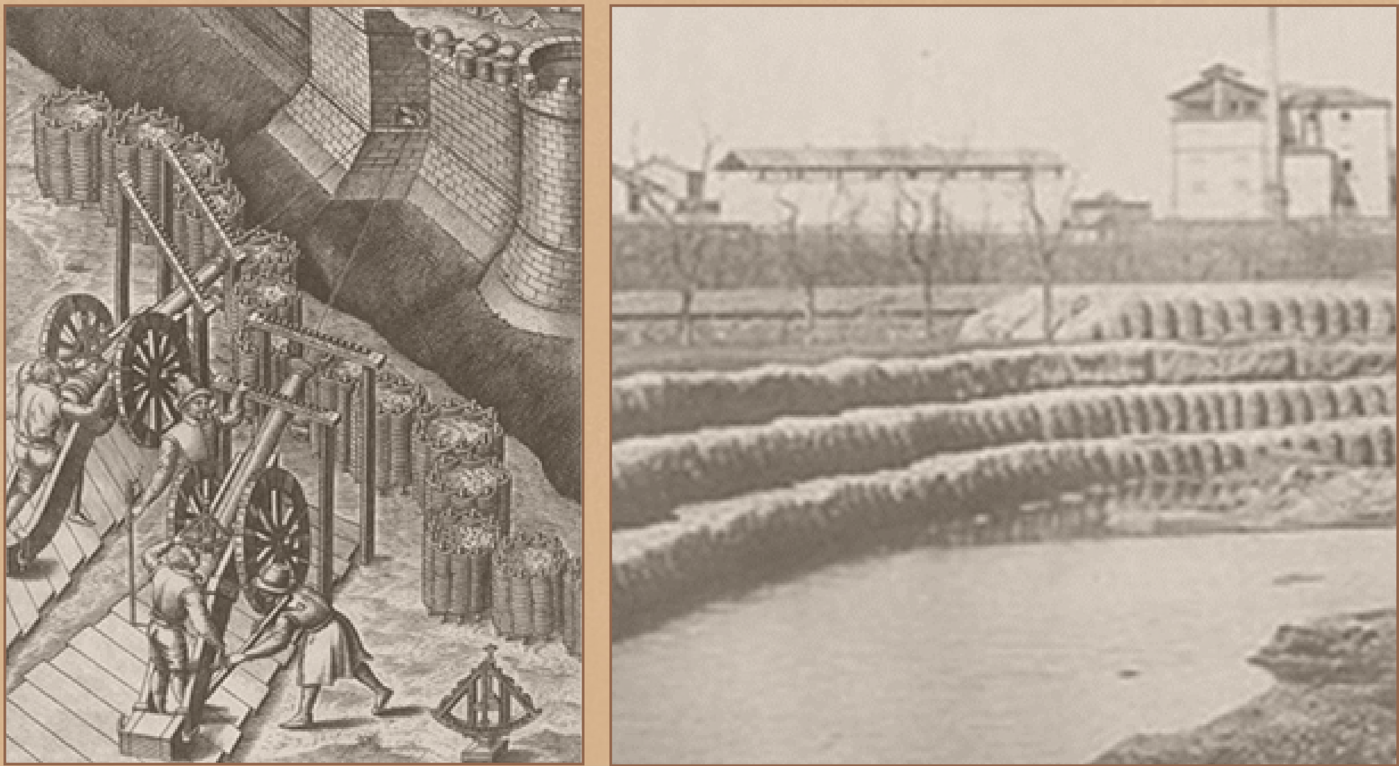


Figure A2 Historical use of gabion structures in infrastructural contexts.
Note. From *Gabion structures and retaining walls design criteria* by E. Uray (2022).

3. PROBLEMSTATEMENT

Figure A3 The targeted Neighborhoods in Homs
Note. From *From Homs city urban recovery profile 2022* by UN-Habitat (2022).

3.1 problem

Among the characteristics found in cities during the post-conflict recovery period, such as Homs, are extensive building debris, habitation within partially ruined structures, and a hot and dry climate that places significant demands on building performance (UN-Habitat, 2022; Naaouf & Torma, 2023). Current construction and demolition waste management methods mainly regard debris as a hazard that needs to be removed, prioritising clearance and safety in order to enable centralised recycling processes (Zwijnenburg & Te Pas, 2015; Kallab & Kaskas, 2024). Within these conceptual frameworks, conflict-generated debris is predominantly viewed as a danger rather than as a potential architectural resource or as a contributor to alternative material reuse practices within the construction sector.

Architectural research shows that in hot and dry climates the building envelope plays an important role in mediating the relationship between interior and exterior conditions, with a direct influence on thermal comfort and energy use (Okba, 2005). However, current post-conflict approaches to construction debris rarely consider the building envelope at the architectural scale, where material choices and climatic demands come together.

At the same time, construction debris management remains primarily driven by policy and engineering concerns. Consequently, the architectural potential of selected, non-hazardous debris for climate-responsive building envelope systems in Homs and similar contexts remains largely unexplored. Within this gap, this research focuses on gabion-based building envelope systems as a specific architectural framework through which the climate-responsive reuse of construction debris in Homs can be examined.

3.2 Relevance

The relevance of this research lies in its architectural positioning within existing post-conflict recovery approaches. While construction debris in post-conflict environments has been widely studied in relation to clearance, material recycling, and engineering-based reuse strategies, these studies predominantly address debris at technical or policy levels. Architectural engagement with construction debris as a design material, particularly at the scale of building envelope systems, remains limited within current research. This absence restricts architectural understanding of how building envelopes can react to simultaneous material constraints and climatic demands in post-conflict contexts.

In hot and dry climates, where building performance depends strongly on the design of the building envelope, there is a limited presence of architectural approaches that address material conditions and climatic demands simultaneously.

3.3 Objectives and motivation

The objective of this research is to explore how selected, non-hazardous construction debris can be engaged architecturally within climate-responsive building envelope systems in the context of post-conflict Homs. In this research, climate-responsive is used to describe an analytical focus on the relationship between building envelope systems and climate, without implying proven or quantified performance. Rather than approaching debris primarily as a waste management or engineering challenge, the research positions it as a material condition relevant to architectural design at the building scale.

This research is driven by conditions in post-conflict areas where a hot and dry climate, demands on building performance, and large quantities of construction debris coexist. These conditions call for architectural approaches that deal with material availability, climate, and construction in relation to one another. As a result, the project takes a design-oriented research approach, emphasising low-tech principles and locally appropriate construction logics at the building envelope scale. The goal is not to provide a final solution, but rather to create an analytical foundation for future architectural design.

3.4 Research questions

This research is guided by the following main research question:
How can construction debris be reused as climate-responsive gabion-based building envelope systems in Homs?

The research addresses this question through three sub-questions:
RQ1. How are gabion-based systems constructed and used in architectural and infrastructural contexts, and which material and structural configurations do they employ?
This question looks at gabion-based systems as a construction principle by examining their common applications, methods of assembly, and material and structural configurations. The aim is to understand how gabions function as building envelope systems in different contexts, and to provide a technical and architectural basis for further research.

RQ2. Which climate-responsive performance characteristics of gabion-based envelope systems are relevant in the context of Homs?
This question investigates the climate-responsive performance characteristics of gabion-based envelope systems in relation to the hot and dry climatic conditions of Homs. It focuses on identifying which performance aspects are relevant at the envelope scale, rather than evaluating complete passive design strategies. These performance characteristics are explored through a qualitative and comparative analysis, rather than through quantitative simulations or optimization models.

RQ3. What types of construction debris remain after basic safety clearance in Homs, and which of these demonstrate the highest potential to meet the performance and construction requirements of gabion-based climate-responsive building envelope systems?
This question addresses the material conditions of the post-conflict environment by identifying the types of construction debris that remain after basic safety clearance and assessing their suitability for use within gabion-based envelope systems. The emphasis lies on the alignment between material characteristics and the previously identified performance and construction requirements.

3.5 Project Scope

This research examines the post-conflict context of Homs, Syria, at the building scale rather than the urban scale, specifically focusing on gabion-based building envelope systems. The study is limited to the architectural scale of the building envelope, where material choices and climatic performance are most directly related. The research addresses selected, non-hazardous construction debris that remains after basic safety clearance and does not engage with the identification, removal, or treatment of hazardous materials. The study focuses on climate-adaptive principles suitable for hot and arid climates and examines their relevance within envelope-scale systems. Social and economic factors, as well as urban reconstruction and large-scale debris management, fall outside the scope of this research.

4. METHODOLOGY

4.1 Research approach

This research adopts a design-oriented architectural research approach. The study is analytical rather than propositional. It does not aim to develop or test a building design, nor to optimise performance outcomes. Instead, it examines existing systems, materials, and theoretical frameworks to explore architectural potential at the building-envelope scale.

This approach is considered appropriate in the post-conflict context of Homs, where reliable quantitative data is limited and architectural questions primarily concern material conditions, construction logic, and envelope-scale performance considerations.

4.2 Analytical structure

The research is structured around three following research questions, each covering a different analytical layer.

RQ1 examines gabion-based systems in architectural contexts. This step establishes how such systems are constructed, configured, and assembled, and clarifies their material and structural characteristics. Understanding the construction logic of gabions is necessary for following analysis.

RQ2 abstracts climate-responsive performance requirements relevant to hot–dry climates at the building-envelope scale, taking into account material-related characteristics of gabion-based envelope systems such as mass, permeability, surface exposure, and aperture, as established in RQ1.

RQ3 applies the previously established system knowledge and performance criteria to the material conditions of post-conflict Homs. It examines which types of construction debris remain after basic safety clearance and assesses their potential alignment with gabion-based envelope requirements. This sequential structure ensures that material analysis is grounded in architectural system logic and climate-responsive considerations.

4.3 Source selection and use

Sources were selected based on their relevance to architectural scale, envelope performance, and material description. The research draws on three main types of sources: theoretical literature on building envelopes and climate responsiveness, descriptive studies on gabion systems and construction materials, and context-specific reports addressing post-conflict conditions in Homs.

Engineering-focused studies were used only where they provided descriptive information on material properties or construction logic. Sources proposing design solutions, optimisation strategies, or quantified performance outcomes were excluded. Policy documents and reports were used to establish contextual conditions rather than to derive architectural prescriptions.

Architectural case-based sources, such as analytical project documentation and educational architectural studies, were used to describe envelope configurations and construction logics where peer-reviewed architectural literature remains limited. These sources are employed descriptively rather than as performance evidence. Each source was assessed critically with respect to its scale, scope, and applicability. Claims were included only where they were explicitly supported by the source material.

4.4 Methodological Scope and limitations

The scope of the research is purposefully restricted. It disregards structural systems other than envelope assemblies and concentrates on the building-envelope scale. For safety and legal reasons, hazardous debris materials, such as asbestos-contaminated parts and unexploded munitions are not included in the analysis.

Simulations, measurements, and optimisation studies have been excluded in the study, nor is thermal performance quantitatively assessed. Climate-responsive performance is addressed qualitatively through conceptual criteria rather than through numerical assessment.

Finally, the research does not propose architectural designs or implementation strategies. It aims to establish an analytical basis that can inform subsequent design exploration within the graduation project

5. GABION-BASED SYSTEMS

5.1 Definition and basic system logic of gabions

A gabion basket is defined as a rectangular cage manufactured from double-twisted steel wire mesh, typically zinc-coated, which is filled with rocks or stones of specific mechanical characteristics (Samayoa et al., 2018; Uray, 2022). To construct a wall, these individual units are stacked vertically and bound together using wire to act as a monolithic structure (Samayoa et al., 2018). Gabion units follow a modular dimensional logic and are typically assembled in standardized box sizes, allowing for flexible stacking and combination within wall assemblies (Chikute & Sonar, 2019; Uray, 2022).

5.2 From infrastructural origins to architectural relevance

Gabion systems historically emerged from hydraulic engineering and infrastructural domains, utilized primarily for retaining structures and erosion prevention (Shabanova et al., 2024; Uray, 2022). These applications established the system's fundamental material logic: a flexible, permeable mass capable of adapting to ground settlements without requiring auxiliary drainage (Uray, 2022). Such characteristics, including structural simplicity and modular assembly, were developed to manage lateral soil loads and hydraulic forces (Chikute & Sonar, 2019; Uray, 2022). When considered at the architectural scale, these infrastructural properties, particularly porosity and material mass, become relevant to building envelope behavior without being explicitly addressed as architectural design criteria in existing literature (Shabanova et al., 2024). Yet, current technical literature remains focused on geotechnical stability, leaving the design criteria for architectural applications insufficiently developed (Shabanova et al., 2024; Uray, 2022).

5.3 Loadbearing envelope and façade applications (limited)

In building applications, the structural logic shifts to forming load-bearing vertical envelopes composed of stacked gabion boxes (Samayoa et al., 2018). To ensure stability, perpendicular walls require interlocking connections between adjacent gabion units, comparable to a "LEGO"-type configuration (Samayoa et al., 2018; Figure A4). In a limited number of documented architectural projects, gabion systems have been applied as load-bearing wall assemblies in low-rise buildings (Conti et al., 2016). Current technical literature indicates that these applications are primarily restricted to one-storey or low-rise residential and community structures rather than multi-storey complexes (Samayoa et al., 2018). This is due to their behaviour as 'porous gravity walls' that rely on friction rather than tensile strength (Chikute & Sonar, 2019; Samayoa et al., 2018). As wall height increases, the lack of continuous tensile capacity limits the system's ability to transfer increased shock inertia forces, which explains why documented applications remain confined to one-storey or low-rise configurations (Samayoa et al., 2018).

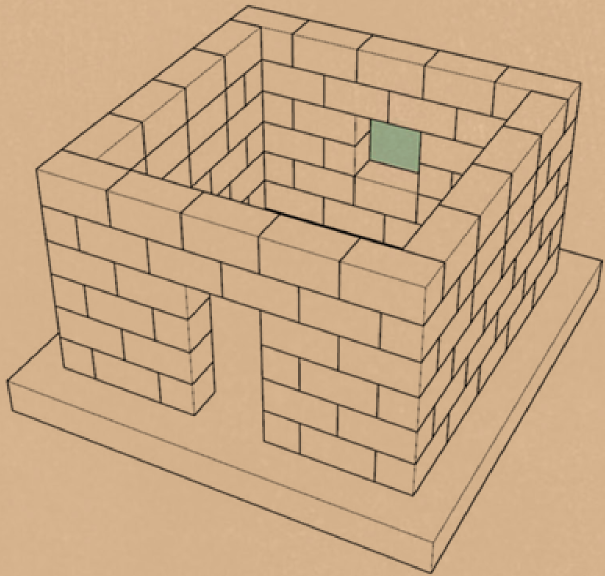


Figure A4 The considered gabion box walls building.
Note. From "Seismic Behavior of One-Storey Gabion-Box Walls Buildings" by J. Samayoa

To ensure global stability and address seismic risks, the architectural layout relies on a cellular arrangement where perpendicular walls are interlocked, simulating a monolithic connection between orthogonal elements (Samayoa et al., 2018). Because the gabion medium lacks inherent tensile strength, openings for doors and windows interrupt the structural continuity. Consequently, specific construction details such as timber lintel beams are required above these voids to prevent the local detachment of the stacked stone units (Samayoa et al., 2018).Representative architectural configurations of this systems are illustrated in Figure A5.

FigureA 5 Gabion-box wall construction in architectural applications.
Note. From "Seismic Behavior of One-Storey Gabion-Box Walls Buildings" by J. Samayoa et al. (2018),

In structural applications, the gabion wall is defined as a monolithic "porous gravity wall" that relies on the mass of the stone fill for stability rather than rigid binding agents (Samayoa et al., 2018). Due to the inherent void ratio of the infill material, which ranges between 0.3 and 0.4, these walls allow for free drainage and prevent the buildup of hydrostatic pressure, but consequently fail to act as a sealed cli-mate envelope in their standard form (Samayoa et al., 2018). While such permea-bility is acceptable for simple shelters or retaining structures, residential applica-tions requiring internal climate control necessitate the integration of a secondary barrier within the structural matrix. To address this limitation, some theoretical studies describe the addition of an internal barrier layer within the gabion assembly to enable enclosure. Kairl and Soebarto (2015) discuss a model in which an inject-ed insulation layer is introduced to reduce air and moisture penetration (see Figure A6). However, this approach is presented as a theoretical modification rather than a standard or verified construction practice.

5.4 Non-loadbearing envelope and façade applications

In contrast to structural applications, gabion systems are utilized as non-load-bearing cladding or architectural skins. In this configuration, the stone envelope is explicitly dissociated from the building's load-bearing function and does not support vertical loads from the roof or floor plates (Fortier et al., n.d.) Instead, the gabion wall acts as a vertical screen attached to an independent primary structure, typically composed of steel or concrete, which bears the actual weight of the building (Fortier et al., n.d.) This separation between the primary structural frame and the gabion envelope is illustrated in Figure A7, where the stone-filled wire cages are shown as a secondary façade layer detached from the load-bearing structure.

This structural separation enables the gabion system to function independently of the building's stability requirements. The assembly logic remains modular, using wire cages filled with stone, but the envelope is secured to the structural skeleton rather than relying solely on self-weight and interlocking friction for stability. As a result, variations in stone size, packing density, and visual porosity can be accommodated that would be structurally unsuitable in load-bearing applications (Fortier et al., n.d.)

In non-loadbearing applications, the gabion functions as a detached, permeable skin that mediates the relationship between the exterior environment and the pri-mary building envelope.

Figure A6 Schematic cross-section of a load-bearing gabion wall with an internal barrier layer.
Note. From *LIMITATIONS OF BUILDING PERFORMANCE SIMULATION: MODELLING A BUILDING WITH GABION WALLS* by Kairl and Soebarto (2015).

Herzog & de Meuron's Dominus Winery exemplifies this approach, where the "stone wickerwork" filters light and temperature, creating interstitial spaces such as loggias where the boundary between inside and outside is blurred and moisture is permitted to penetrate the outer layer (Fortier et al., n.d.). This sepa-ration is ex-plicitly detailed in the Zilverlinde project, where the gabion façade is constructed as a vegetation-supporting screen positioned independently from the thermal en-velope (see Figure A8). The construction detailing reveals an identifiable opening be-tween the stone baskets and the inner structure, which includes wooden cladding and insulation to keep the primary building volume weather-tight (Schaap et al., 2025). Additionally, the outer gabion layer allows rainwater to pass through the mesh and irrigate the flora before infiltrating the ground, proving its role as an open, ecological buffer compared to a waterproof barrier (Schaap et al., 2025).

5.5 Material and structural configurations

The gabion basket is the component of the system. It consists of a rectangular cage made from hexagonal, double-twisted steel wire mesh (Uray, 2022). Wire diameters usually range from 2.2 to 3.4 mm. The Mesh is coated with PVC or zinc to ensure endurance (Chikute & Sonar, 2019; Samayoa et al., 2018). 60x80 mm, 80x100 mm, and 100x120 mm are standard mesh opening measurements (Chikute & Sonar, 2019). The material mesh configuration of a typical gabion basket are illustrated in Figure A9. Gabion units follow a modular dimensional logic, commonly occurring in multiples of 0.5 m (Chikute & Sonar, 2019).

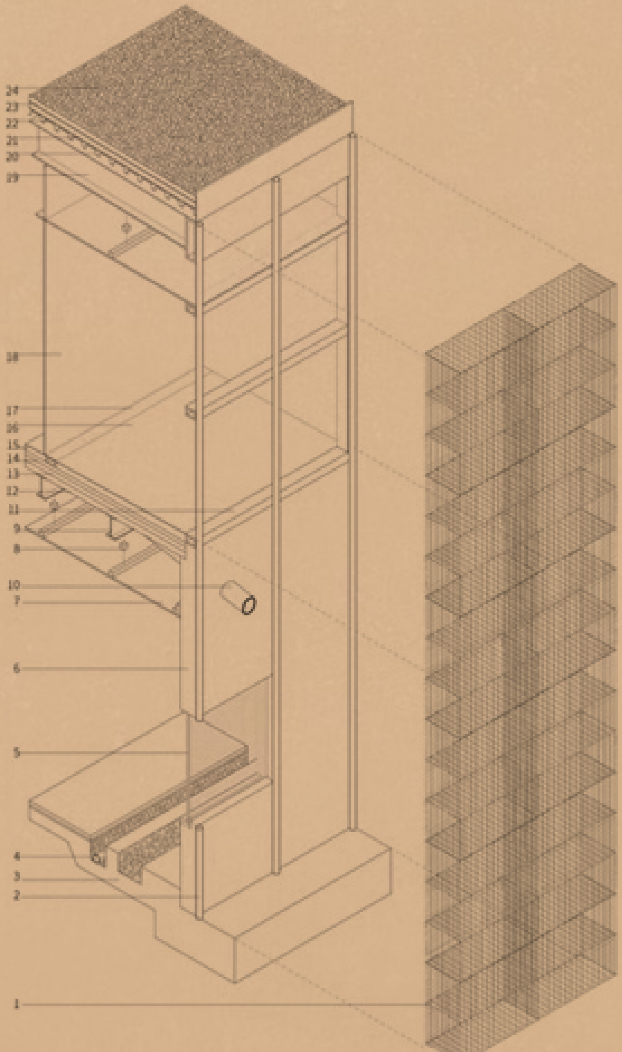


Figure A7 Non-loadbearing gabion façade detached from primary structural frame.
Note. Diagram from "R | Dominus Winery Herzog & De Meuron | Archisinthesection." retrieved from https://sglarchbezalel.wixsite.com/archisinthesection/dominuswinery

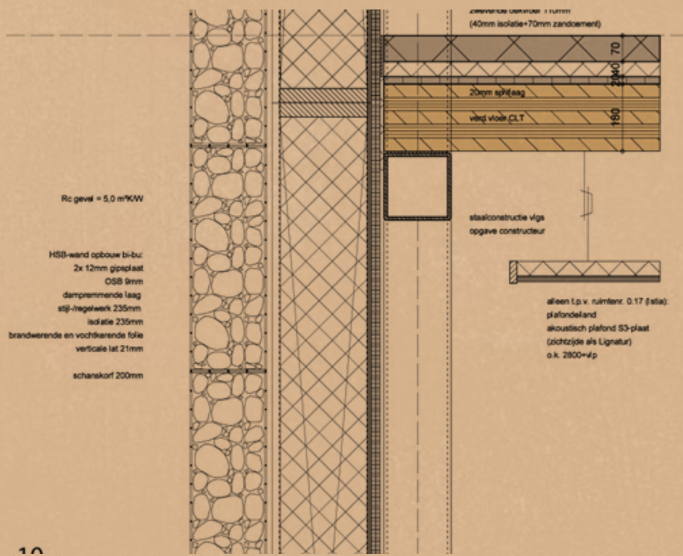


Figure A8 Non-loadbearing gabion façade
Note. From * Zilverlinde * by Schaap et al., 2025.

In terms of the filling, the technique often uses stones or boulders that are sufficiently robust and resistant to frost. Chikute and Sonar (2019) also identify recycled concrete blocks as a potential substitute for natural stone. Infill dimensions are defined in relation to the mesh size; individual stones exceed 1.3 times the nominal mesh opening to prevent material loss, with a maximum size of 250 mm (Shabanova et al., 2024).

5.6 Construction quality and limitations

These failure modes are predominantly documented in infrastructural applications and are therefore not directly transferable to building envelope systems. They are included here to clarify the material and construction-related limitations from which architectural envelope applications depart. Field surveys of existing gabion structures identify bulging as the most frequently reported failure mode, occurring in approximately 73% of inspected cases (Chikute & Sonar, 2019).

This deformation is primarily associated with loose infill packing and irregular

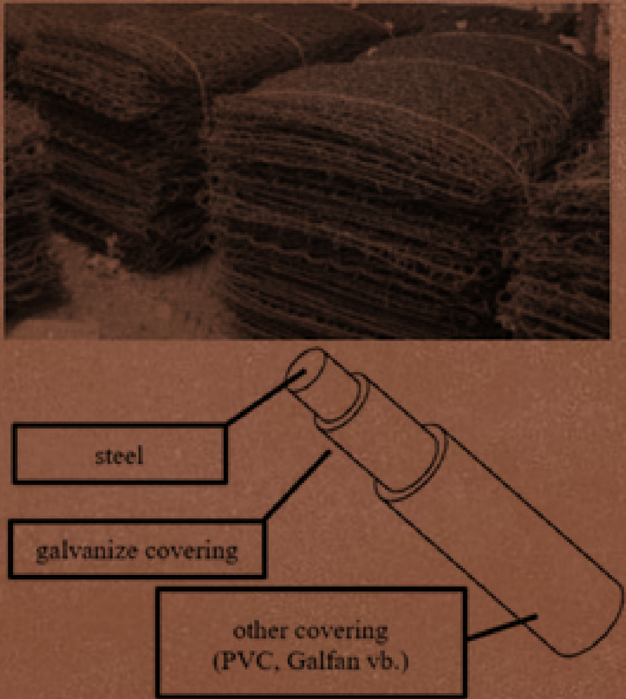


Figure A9 Gabion basket and wire mesh coating
Note. From *Gabion structures and retaining walls design criteria* by E. Uray (2022).

stone geometry, which reduce internal friction and the overall density of the composite unit (Chikute & Sonar, 2019). In addition, the use of unsuitable infill materials, such as soft carbonate rocks or stones lacking frost resistance, can lead to material disintegration and subsequent structural settlement (Shabanova et al., 2024). Typical examples of wire mesh damage and local deformation are illustrated in Figure A10.

Corrosion of the wire mesh represents a further degradation mechanism. Mechanical damage to protective coatings during filling operations, often caused by sharp stone edges, can initiate corrosion processes (Chikute & Sonar, 2019).

In humid or aquatic environments, the use of low-quality wire mesh accelerates material degradation and compromises structural integrity (Shabanova et al., 2024). Furthermore, the absence of filter fabrics at the soil interface may result in backfill erosion due to the inherent permeability of the system, potentially causing horizontal wall movement and reduced bearing capacity (Uray, 2022).

Figur A10 Examples of wire mesh deformation and coating damage in gabion structures.
Note. From "Failures of Gabion Walls" by Chikute & Sonar, 2019.
(a) (b) Corrosion of Gabion Mesh
(c) Bulging of Gabion Mesh

In non-loadbearing architectural applications, however, the implications of these construction-related risks shift. Because the gabion envelope is structurally decoupled from the primary load-bearing system, variation in infill packing density is described in an architectural case study as being accommodated without compromising overall building stability (Fortier et al., n.d.). In such configurations, overall stability is governed by the independent steel or concrete frame, while the self-weight of stacked gabion units is managed through detailing strategies such as steel lintels and controlled maximum stacking heights, often determined through full-scale mock-ups (Fortier et al., n.d.)

Despite this structural decoupling, wire corrosion remains a critical limitation in both load-bearing and non-loadbearing applications. In environments with high soil acidity, standard galvanization is insufficient, necessitating the use of zinc–aluminium alloy coatings to ensure long-term durability (Fortier et al., n.d.). In addition, the inherent porosity of gabion envelopes introduces specific envelope-related constraints, requiring finer mesh gauges and smaller stone grading at ground level to prevent the infiltration of rodents and reptiles (Fortier et al., z.d.).

Figure A11 Non-loadbearing gabion façade attached to an independent steel structure.
Note. From "LA PENSÉE CONSTRUCTIVE EN ARCHITECTURE." By Fortier et al., n.d.

5.7 Interim conclusion

This chapter examined how gabion-based systems are currently used in architectural envelope applications. Originating from infrastructural and hydraulic engineering, gabions have been translated into a limited number of architectural projects at the scale of low-rise buildings.

Two envelope configurations were identified. In load-bearing applications, gabion walls act as primary vertical structures and require strict construction logic. These applications remain limited in scale. In non-loadbearing applications, gabion systems function as secondary envelope layers attached to independent structural frames. In this configuration, material characteristics such as porosity and loose packing are enabled by structural decoupling rather than representing structural deficiencies.

Across both configurations, material-related limitations persist. Wire corrosion and infill-related deformation remain relevant constraints that influence long-term performance. Together, these findings clarify the construction logic and current architectural use of gabion-based envelope systems and provide a grounded basis for the examination of their climate-responsive performance in the following chapter.

6. PERFORMANCE GABION-BASED ENVELOPE SYSTEMS

6.1 Introduction

Given the hot–dry climatic conditions characterising Syria (Naaouf & Torma, 2023), the building envelope is required to function as a selective interface regulating energy exchange between interior and exterior environments (Okba, 2005).

At the envelope scale, performance requirements are articulated in relation to the control of conductive, convective, and radiant heat transfer processes (Okba, 2005). Okba (2005) describes the relevance of thermal resistance, material mass, surface properties, and aperture control as key aspects influencing envelope behaviour in hot–dry climates. These considerations frame the identification of climate-responsive performance dimensions at the level of the building envelope, rather than prescribing specific design solutions.

6.2 Envelope-scale performance dimensions in hot–dry climates

In hot–dry climates, a key performance consideration relates to limiting external heat gains during daytime conditions while allowing heat dissipation during cooler periods (Okba, 2005). This regulation is articulated through the control of conductive, convective, and radiant heat transfer mechanisms at the envelope scale (Okba, 2005). These envelope-scale performance dimensions are schematically illustrated in Figure A12.

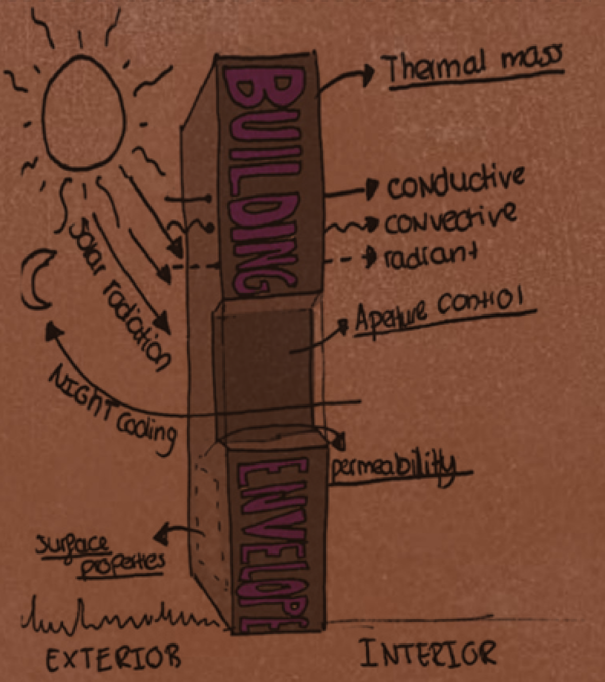


Figure A12 Schematic representation of envelope-scale performance dimensions in hot–dry.
Note. Author's own drawing.

Material-related properties constitute an important performance dimension, described in relation to thermal resistivity and surface reflectivity (Okba, 2005). Okba (2005) also discusses the role of thermal mass, where high-capacitance construction contributes to a time lag that delays heat transmission through the envelope assembly.

In addition, the configuration of apertures is identified as relevant to envelope performance, discussed in relation to window-to-wall ratios and the use of shading elements to limit direct solar exposure (Okba, 2005). Beyond solar control, aperture configuration also influences the degree of enclosure provided by the building envelope, mediating openness and closure at the interface between interior and exterior environments (Okba, 2005). Glazing performance is further addressed in terms of controlling solar energy transmission through transparent envelope components (Okba, 2005).

6.3 Material-related performance characteristics of gabion-based envelopes

Building on the material and construction characteristics described in RQ1, this section focuses on those material properties of gabion-based envelopes that are relevant to envelope-scale performance. Gabion-based envelope systems consist of rectangular cages fabricated from double-twisted steel wire mesh and filled with loose stone material (Samayoa et al., 2018). A defining characteristic of the system is its substantial material mass, with the apparent density of the stone infill exceeding 17.5 kN/m³ as reported in existing studies (Samayoa et al., 2018; Shabanova et al., 2024). The internal configuration of the infill results in a porous assembly with interconnected voids, which contributes to the system's permeability to air and water (Samayoa et al., 2018; Shabanova et al., 2024). The material configuration and internal structure of a gabion-based envelope are illustrated in Figure A13.

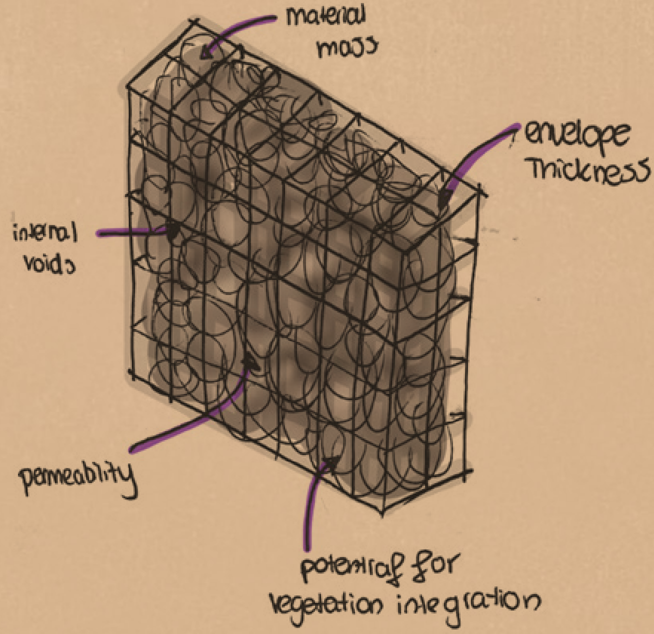


Figure A13 Schematic representation of material-related characteristics of a gabion-based envelope
Note. Author's own drawing.

In non-loadbearing envelope configurations, where gabion assemblies are structurally decoupled from the primary load-bearing system, such material characteristics can be expressed more freely without being constrained by structural stability requirements. This condition primarily affects the degree of porosity, envelope thickness, and material openness, rather than introducing additional performance mechanisms. Variations in envelope thickness and material openness under non-loadbearing conditions are conceptually illustrated in Figure A14.

The infill material is required to exhibit specific durability properties, including resistance to water and frost, while excluding soft or soluble stone types that may degrade over time (Shabanova et al., 2024). Infill geometry is constrained by the mesh aperture, with stone dimensions selected in relation to the nominal opening size to ensure material retention and structural stability

Figure A14 Envelope thickness and material openness in non-loadbearing gabion envelope configurations.
Note. Author's own drawing.

(Samayoa et al., 2018). In addition, gabion-based systems undergo gradual consolidation over a period of three to five years, as voids within the stone infill become partially filled with soil and organic matter (Shabanova et al., 2024). This process alters the internal structure of the envelope over time and enables the incidental integration of vegetation within the gabion assembly (Shabanova et al., 2024).

6.4 Operationalisation of climate-responsive performance criteria

To operationalise climate-responsive performance at the building envelope scale, this research defines a set of qualitative criteria derived from theoretical descriptions of building envelope behaviour in hot–dry climates (Okba, 2005) and envelope-related performance considerations discussed in recent literature (Elnabawi et al., 2024).

The first criterion relates to thermal regulation and considers the presence of material mass and envelope resistance in relation to heat gain control and temporal heat delay (Okba, 2005; Elnabawi et al., 2024). The second criterion addresses solar control and focuses on surface properties and the regulation of solar transmission through envelope openings and glazing characteristics (Okba, 2005; Elnabawi et al., 2024). The third criterion concerns permeability and examines the capacity of the envelope to allow air movement and heat dissipation through porous material configurations or integrated openings, as described in the literature (Okba, 2005; Shabanova et al., 2024).

6.5 Implications for enclosure and inhabitation

While enclosure is not treated as a primary performance criterion, the material configuration of gabion walls defines the physical boundary between interior and exterior. The assembly consists of a steel wire mesh cage with defined opening dimensions, filled with loose stones sized between 1.5 and 2.5 times the mesh opening to prevent material flow-out (Samayoa et al., 2018). Consequently, the untreated envelope does not provide a hermetic barrier, a condition evidenced by architectural applications where additional interior coatings, such as clay or lime plaster, are introduced to ensure hygiene and complete physical separation for specific functional requirements (Conti et al., 2016).

Regarding water interaction, the hollow structure of the stone packing enables free drainage through the envelope, preventing water accumulation within the wall assembly (Uray, 2022). Ultimately, the mesh geometry and stone grading determine the void sizes within the assembly, defining the degree of permeability and physical separation as implications of material openness rather than as functional design objectives.

6.6 Interim conclusion

This chapter identified envelope-scale performance aspects relevant to hot and dry climatic conditions and translated them into a set of qualitative analytical criteria. Drawing on theoretical literature and descriptive studies on gabion-based systems, the analysis defined criteria related to thermal regulation, solar control, and permeability. These criteria do not evaluate performance outcomes, but establish a structured framework for examining material properties at the building-envelope scale. This framework provides the basis for assessing the potential alignment between selected construction debris and climate-responsive envelope requirements in the following chapter.

7. CONSTRUCTION DEBRIS IN HOMS: ENVELOPE-SCALE ALIGNMENT

7.1 Introduction

In the context of Homs, “basic safety clearance” refers to restricted interventions prioritising re-establishing of mobility along primary transport routes over extensive site remediation (UN-Habitat, 2022). While this process successfully cleared main streets to facilitate initial returns, it did not result in the full removal of conflict-generated waste from the urban fabric. Instead, significant amounts of debris remain as a residual material condition, obstructing secondary streets and building up in informal dumpsites within residential sectors (UN-Habitat, 2022). This limitation means that inhabitants returning to these areas continue to live amidst millions of tonnes of pulverised building materials, facing prolonged exposure to dust and unmanaged debris piles situated directly within their living environments (Zwijnenburg & te Pas, 2015).

7.2 Material composition

Quantitative analysis of the residential sector in Homs identifies 17 distinct material types within post-conflict construction debris, heavily dominated by cementitious components (Zydia et al., n.d.). Reflecting prevailing pre-war construction practices, the debris inventory consists primarily of concrete- and masonry-based materials. Reinforced concrete represents the largest single fraction of the damaged material stock, followed by substantial volumes of plain concrete and cement bricks (Zydia et al., n.d.). Mortar and clay are also present as significant constituent elements within the debris, contributing to the overall volume of mineral material (Zydia et al., n.d.).

In comparison, metal components occupy a markedly smaller share of the total mass, with steel identified as a minor but distinct category. These six components, reinforced concrete, plain concrete, cement bricks, mortar, clay, and steel, constitute the dominant fractions of the recorded demolition waste in Homs (Zydia et al., n.d.) The quantitative composition of post-conflict construction debris in Homs is summarised in Table A1, indicating the dominance of concrete- and masonry-based materials within the damaged building stock (Zydia et al., n.d.).

Building Material	Material inventory (Kg/m²)	Materila stok (ton)	Damaged (ton)
Plain concrete	365.89	16588499	1141425
Reinforced Concrete	457.49	20741459	1427182
Steel	27.33	1239092	85260
Cement Bricks	377.37	17108740	1177222
Mortar	64.95	2944446	202602
Clay	122.76	5565473	382950

Table A1
Material inventory, material stock and the damaged materials in Homs
Note. From “Material Inventory Analysis of Residential Buildings in Homs, Syria for Rehabilitation” by Zydia et al. (n.d.).

7.3 Exclusion of hazardous and non-reusable debris

This research excludes specific debris categories based on safety and regulatory considerations. Construction rubble containing hazardous substances, particularly asbestos, is excluded due to the severe public health risks associated with exposure and handling (Zwijnenburg & te Pas, 2015). Furthermore, the analysis excludes debris contaminated by the collapse of waste management systems, which has resulted in the mixing of construction by-products with household and medical waste (Zwijnenburg & te Pas, 2015). Finally, sites contaminated by undetected explosives are defined as outside the scope of research, as these remains constitute critical security hazards requiring specialized clearance rather than architectural material assessment (UN-Habitat, 2022).

7.4 Material properties relevant to gabion-based envelope systems

The physical properties of post-conflict construction debris in Homs, primarily concrete- and masonry-based materials, define the parameters within which such materials can be considered in relation to gabion-based envelope systems (UN-Habitat, 2022; Zwijnenburg & te Pas, 2015). Existing literature on gabion construction shows that infill fragments must exceed the nominal mesh opening by at least 1.3 times, with maximum dimensions of approximately 250 mm, to ensure material retention and stable packing (Shabanova et al., 2024). Apparent density and fragment angularity further influence internal friction and overall stability within the gabion assembly, particularly when irregularly shaped concrete and brick fragments are used as fill material (Ghimire et al., 2024). These material characteristics establish both the potential and the limitations of using heterogeneous construction debris within gabion-based envelope systems.

Figure A15 schematically illustrates how fragment size and packing behaviour influence material retention within gabion assemblies

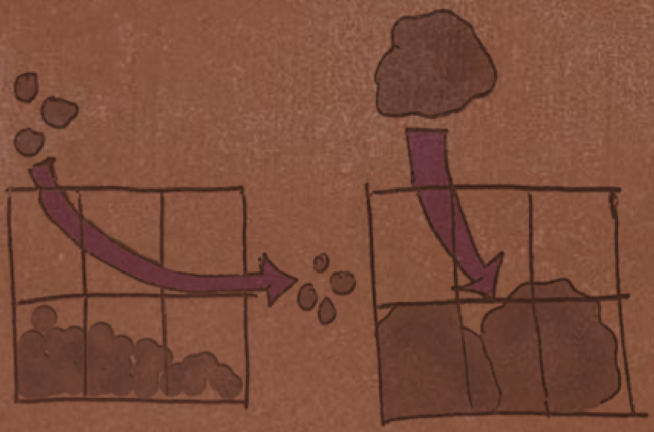


Figure A15 Schematic representation of fragment size and packing behaviour in relation to gabion mesh retention.
Note. Author's own drawing.

7.5 Matching debris types with envelope-scale performance criteria

To enable a systematic comparison between heterogeneous debris types, this nalysis assesses material properties through three envelope-scale parameters: fragment size, packing density, and resistance to water-related degradation. Figure A16 schematically illustrates how fragment size, packing density, and water resistance influence the relative alignment of debris materials with envelope-scale performance criteria. Reinforced concrete and masonry fragments exhibit high material density and mass, corresponding to the thermal mass criterion identified at the envelope scale in RQ2. According to Shabanova et al. (2024), an apparent density exceeding 17.5 kN/m³ is required to ensure stable packing and structural safety in gabion assemblies. In addition, the angular geometry and irregular shape of fractured concrete and brick fragments introduce variable voids within a gabion assembly, which can be related to envelope-scale considerations of permeability and enclosure (Ghimire et al., 2024; Shabanova et al., 2024).

At the same time, limitations are evident. Pulverised materials and fine particulates present within Homs' debris inventory fail to meet standard granulometric requirements for gabion infill and may obstruct permeability (Shabanova et al., 2024; UN-Habitat, 2022). Furthermore, soluble or weak inclusions in masonry residues, such as degraded mortar, introduce durability constraints that may lead to deformation or settlement when exposed to moisture (Shabanova et al., 2024). Within this analytical framework, large concrete and masonry fragments have the highest degree of alignment with the envelope-scale performance criteria, whereas small particles and weak or permeable inclusions are limiting material conditions.

7.6 Interim conclusion

This chapter investigated the material condition of post-conflict construction debris in Homs following basic safety clearance. It established that significant amounts of non-hazardous mineral debris, mainly consisting of concrete and masonry fragments, remain embedded in the urban fabric. By excluding hazardous and non-reusable materials, the analysis concentrated on debris types that are relevant to architectural reuse. The chapter identified which material conditions align more closely with envelope-scale performance criteria based on fragment size, packing density, and water resistance. This provides a solid material foundation for assessing the architectural potential of debris used in gabion-based building envelope systems.

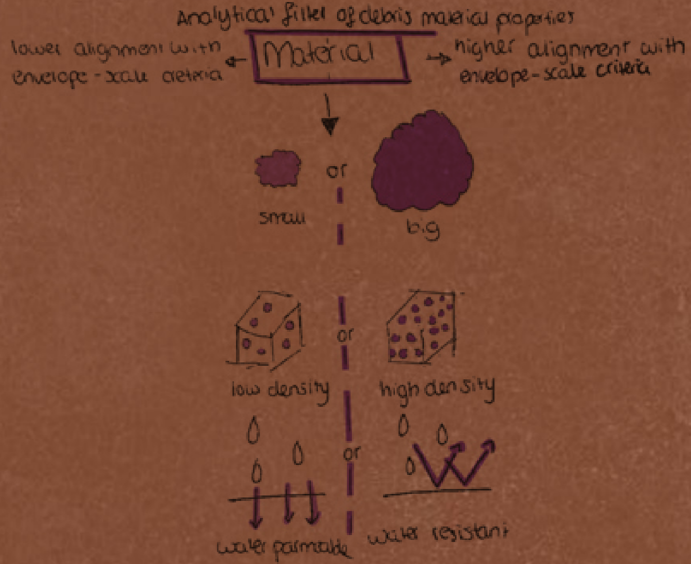


Figure A16 Analytical filter relating debris material properties to envelope-scale performance criteria in gabion-based envelope systems
Note. Author's own drawing.

8. CONCLUSION

This research examined the reuse of construction debris as climate-responsive gabion-based building envelope systems in post-conflict Homs, Syria. The analysis synthesised findings across construction logic, envelope-scale performance criteria, and material alignment.

The examination of construction logic established that gabion systems can be translated from infrastructural origins to the architectural envelope scale. Two primary configurations were identified: load-bearing assemblies, which require monolithic interlocking for stability, and non-loadbearing skins, which are structurally decoupled from the primary frame (Samayoa et al., 2018; Uray, 2022). The latter permits variations in porosity and packing density that are structurally constrained in load-bearing applications (Fortier et al., n.d.).

In the hot and dry climate of Homs, the building envelope must mediate severe thermal exchange (Naaouf & Torma, 2023; Okba, 2005). The analysis identified thermal mass, solar control, and permeability as key qualitative performance criteria at the envelope scale. Gabion assemblies relate to these criteria through their substantial material mass, with apparent densities exceeding 17.5 kN/m^3 , and their inherent porosity, which allows air and heat transfer (Samayoa et al., 2018; Shabanova et al., 2024).

The material inventory in Homs reveals a dominance of concrete- and masonry-based debris (Zydia et al., n.d.). Large fragments of reinforced concrete and brick demonstrate the strongest alignment with the identified envelope-scale criteria, particularly in relation to thermal mass and stable packing. In contrast, pulverised materials and fine particulates obstruct permeability and fail to meet granulometric requirements, limiting their applicability within gabion-based envelope systems (Zwijnenburg & te Pas, 2015; Shabanova et al., 2024).

This research is analytical rather than propositional. The primary limitations consist of the exclusion of hazardous materials, the qualitative nature of the performance assessment, and the lack of quantitative simulations. These findings establish an analytical foundation that informs the selective material focus and envelope-scale exploration developed in the graduation project.

APPENDIX C : ASBESTOS: THEORETICAL BOUNDARY (NOT PART OF RESEARCH PAPER)

1 Identification and Exclusion Logic

Asbestos is a naturally occurring fibrous silicate material that was historically applied for its insulating and mechanical properties. Its commercial use mainly involved chrysotile (serpentine) and amphibole types such as amosite and crocidolite (Spasiano & Pirozzi, 2017). Due to a proven connection between fiber inhalation and severe health effects, the material is banned in many jurisdictions. Standard safety practice requires the complete removal and disposal of asbestos-containing materials (ACM) in controlled waste sites to prevent fiber release (Spasiano & Pirozzi, 2017).

Furthermore, literature indicates that debris free of inbuilt asbestos may still require exclusion from reuse streams because of cross-contamination. During "whole-building demolition" of constructions, porous and hard ACMs can mix with solid rubble, polluting the entire debris volume. Consequently, even mineral debris that does not naturally contain asbestos must be classified as hazardous until proven differently, resulting in severe exclusion rules (Webber et al., 2004; Perkins et al., 2007).

2. Economic and Logistical Aspects

The management of asbestos waste is increasingly restricted by rising costs and logistical difficulties. Recent reviews highlight that while landfilling remains common, it is increasingly viewed as an inadequate long-term solution, driving the development of sustainable thermal and mechanical recycling technologies (Durczak et al., 2024). Traditional disposal via landfilling is becoming unsustainable due to limited capacity and rising disposal fees, which can reach averages of €199 per ton (Marian et al., 2021). While alternative thermal treatments like plasma vitrification were historically costly (€1,000–€2,500/ton), recent innovations have lowered energy consumption significantly.

New inactivation methods are expected to cost approximately €60–€70 per ton, making them economically competitive with landfilling (Marian et al., 2021). However, the logistics of handling ACM remain restricted by regulations requiring specialized containment to prevent environmental scattering, often conflicting with the rapid pace required in post-disaster clearance (Frangioudakis Khatib et al., 2023).

3. Mechanical Separation Approaches (Mulders)

Mulders (2013) describes a high-quality recycling approach using "Smart Crusher" technology. This technique operates on the principle of selective fragmentation, applying specific pressure to crush the weaker cement matrix without breaking the stronger aggregate stones. This removes the cement paste (containing the asbestos) from the aggregate, allowing the hazardous "light weight materials" to be removed via wind sifting (Mulders, 2013).

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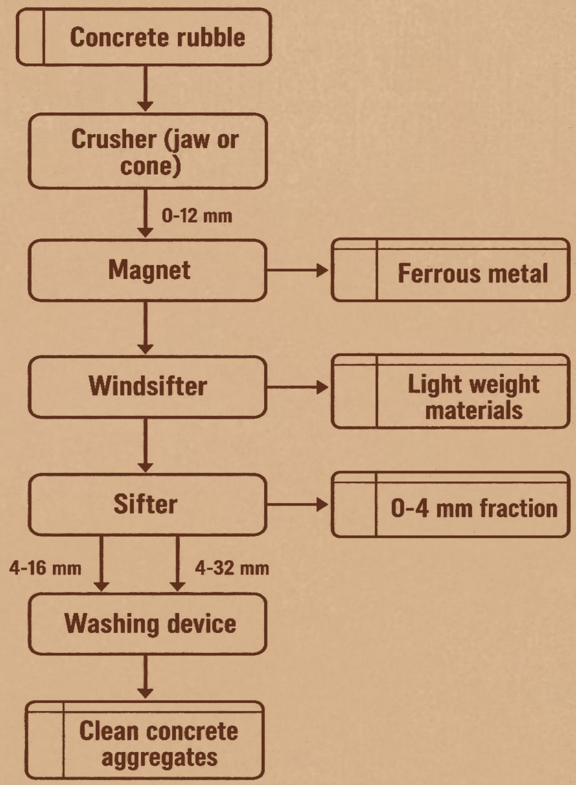

Figure B1 Crushing, sifting, washing method for preparing concrete aggregates for recyclin
Note. From * High quality C&D waste recycling: How can high quality recycling be promoted within the Dutch construction and demolition waste system?* by L. Mulders (2013).

While this method is suitable for producing clean granular aggregates for concrete production, it presents an essential problem with gabion-based reuse. The mechanical action required for removing the contaminated cement paste naturally reduces the material to gravel-sized particles (Mulders, 2013). Consequently, this process destroys the large fragmentary scale (>100 mm) required for gabion infill, making the material structurally unsuitable for architectural applications that rely on large fragmentary elements. While this approach is effective for producing clean granular aggregates suitable for the manufacture of new construction

materials, it simultaneously eliminates the possibility of retaining large fragmentary elements. In contrast, gabion-based reuse operates directly on the availability of such fragments, highlighting a trade-off between material purification and immediate architectural applicability.

4. Laser-based Techniques

Recent literature describes laser-based methods for both identification and treatment of ACM. This type of imaging has been noted as an emerging tool for the rapid, non-destructive identification of asbestos fibers in demolition waste (Serranti & Bonifazi, 2020). Regarding treatment, high-energy laser energy can induce the melting of the cementitious matrix at temperatures exceeding 1200°C. This transforms the surface into a “glassy layer” (vitrification) that traps hazardous particles and renders the asbestos inactive (Huynh et al., 2022). Research indicates that laser-induced vitrification produces a surface layer that is denser and more consolidated than the original material, which may improve resistance to weathering under controlled conditions (Klemm & Rożniakowski, n.d.). Experimental studies further show that nanosecond laser cleaning can result in a limited increase in surface hardness (Gao et al., 2023).

However, a critical safety constraint remains, as the ablation process generates shockwaves that can release fibres before thermal inactivation occurs.Recent studies indicate that up

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33% of particles emitted during laser ablation of asbestos-bearing rocks may be inhaled (Bloise et al., 2024). Therefore, while laser treatment can theoretically "seal" large debris fragments without crushing them, it requires sophisticated HEPA filtration directly at the source to prevent secondary contamination (Bloise et al., 2024; Geavanceerde Saneringstechnieken, n.d.). Several sources indicate that laser-based treatment must be combined with localised extraction systems, such as integrated suction and HEPA filtration, to limit secondary fibre dispersion at the point of ablation (Bloise et al., 2024; Geavanceerde Saneringstechnieken, n.d.).

5. Foam-based Suppression and Labor-based Models

To reduce fiber release during processing, the literature details the use of "amended water" and specialized foam suppressants. These substances reduce surface tension, allowing for deeper penetration into the ACM to cover fibers before they become airborne (Perkins et al., 2007).
In contexts where mechanical crushing is inappropriate, such as the recovery of whole bricks, labor-based models are discussed. "Brick cleaning," the manual or mechanical removal of mortar is noted to be profitable where labor costs are balanced by the high value of reclaimed vintage bricks (Klang et al., 2003). For ACM-contaminated bricks, this process requires strict containment and wetting protocols to ensure worker safety (Obminski & Janeczek, 2020).

6. Mobile Equipment and Economic
Feasibility

The literature emphasizes the role of mobile or transportable equipment in post-conflict or remote contexts. High-tech solutions, such as laser cleaning, entail high capital costs that are often expensive for single sites. However, the use of mobile units allows these fixed costs to be spread across multiple projects (ALARA, 2000). By sharing the technology as a transferable asset, the unit cost per ton of treated debris is significantly reduced. This approach aligns with recent developments in plasma technology, where mobile or modular systems are being designed to treat hazardous waste closer to the source, reducing the risks and costs associated with transport (Deegan et al., 2006).

7. Synthesis of Theoretical Constraints

The reviewed literature does not describe a single integrated process for addressing asbestos contamination in construction debris at a scale relevant to architectural reuse. Instead, individual studies focus on isolated aspects such as identification, fibre suppression, mechanical separation, or thermal surface treatment. When considered together, these studies illustrate the range of technical conditions and constraints that would need to be addressed before mineral debris could be classified as inert.

This alignment is presented as an analytical and hypothetical reading of the literature. While it does not constitute a validated or operational process, it illustrates how separate

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techniques described in different bodies of research could conceptually be

8. Conclusion for Research Scope

Although the literature describes several techniques that address specific aspects of asbestos contamination, there is insufficient empirical evidence to demonstrate that these approaches can be integrated into a reliable process for architectural material reuse. As a result, asbestos-containing debris is excluded from the present research.The architectural investigation therefore enters the material chain at the point where construction debris has already been identified, verified, and classified as asbestos-free. The processes required to reach this condition are acknowledged but treated as a precondition rather than as part of the architectural scope. The hypothetical alignment of asbestos treatment techniques outlined above is not examined or tested within this graduation project. It is included to clarify the position of the architectural research within the broader material chain. The feasibility, safety, and operational integration of such a sequence remain subjects for future tech nical research beyond the scope of this work.

Figure B2 does not represent a validated or proposed process. It visualises a hypothetical alignment of individual operations described across different bodies of literature to illustrate the complexity of asbestos handling prior to architectural reuse

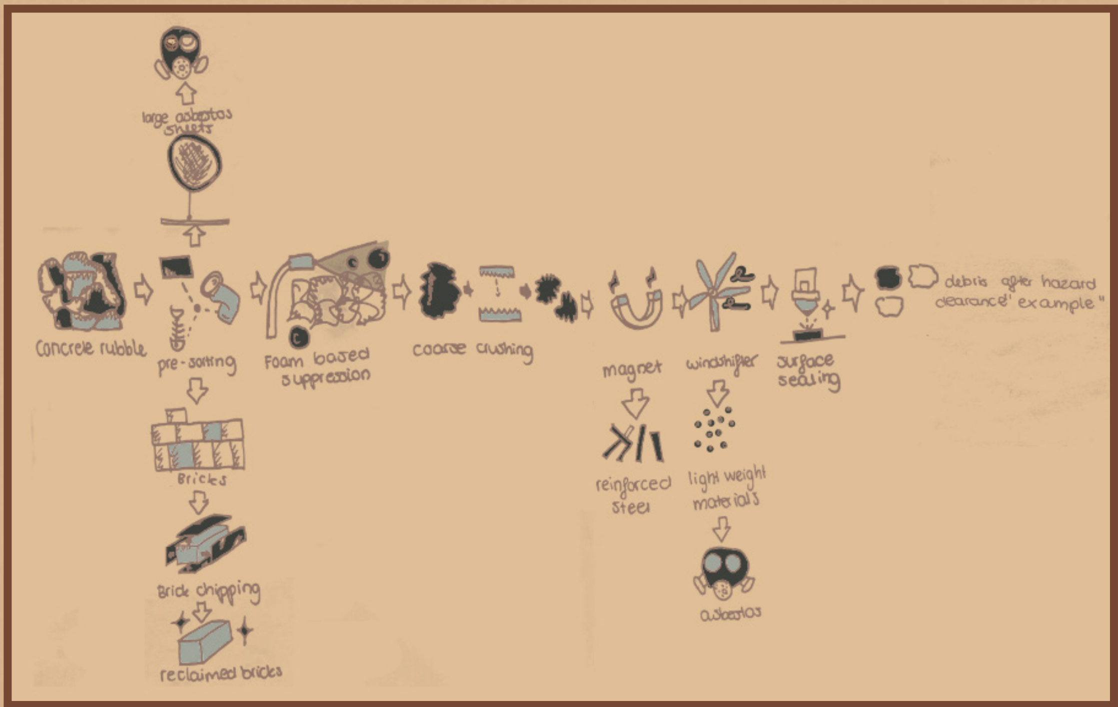

Figure B2 Hypothetical alignment of asbestos-handling operations described in literature
Note. Author's own drawing.

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