DIGITAL MODULARITY

Systematic Computational Aggregations of Digitally (Pre)fabricated Modules

Theodor Tsesmatzoglou
Chalmers University of Technology
Department of Architecture and Civil Engineering
Examiner: Jonas Lundberg
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Theodor Tsesmatzoglou
Master Thesis in Architecture and Urban Planning
June 2019
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ABSTRACT

The architectural discipline has in general taken the role of the follower of the technological advancements in the building industry. This fact, in combination with the consolidation of the overall industry, the mass prefabrication and the diminished role of the architect, render the future of the discipline itself unsure. In this era of change, digitalisation and technology integration, architects have a unique chance to embrace technology, use computation, learn from material sciences, engage with the modes of production and consequently gain the lost territory in the sector. This can be achieved through understanding and adopting the need of modularisation and prefabrication in the contemporary building industry, creating modules that, by their aggregation, can add architectural qualities to the interior of the buildings and diversity in the urban fabric.

This thesis aims to result to a functional building through computational aggregations of a modular system consisting of a small number of different, reversible modules from the same module-family. This kind of modular system provides the architect the tools to work with tectonics in a prefabricated building that is inherently flexible and reversible, allowing the tenants to expand and contract their living space according to their needs. Using existing technological advancements, mostly in digital fabrication, the architect designs the fabrication and assembly of the modules taking control of the modes of production. In addition, the architect is in control of the assembly process on the building site, since the assembly sequence is a result of the module-family's characteristics. All in all, this thesis addresses prefabrication and mass production in architecture, under the scope of computational aggregations and digital fabrication.

Keywords: Computation, Aggregation, Discrete, Modular System, Digital Materials, Prefabrication, Mass Production, Digital Fabrication

CONTENTS

Figure 1. Productivity Gains by Industry in the United States. (The Economist)

The efficiency in the US building sector the past almost 100 years has been steady or even decreased. On the other hand, in sectors as manufacturing and agriculture the efficiency has risen 800% and 1600% respectively mostly due to standardisation and the adoption of digital technologies. This is not just a phenomenon present in the American market despite the construction companies basing their operations to prefabrication and economy of the scale.

The conservative building sector is starting to adapt to the markets' needs in an alarming way for architects especially in Sweden. Construction companies became bigger through consolidation from the 60's and onwards creating a market resembling an oligopoly. Their stature allows them to dictate how the buildings are going to be built. They are training their builders to work with a handful of building systems bought cheap -thanks to the economy of scale- leaving small, if not none, space for creative building solutions to the architects, leading to a homogeneous built environment that frustrates the society. A contributing factor to this situation is the turnkey contracts, that are the rule in the building sector of Sweden, allowing the construction companies to use the architects as consultants and hire different practices in latter stages of the projects. Practices that often do not question the standardised solution the contractor is using, resulting to buildings of questionable qualities, that have no traces of the earlier ideas and qualities the original architect had. At the same time the contractor get a healthier bottom line in the quarterly financial report.

Another alarming signal is the ongoing consolidation in the building consultant area. Large consultant firms, which during the 90's and 00's were focusing in consulting as structural, MEP and acoustic engineers, are buying up architectural firms, providing complete solutions to the construction companies, while the architectural discipline diminishes to a consultancy role, instead of being the force evolving and improving the built environment. In other words, this model provides a more attractive package to contractors working with turnkey contracts.

Although the blame should not be thrown solely to the construction and consultancy sector. The architects themselves led the discipline to this point. Modernism's ghost still hunts the discipline leading the architects to feel guilty for their forefathers' sins. At least, these "guilty" forefathers, had the courage to propose a new kind of architecture that would answer the questions of the modern living proposing not just a new architectural style but also proposing a vision about the society. In the contrary, the contemporary practices choose, most often, to debate with each other inside the "protected" environment of the discipline itself instead of being active in the public debate. The overall stakeholders, though, are vocal in public debates, promoting standardisation and deregulation as the only way to solve the housing problem in the country, a development that will enable them to build even cheaper with even less architectural qualities.

Furthermore, the stakeholders in the building sector (besides architects) try to embrace new technologies to make the production cheaper and more effective following mostly the established capitalistic paradigm. Construction companies collaborate with industrial partners to automate obsolescent and dated processes (e.g. gypsum board mounting robots) to reach their goal of even more profitability. But is the automation and digitalisation of old techniques really what is going to create a better built environment? What is the future of the architectural discipline if it becomes a follower of new techniques and technology dictated by the building sector, instead of an innovator in these field? This thesis stems from the premise that the role of the architect-consultant is going to be minimal, if not non-existent, in the future. Neil Leach argues that, "the profession is struggling to survive in a period of volatile economic conditions, especially as the territory of the architect has been encroached on by other professionals within the construction industry, such as project managers, construction managers, engineers and quantity surveyors." (Leach, 2017) But the discipline has a great opportunity to reverse this trend by adaptation of digital technologies and the promotion of innovation by the architects themselves.

The available digital tools give the opportunity to architects to engage with the modes of production, bypassing the construction companies in order to design buildings that are both economically viable and qualitative. As Gilles Retsin argues, "Architects can use their understanding of digital work-flows to contribute ideas to a vivid cultural and political debate about the future of capitalism, automation, the status of the city, housing, etc." (Retsin, Discrete and Digital, 2016). Although, this cannot be achieved solely by architects. Nowadays, both the society and building sector are very complex for just one discipline to come with solutions. Multidisciplinary work is needed to tackle the complexity. The adoption of new technologies implies per se the close collaboration with computer scientists, for example. When it comes to the building sector though, the architect should be the coordinator of the different disciplines, since the architectural education provides the tools to understand both the technical aspects of the engineering as well as the standing points of disciplines as sociologists.

An interesting approach to this problematisation is the use of so-called "Digital Materials". This approach is used mostly in Unit 19 of UCL Bartlett where researchers as Gilles Retsin, Manuel Jimenez Garcia and Mollie Claypool teach. Their research is focusing in the use of modules in buildings that have specific properties. These properties are also apparent in materials evolved by MIT's Center for Bits and Atoms, led by professor Neil Gershenfeld, where the name "Digital Materials" stems from. The duality of the term, though, can be confusing to many since the "digital" is mostly associated with something virtual, while the "materials" are by definition physical. This duality works very well for the provocative theories expressed by the researchers of Unit 19, since they are proposing a wholly digital approach to architecture where no physical aids (e.g. drawings) are needed. The proposed approach might work well in an academic environment where the goal is to stimulate the students' creativity, although, in order to reach to "All Digital" in the built environment there has to be a transition period.

Figure 2. Gypsum-board mounting robot, developed by NCC, ABB and Build-R. (Dagens Industri)

BACKGROUND

THE CASE OF “DIGITAL MATERIALS”

“We have never been digital”. A completely true statement. Nowadays when architects are referring to digital architecture, they mean architecture that has been designed with digital tools as CAD and BIM programs or with the help of computational methods such as programming, both traditional coding and visual programming. As Neil Leach argues “there is no product as such that might be described as digital” (Leach, 2015). Even if an object is created with the help of a computer program that can be defined as digital, the manufacturing techniques available such as CNC carving or 3D-printing require a post-rationalisation of the object, more often slicing, in order to be produced. This post-rationalisation is a fundamentally analogue process.

Mario Carpo have made a distinction to the different eras of the digital design. According to Carpo, the first generation of architects working with digital design, was using continuous mathematical models (NURBS) to create their designs. In other words, both the design and the final product were analogue. The second generation is characterised by the use of computational methods, which are inherently digital, to design although the product is analogue since the production methods are analogue. What Retsin is arguing is that the natural evolution is to use computational methods to design physically digital products.

In order to be able to answer this question we have to define what digital actually means. According to the Merriam-Webster dictionary digital is an adjective “of, relating to, or using calculation by numerical methods or by discrete units” or an adjective that characterises something “composed of data in the form of especially binary digits”, in other words, zeros (0) and ones (1). For example, we can communicate the information of the capital letter “A” with an 8-bit binary system in the following way: “01000001”. The capital letter “B” in its turn is being communicated with the following string: “01000010”. Both strings contain the same number of zeros and ones, although the sequence is different, allowing the system to understand what we are communicating to it and enabling us to change the communicated information just by rearranging the sequence of the foundational bits. This example that contains 6 zeros and 2 ones can give us:

$\frac{8!}{6!\times 2!} = 112$ different combinations.

The researchers at the MIT Center for Bits and Atoms are researching the development of physical materials that consist of components that could be described as puzzle or LEGO pieces. Those materials have the following attributes:

1. All components can be decomposed into smaller elementary geometrical shapes.
2. There is a finite number of combinations between two components.
3. The links between the components are reversible, meaning that when components are connected to each other, creating a material, they can be disconnected without damaging the pieces themselves, allowing them to reconnect again if needed.

The attributes 2 and 3 are the same that the zeros and ones have, supporting the characterisation of these materials as digital. The scale of these components is very small, more often a couple tens of a micrometre, thus being not useful in the larger architectural scale of buildings such as housing complexes. Furthermore, these materials are highly repetitive and homogeneous resulting to structures that are efficient , but not complex in terms of formal possibilities.

Figure 3. Physical model of Digital Materials developed by the Center of Bits and Atoms, MIT

Figure 4. Structure made of Digital Materials

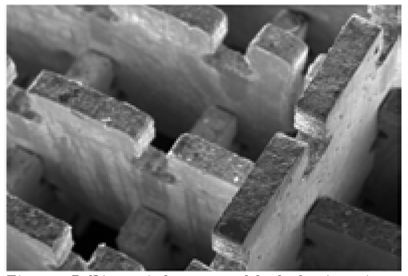


Figure 5. Discretely assembled electronic Digital Materials, Center for Bits And Atoms, MIT


Figure 6. Greg Lynn, Embryological House: Size "A" eggs, ca. 1999


Figure 7. T1-chair studies, Philippe Morel


Figure 8. Digital Grotesque II, Michael Hansmeyer, Benjamin Dillenburger

Mario Carpo, in his article "Breaking the Curve", argues that the first generation of computer-based design was hijacked by the Spline, which is fundamentally a mathematical, thus continuous, model proposed by Pierre Bézier and Paul de Casteljau, in the late 50's, early 60's, to aid car designers. During the 90's spline modelling tools became widely available and free-form architecture started emerging. Although there is a fundamental distinction between "spline-makers" and gifted designers as Gregg Lynn and Frank Gehry. The former was using calculus as primary tool for his designs, while the latter used computers to scan, measure, notate and build irregular, non-geometric three-dimensional shapes.

In the early 00's the Internet boom signalised the start of a new era with emphasis in participation and interactivity. Little did it impact the designers though. A new generation of designers being taught by the early pioneers of the 90's, continued in the same trail, establishing the spline making as the style of the digital age. A big contributory factor to that was the evolution of the fabrication methods that allowed the designers to materialise free forms.

One of the recent trends in computation, that is gaining momentum, is big data, or data analysis. Throughout human history, the storage and relay of data was limited by several factors. Two simple examples are the size of physical books, that demanded a condensed version of the information, and the ways older computers stored information, that in it's turn required big physical space and a lot of computational power to access the desired information. Nowadays though, storing the information has been simpler, cheaper and more accessible as long as there is a computer with an internet access. The advancements in hardware manufacturing have also enabled the process of all data that can be gathered. This evolution has led to a fundamental shift. Instead of trying to find general rules to describe a phenomenon, we can just process existing data from its appearance and predict its reappearance. Such strategies are already being widely used in applied sciences, such as weather forecasting.

A similar approach can be observed even in design. Instead of working with splines, designers work with discrete fragments of splines, or subdivisions, being able to increase and decrease the resolution at will. Digital designers learn by doing, but at a much bigger scale, since digital simulations give them the power to test hundreds or thousands of iterations, in very short period of time. Lastly, Carpo points out that the tools we use to design, inevitably inform the design itself. Since big data are perceived by humans as chaotic, messy and rough, the architectural outcome of such a tool will also have the same properties.

A different approach to the use of big data and discretisation in architecture is the use of architectural digital materials. Using the research of Neil Gershenfeld from Center for Bits and Atoms on digital materials Gilles Retsin proposes the use of architectural digital materials, that are bigger in scale (metres instead of millimetres), are serialised, can be mass pre-fabricated and are easy to assemble. The term architectural digital material can be perceived as provoking by many and the fact that the up-scaled digital materials resemble more a module, lead me to call them modules from now on.

Since digital materials are a physical representation of the digital space, there is a direct connection between the virtual 3-d design and the built result. It is easier to simulate possible conflicts during the assembly, thus making the design process much more efficient and the assembly easier. The male-female connection between the modules, that is intently designed, simplifies even more the assembly, since two pieces either fit or do not fit to each other, thus having a pure Boolean logic inherent in their design, amplifying their digital nature.

Besides the efficient assembly method, the architect can also add architectural qualities to the module itself. Taking the serialisation of the module in consideration, the architect can change the form of the module so that, when aggregated, it creates the desired spatial effect.

The modules proposed by Retsin, provide advantages by their own construction as well. Being hollow boxes created by sheet materials are cheap and can easily be mass-produced by machines available even in almost every architecture school, let alone in industrial plans. This hollowness also provides the possibility of using this space for MEP installations or insulation.

The most interesting aspect of these modules, though, is the expandability and contractibility of the structures they create. Because these modules are the architectural evolution of Gershenfeld's digital materials, the reversibility is an essential inherent property, implying that the user of the space can in the future, if needed, expand or contract the space, without needing to move to a different smaller space or build an extension that usually is time consuming and expensive undertaking.

Finally, the module is a module. It is not a wall, it is not a beam, it is not a stair. If combined in the right way it can be whether a wall, a beam or a stair, providing even more flexibility to the end user for future alterations as well as a higher degree of prefabrication, leading to cheaper production.

To sum up, I argue that the use of these kind of modules allows the architect to gain control of the building process. Simultaneously, the architect is the sole designer of the module, thus controlling the final outcome, providing both economic and qualitative buildings to the end user. The simplicity of assembly and production gives the architect the control of the modes of production and the economy of the project, leading to bypassing the conservative building companies and eventually giving the architects a more important role and more responsibility into the building industry.

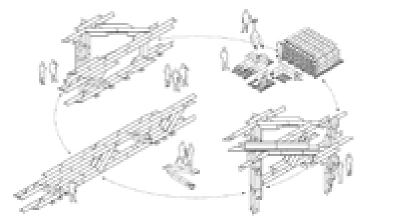


Figure 9. Assembly drawing. Tallinn Architecture Biennale Pavilion, Gilles Retsin

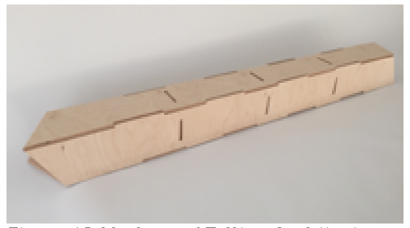


Figure 10. Mock-up of Tallinn Architecture Biennale Pavilion module


Figure 11. Tallinn Architecture Biennale Pavilion

THESIS APPROACH

The first element to be investigated is the basis for the development of a system based on the ideas stemming from the digital materials. The module itself. Setting the criteria of the module evaluation, a module based on the intersection of two hexagons is chosen and further iterated.

The next stage is the aggregation system. After some manual iterations to understand the module's possibilities and limitations a computational aggregation system is being developed, based on the Grasshopper plug-in WASP, developed by Andrea Rossi in TU Darmstadt. This system is boundary driven and the most important parameters of it is the resolution of the aggregation and the number of modules used.

The structural system upon which the aggregation is based is also an important part of the process. Through iterations the slab takes the form of a flat vault distributing the loads equally along its area, leading to the development of a grid based on the dimensions of the module. The structure is reinforced with beams consisting of the modules and by a core in the middle of the grid where the MEP installations are located. This core acts stabilising in the structure as well. Following the structure is the detailing, where the connections between the modules are developed as well as the connections of the beams and the slabs to the core. One more detailed examined is the windows, where in some cases special profiles are needed whereas in some others, more conventional solutions are preferred with the addition of extra pieces between the modules and the windows.

Lastly, the building volume is being defined taking into account all the above-mentioned parameters.

The information gained from every step was fed back to the previous iterations and steps through a feedback loop which led to further developments and adjustments. In order to make every step legible, I chose to present them individually.

THESIS APPROACH

In the context of the thesis, this approach provides a wide spectrum of investigations and allows the design of a building. Each of those fields (module, aggregation system, structure, detailing) could certainly be investigated deeper, although such investigations are extensive and could be four separate master theses.

The intention from the beginning was to touch each of those parts as much as possible in order to put them into the test. The module is chosen after some iteration and pushed to its limits. The aggregation system is not fully optimised. The structure is an attempt of a non-engineer to create a structurally sane solution. The detailing has its own imperfection, for example the waterproofing.

Although, this thesis was, from its beginning, treated as the start of a research project that will solve all these issues. The final iteration of this stage, the design proposal, embodies all the knowledge built up in the earlier stages and would not be feasible to achieve without going through all these stages of exploration and experimentation.

The ambition is to get all the aspects that work and do not work and feed them back to each aspect in order to further develop this research project in the future.

"With the construction industry increasingly developing into a semiatonomous sector, a tempting notion of architecture without architects presents itself." *-Reinier de Graaf*

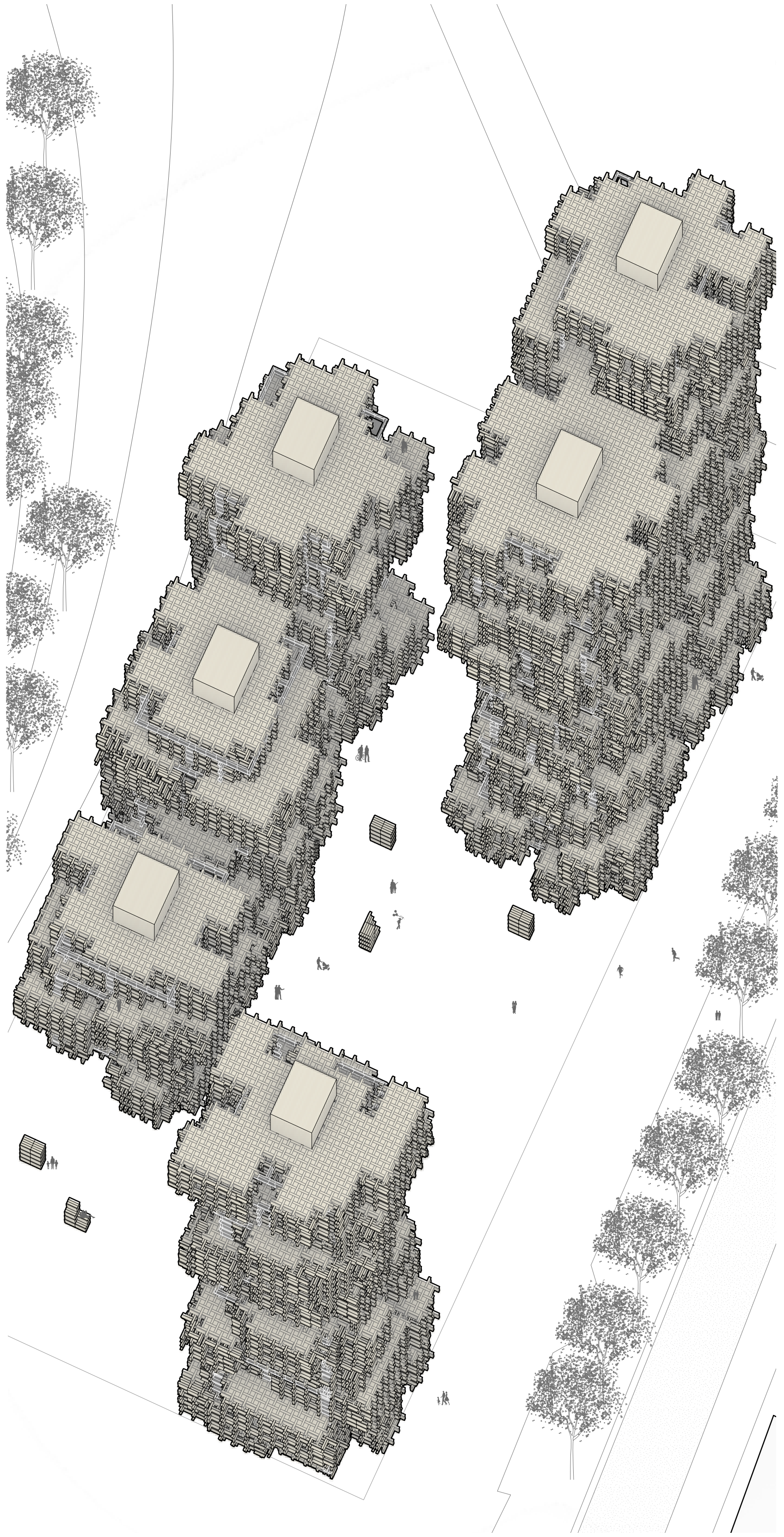
PROPOSAL

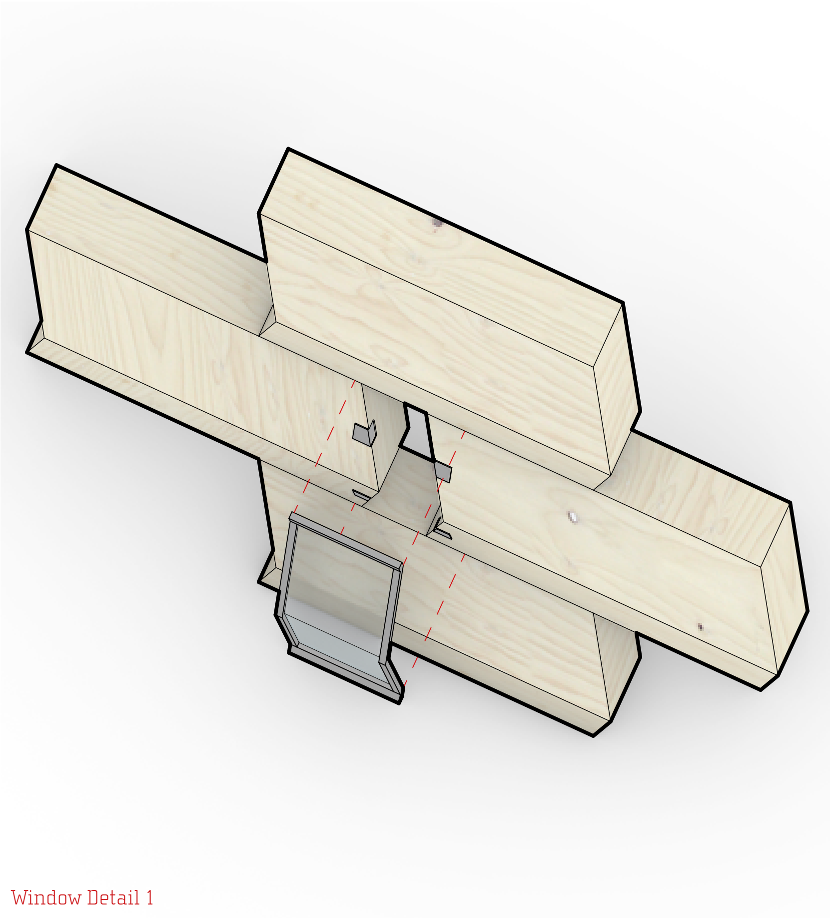
In order to put the system to the test, I worked with a housing high-rise as a case study. This typology fits the purpose of investigating the proposed system, since its inherent flexibility and the fast way it can be deployed would be ideal as an alternative to the contemporary housing construction norms.

The site is not thoroughly investigated. It acts mostly as a place-holder for this iteration of the system implementation. Its distance from the urban fabric provides the opportunity not to consider contextuallity, which would ideally be investigated in later iterations.

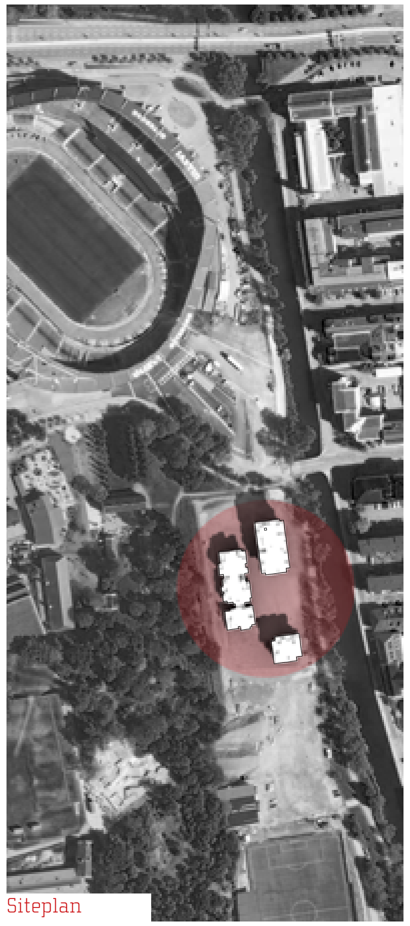
Six main buildings are placed to the site. One as a free-standing volume. Three are placed in such a distance between them that in some floors they can be connected. The same happens with the two buildings placed on the north-eastern corner of the site.

The form of each floor is free and not dependent of the the floors above or beneath. This is chosen in order to pinpoint the inherent flexibility of the system, since all the floors are made of the same modules, using the same detailing. This makes easy to understand that the form of every apartment and floor is completely free and the user can decide himself how to use the available grid, through negotiations with his neighbours that can create a unique kind of community.

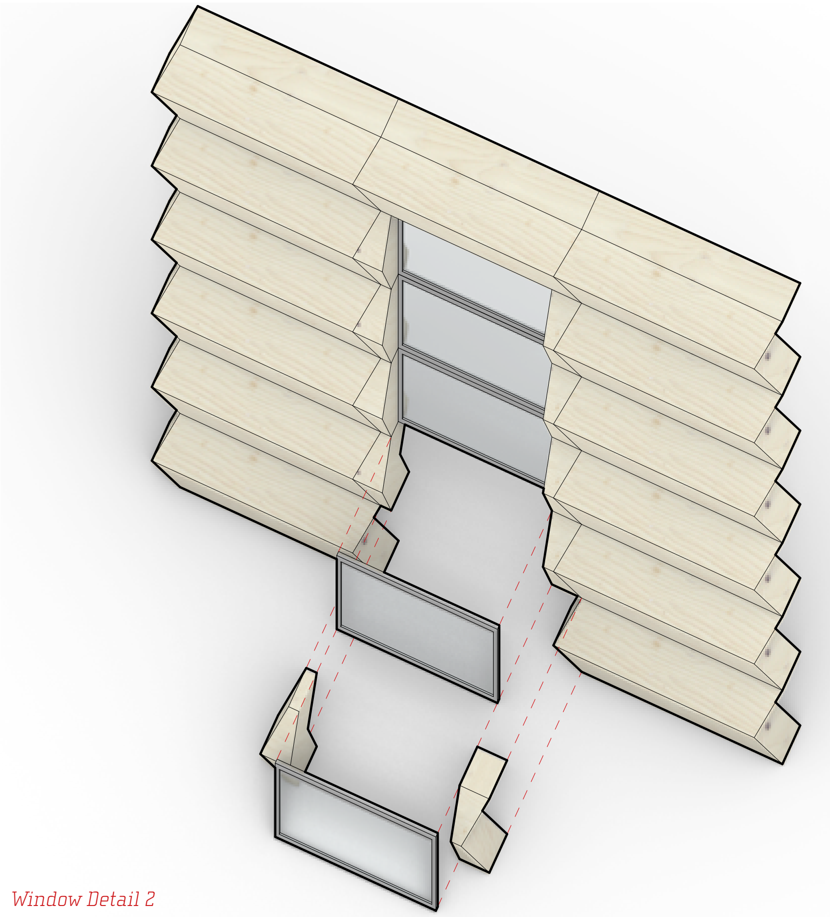




Window Detail 1



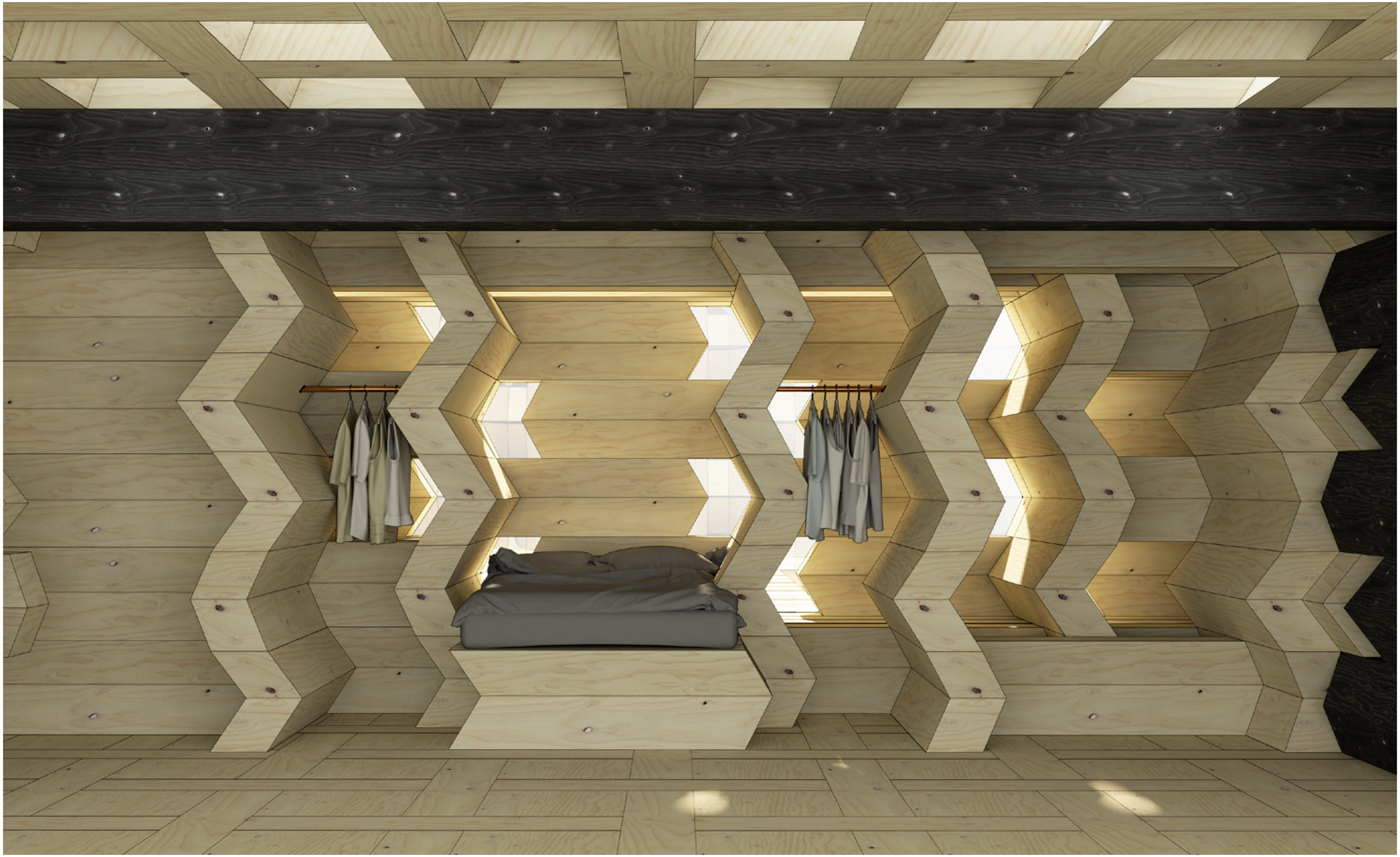
Siteplan



Window Detail 2

EXTERIOR

INTERIOR



INTERIOR

Since the module aggregates the best way in 90 degree angles, a grid approach is chosen for the structure. The grid shell size is based on the size of the module itself.

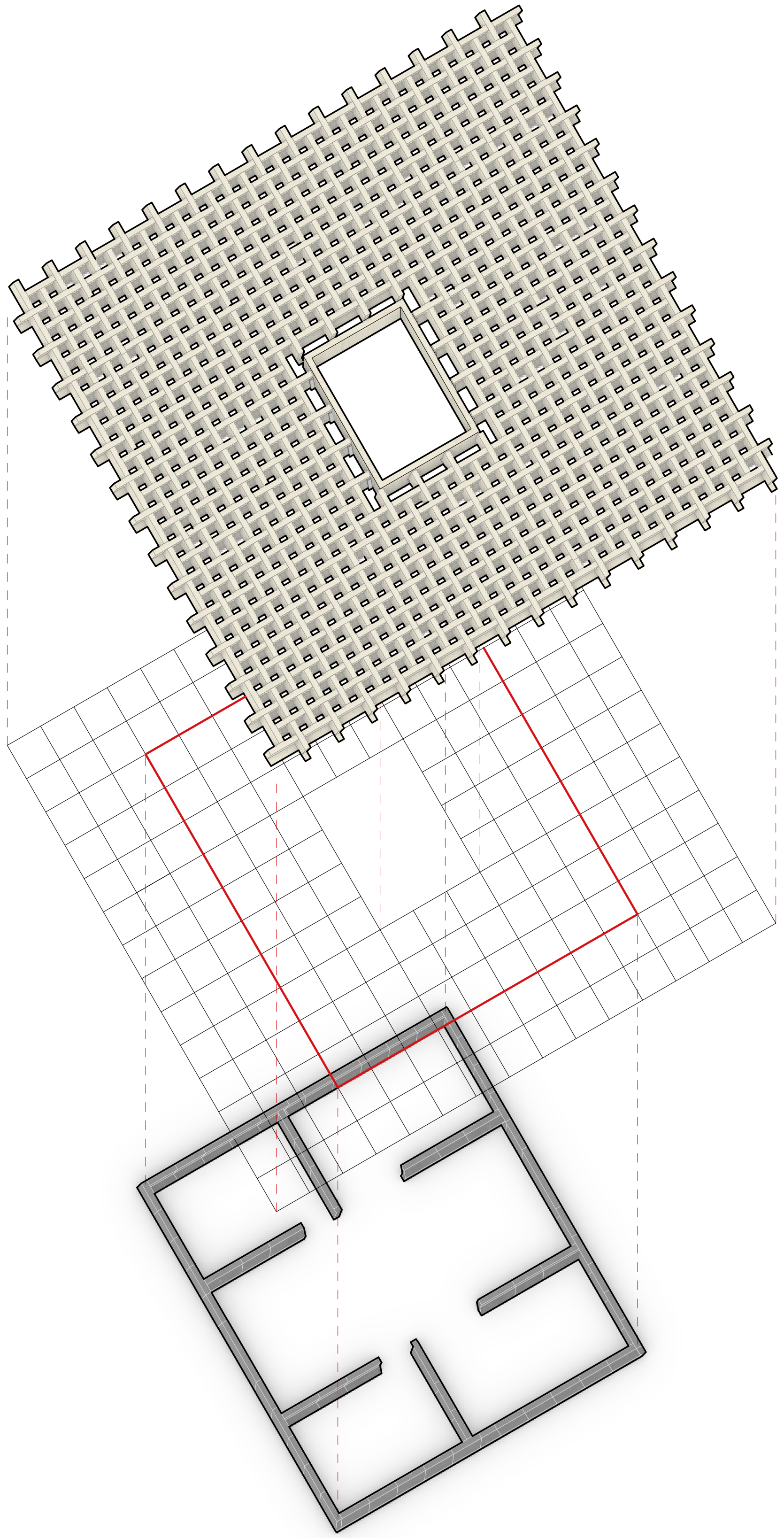
This combination of the module in grids creates a structural flat vault that distributes the loads equally along its surface.

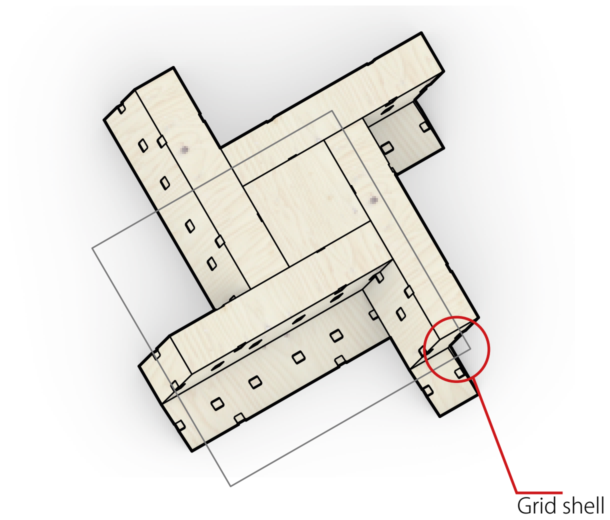
After consultation with a structural engineer the maximum allowed size of the grid is determined as well as the placement of the beams that distribute the loads further down to the next vault through the walls that are been connected either to the vault of the beams.

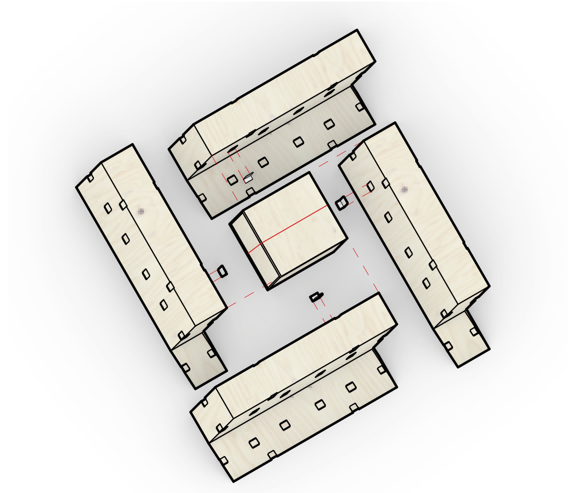
The beams themselves are also created from the same modules painted black though, in order to signalise that those modules are structural and should not be moved.

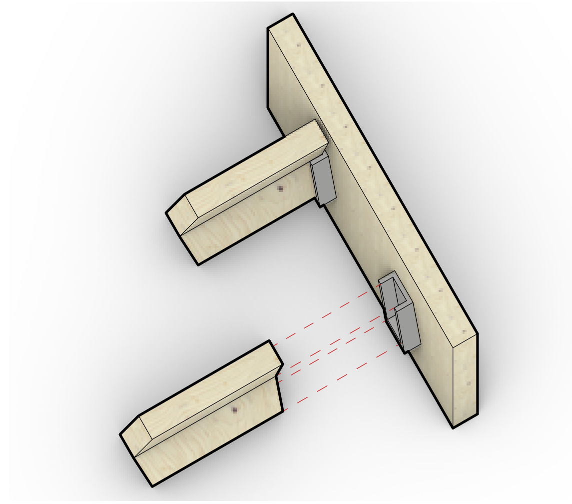
In the centre of the vault there is the stabilising core made by CLT. This core is also used for the installations of the building, so the user can be as free as possible to change the configuration of the apartment as wished. This means that in every apartment the bathrooms and the kitchens are being placed in connection to this core.

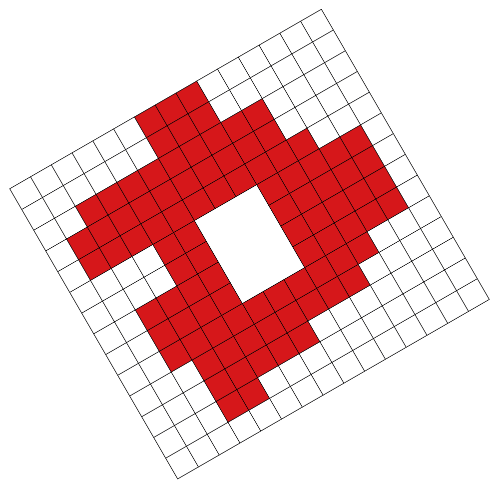
The gaps between the modules in the vault are being filled by boxes that can contain insulation as well as sound absorbing materials to prevent the sounds transmitting between floors.











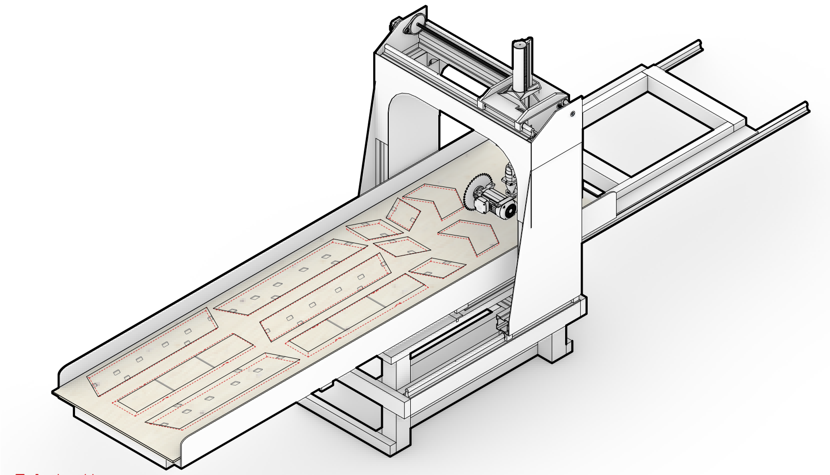
The module itself is build by plywood which thickness varies between 12mm and 25mm depending on which floor the module will be placed. The thicker ones are used for the lower floors of the building since the forces are greater, while the thinner ones higher up.

The modules are mass fabricated in a factory. The plywood is first cut by a 5-axis CNC circular saw and is milled in order to create the sinks for the joints. These machines are widespread in the timber industry and are used in all modern factories producing engineered wood.

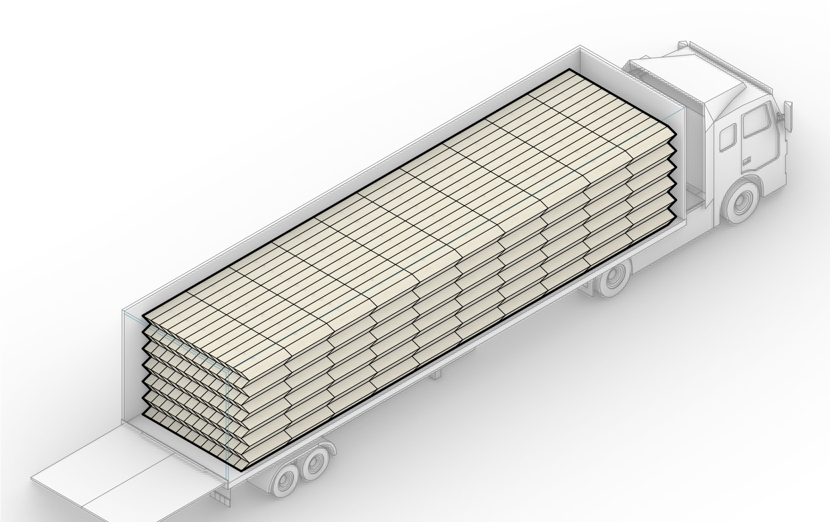
The modules are afterwards assembled on the factory floor using glue to achieve the best detailing possible. The glueing and milling processes where tested in a full scale prototype build and is a time-efficient and uncomplicated process. The mitered edges lead the way the pieces should be glued together without needing drawings or complicated instructions. In this stage the modules can be customised by adding e.g. insulation inside.

The modules are being reinforced in the middle by vertical pieces that make the module more robust and the assembly process even easier.

The modules are then transported to the site with trucks in order for the assembly of the building to begin.

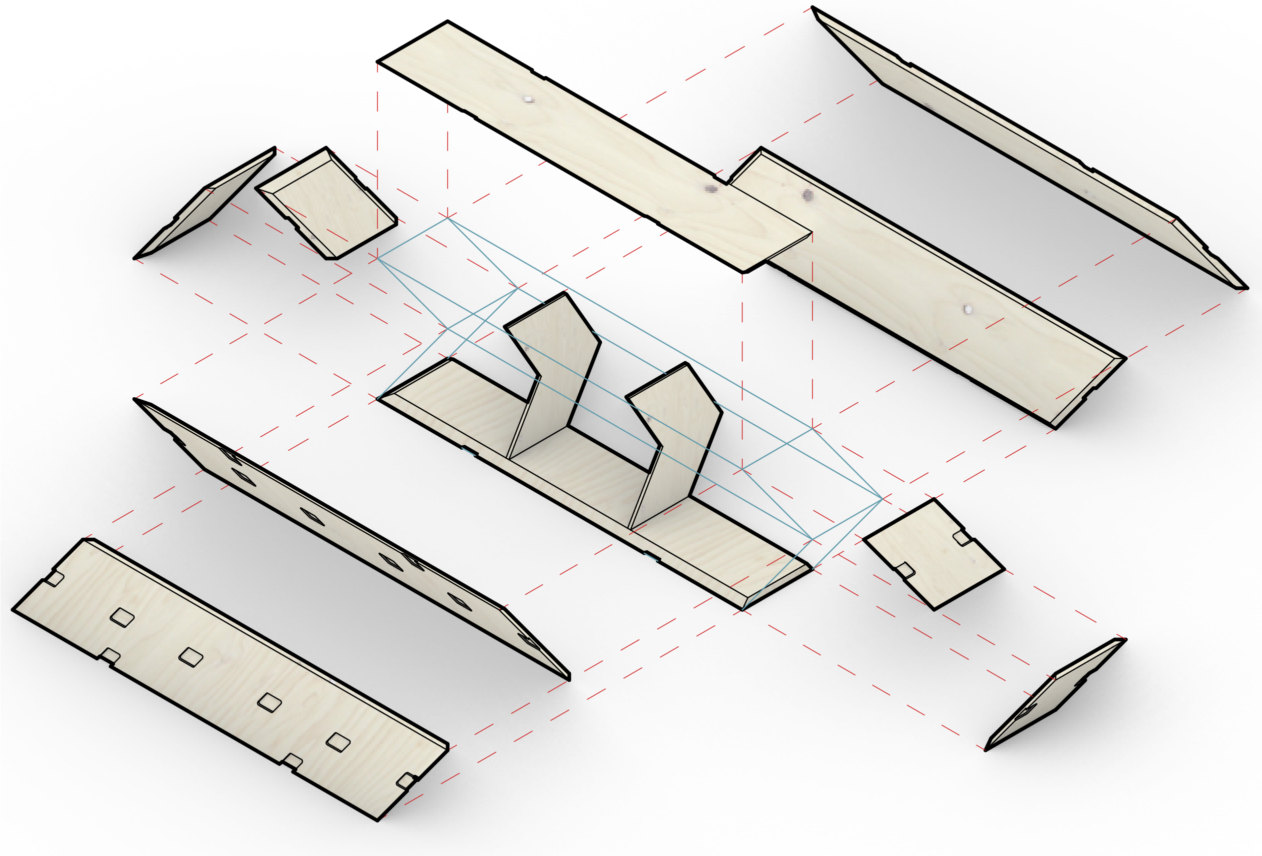


Fabrication



Transportation

MODULE DETAILING



Assembly

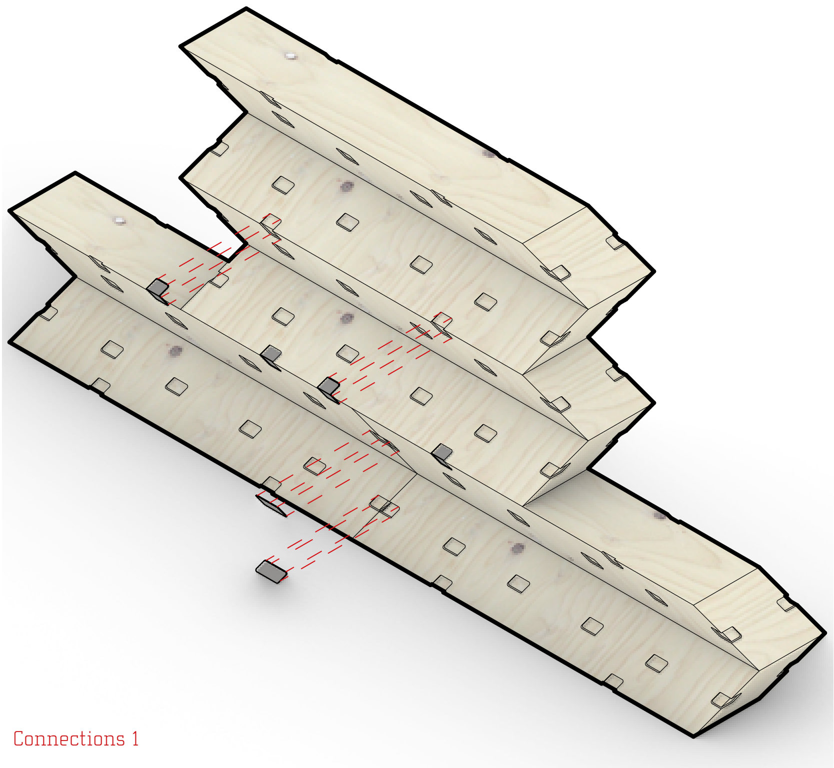
PROTOTYPE

MODULE JOINTS

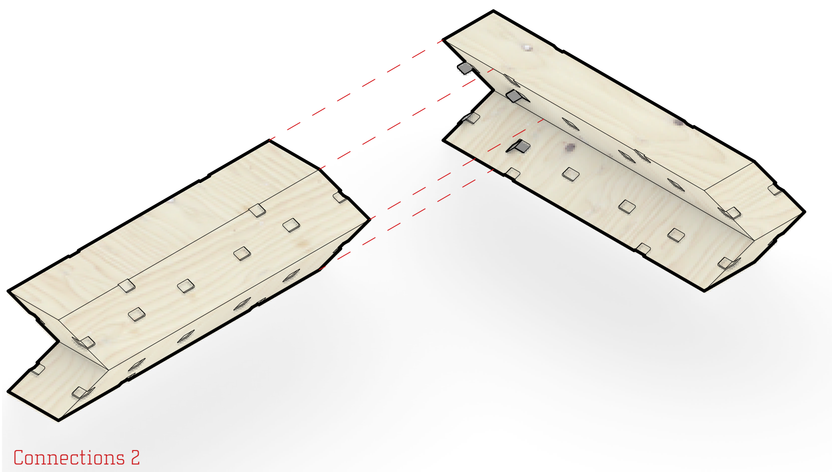
The joints for the modules were developed having in mind that it should be easy to change the module configuration without needing to make big interventions.

The module itself has milled out parts that fit steel plates, angled or not, depending on how the modules are connected to each other. Those plates are then screwed to the modules and the joint is afterwards covered by a wooden piece in order to have as smooth surface as possible exposed.

Those joints are studied so the disassembly from inside the building is possible and their positions informed the aggregation script.

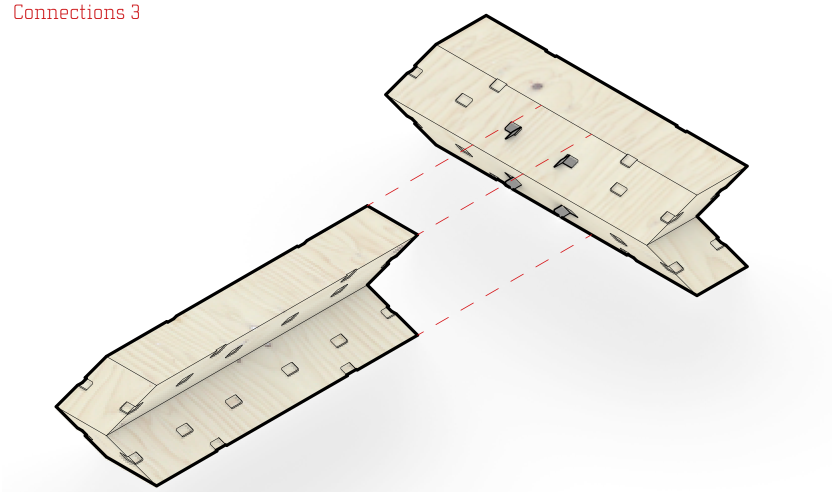


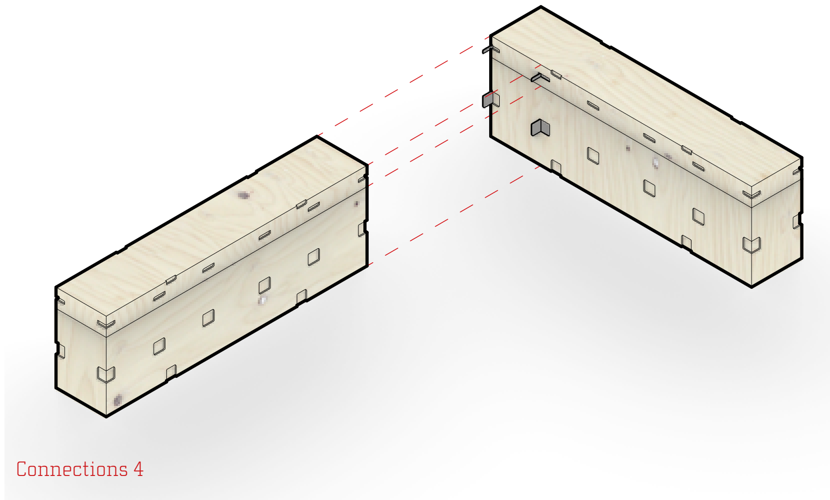
Connections 1



Connections 2

Connections 3





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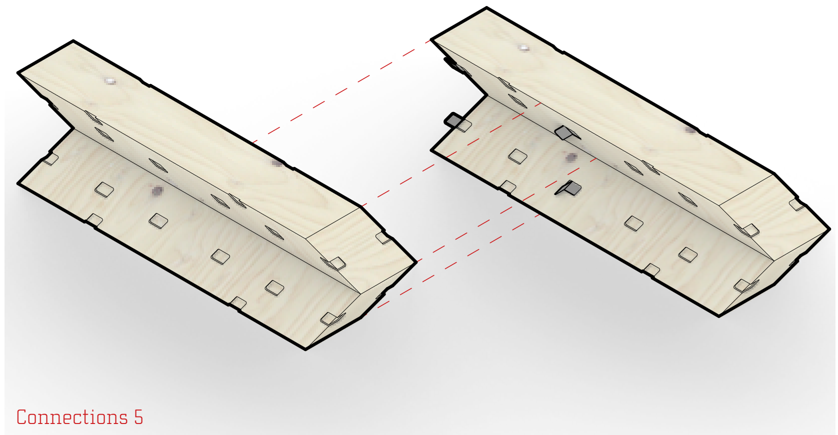
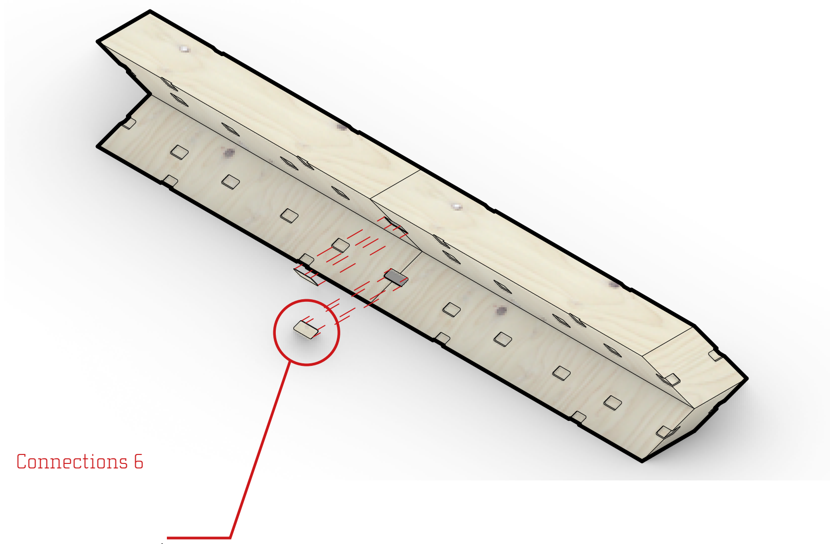
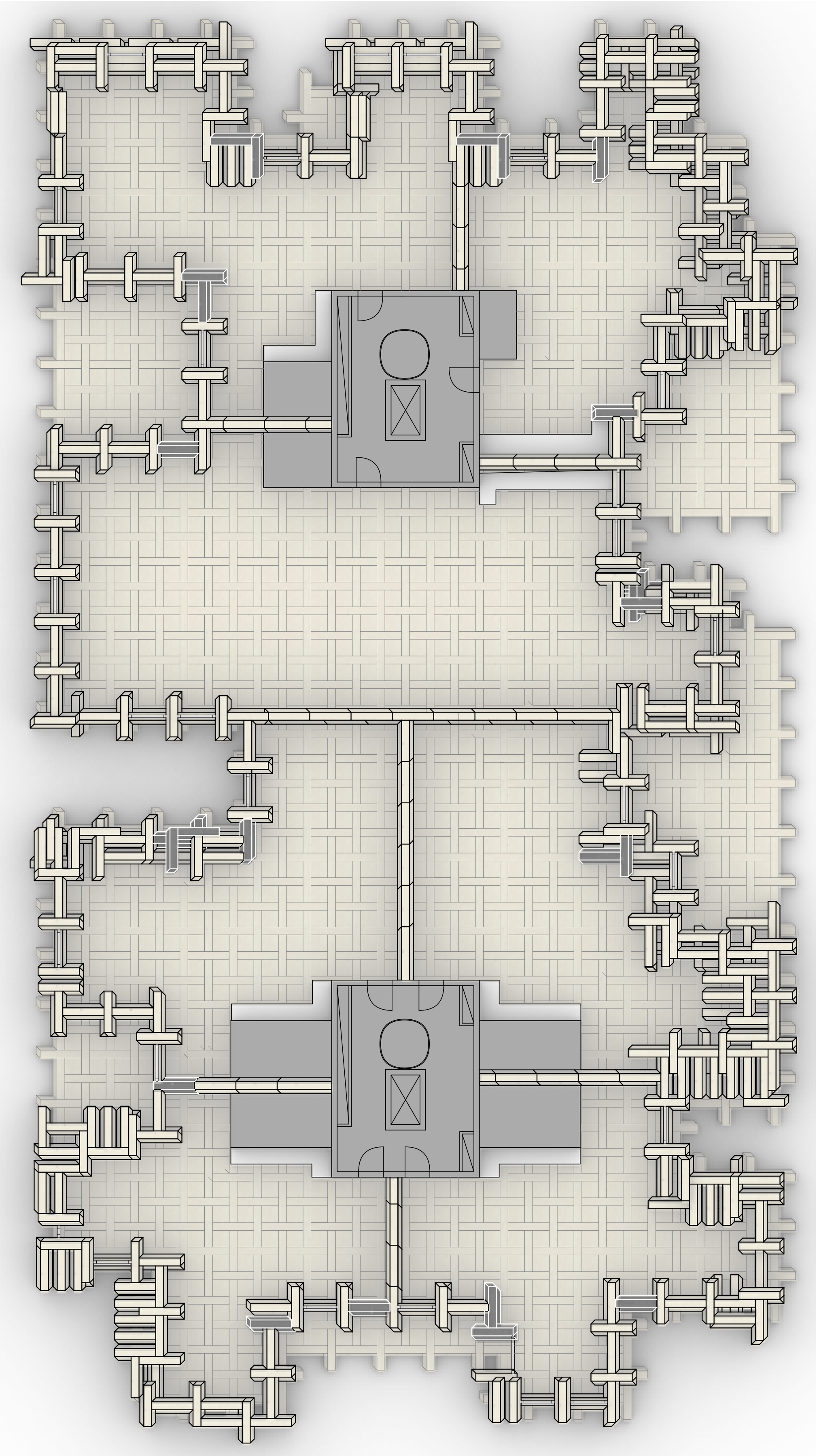


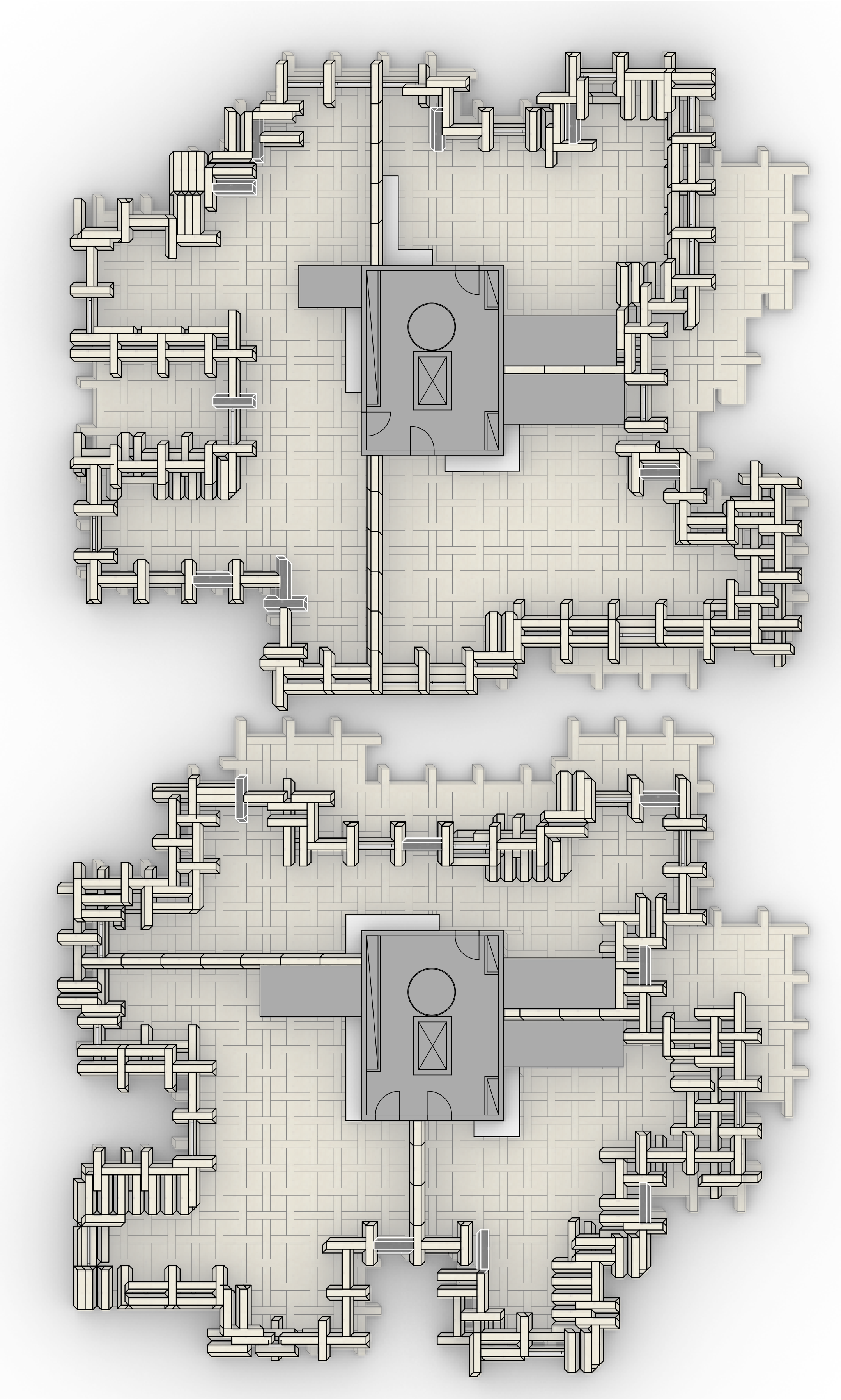
Connections 5



Connections 6

Covering Wood Pieces

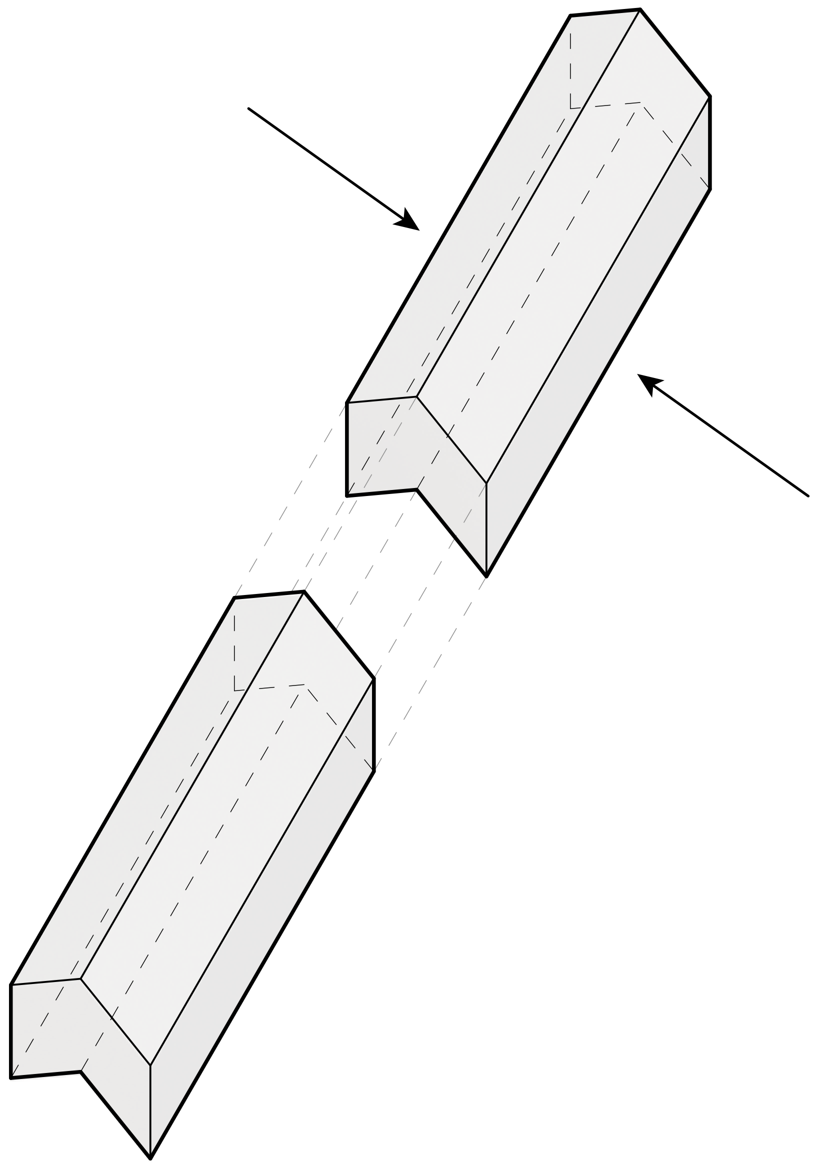


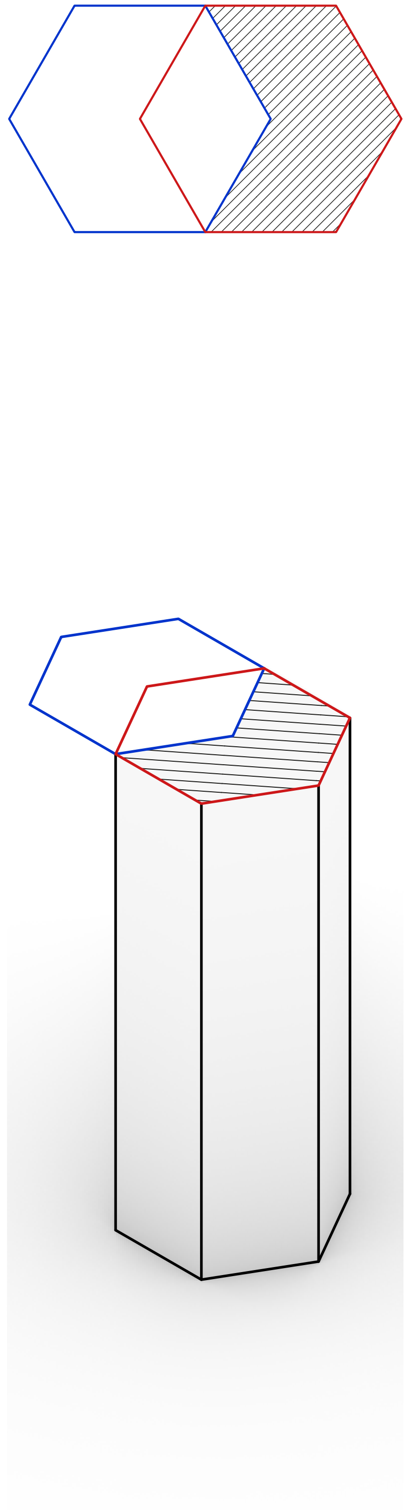


MODULE STUDIES

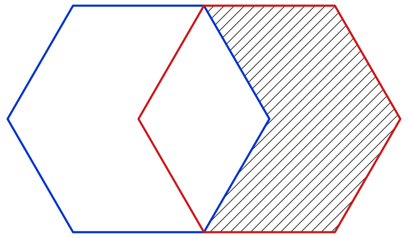
- **Lightweight.** Built by LVL or Plywood.
- Main module in **human scale** to enable its handling by a couple of builders.
- Form that produces **interesting aggregations** and provides **intricate formal possibilities**.
- Complex but still **easy to fabricate** with digital fabrication methods.
- Working with a **module-building block** rather that a building element.

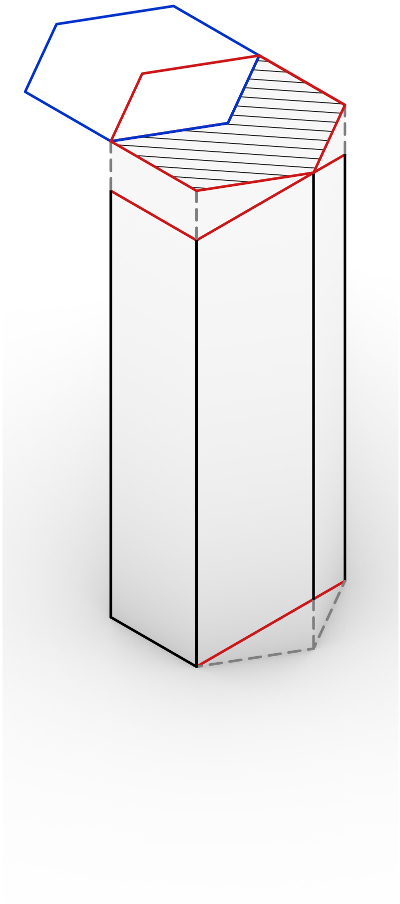
Iteration 1





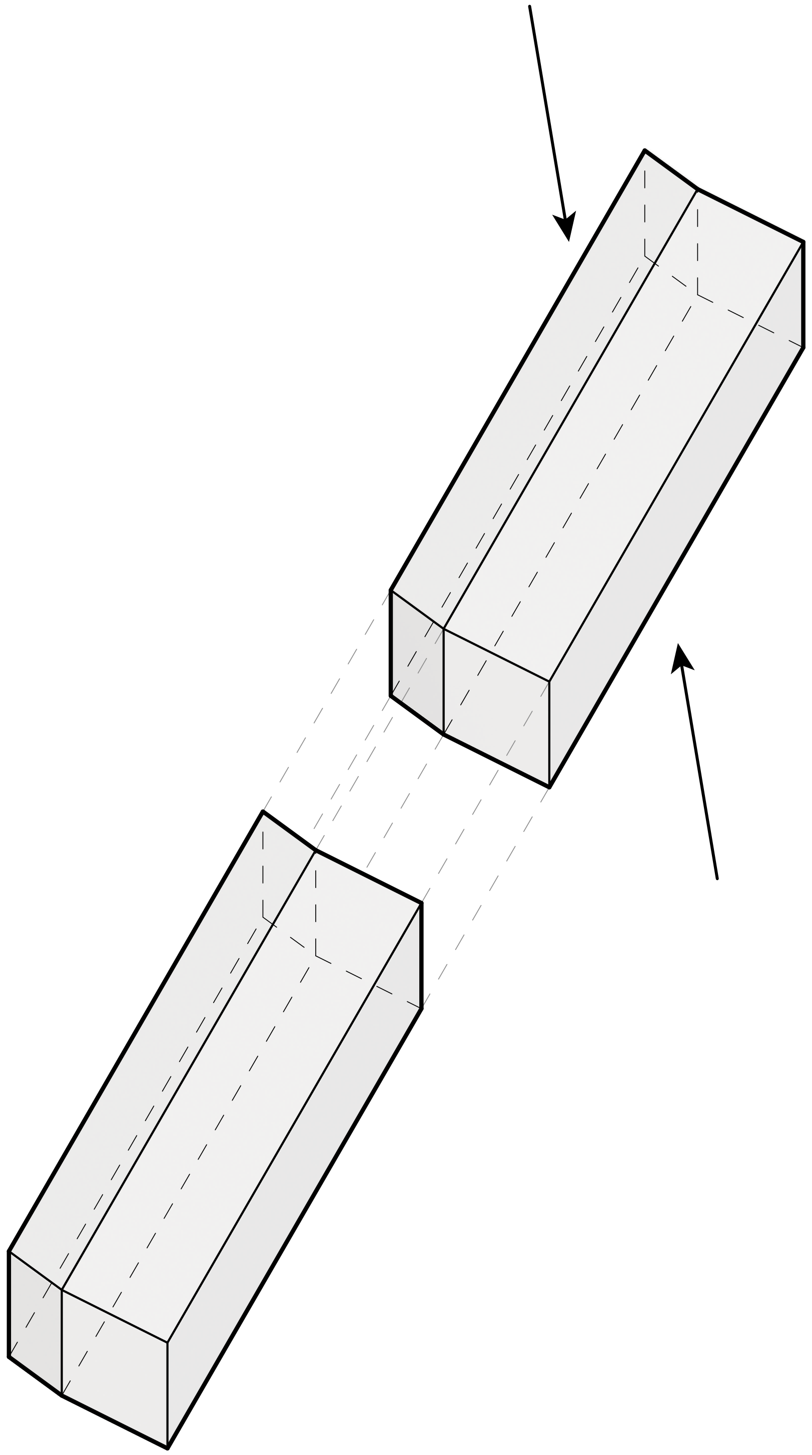
- Friction joint.
- Vulnerable to forces from all directions.
- Stackable.



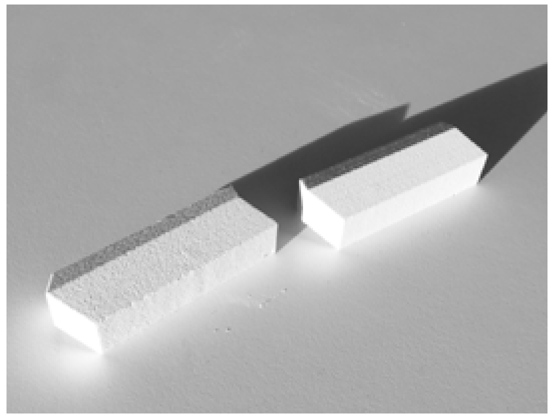


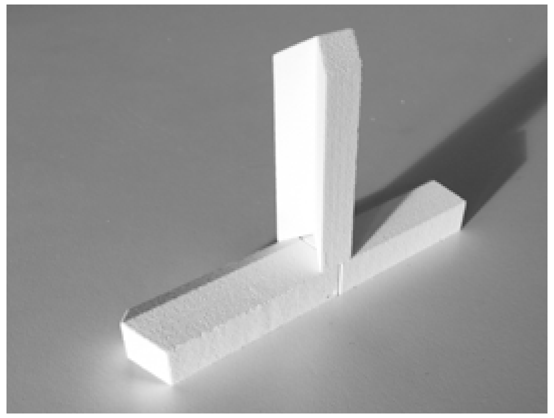
- Friction joint.
- Vulnerable to forces one direction.
- Stackable.

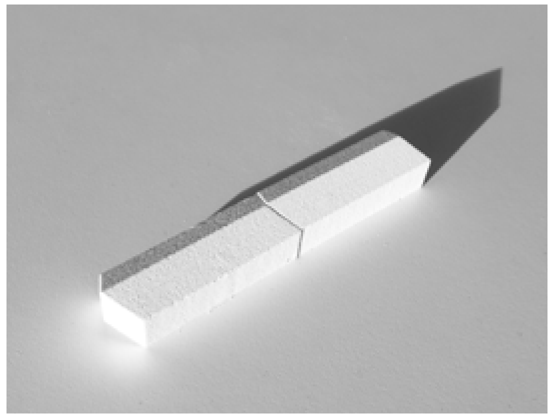
Iteration 2

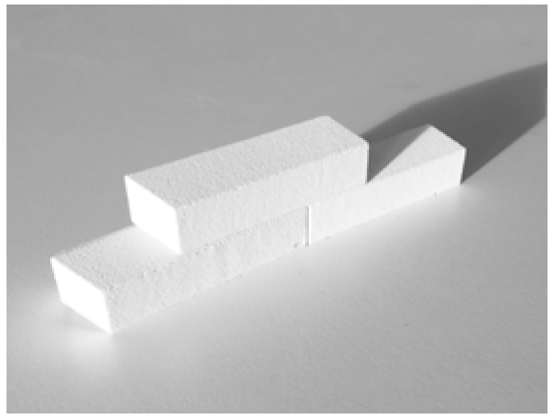


MODULE STUDIES

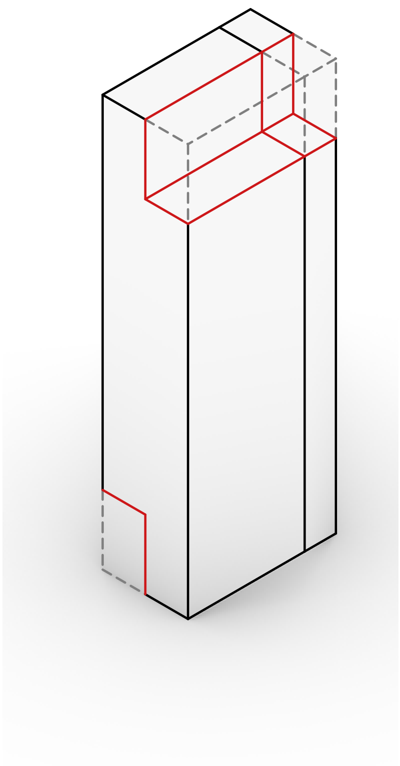






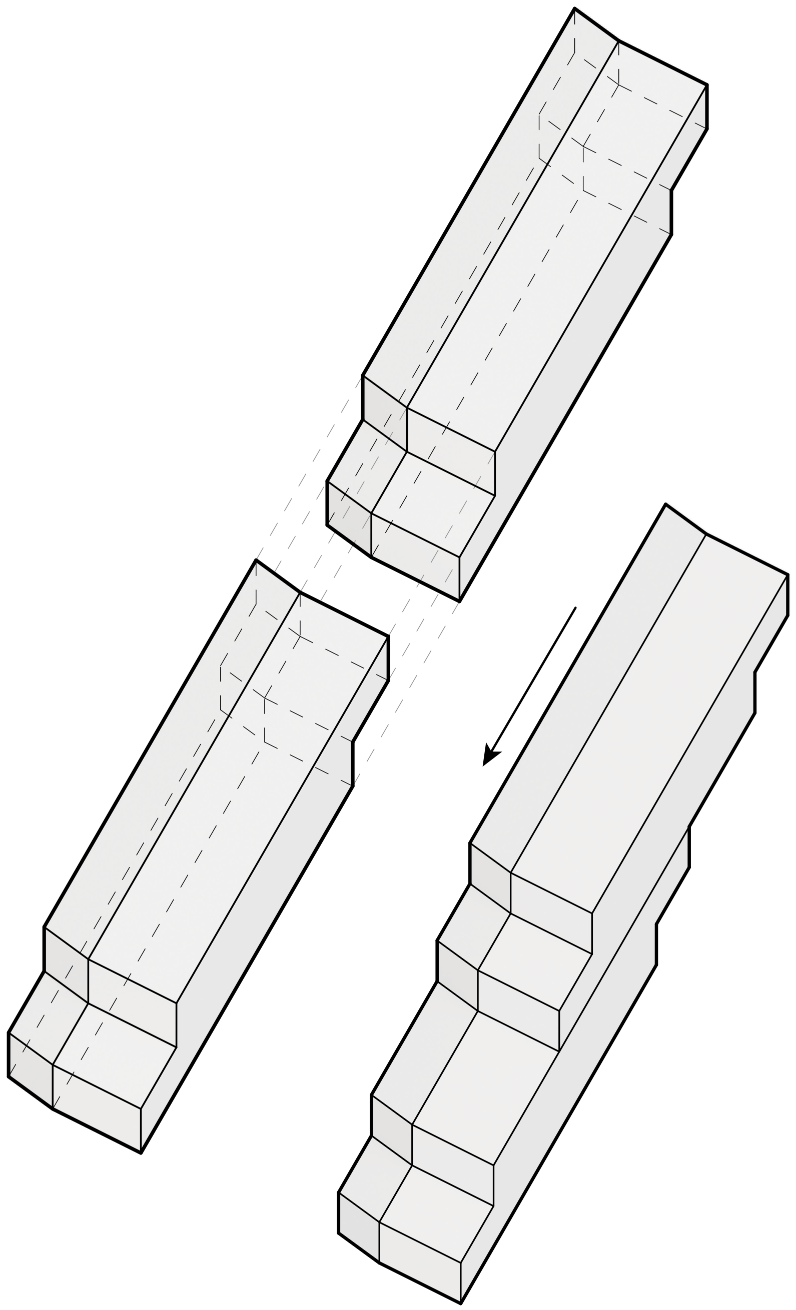


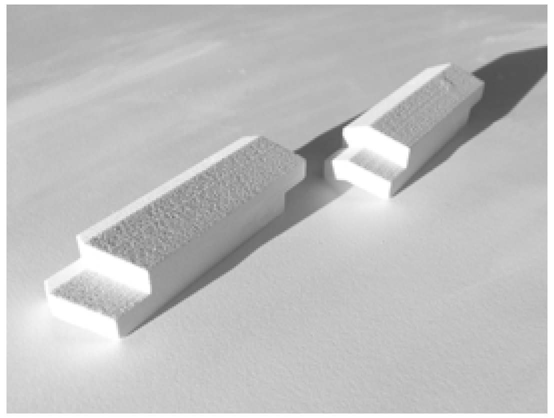
MODULE STUDIES

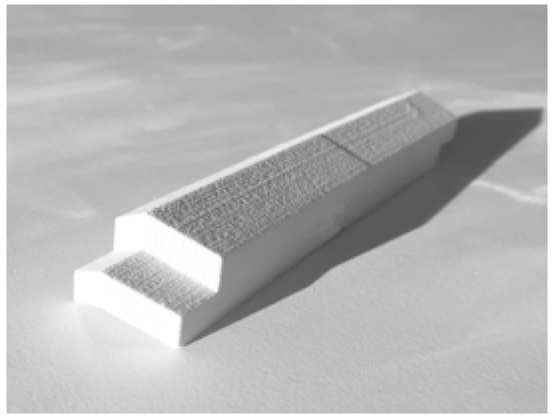


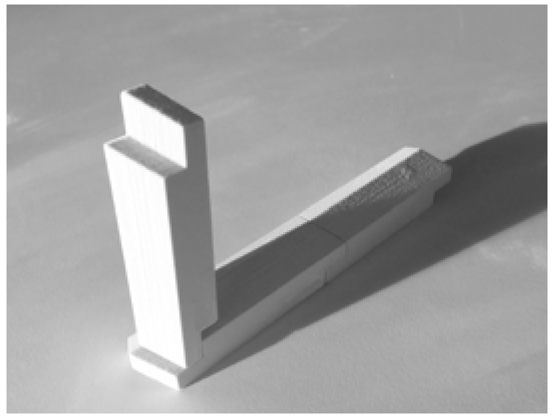
- Interlocking geometry manages the directional forces.
- Sliding when stacked.
- Complex form rendering the construction from sheet material very hard.

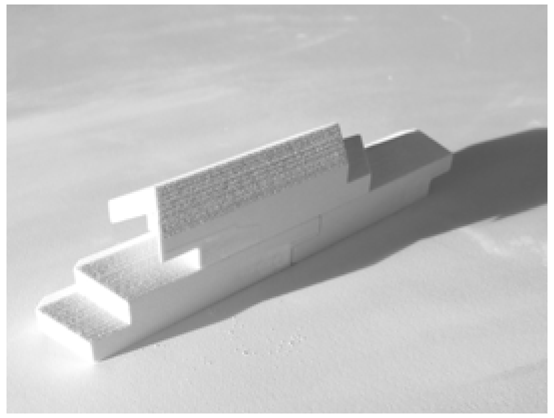
Iteration 3



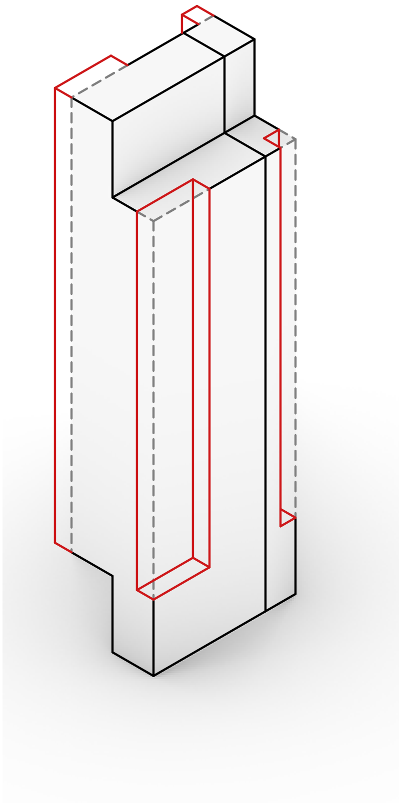


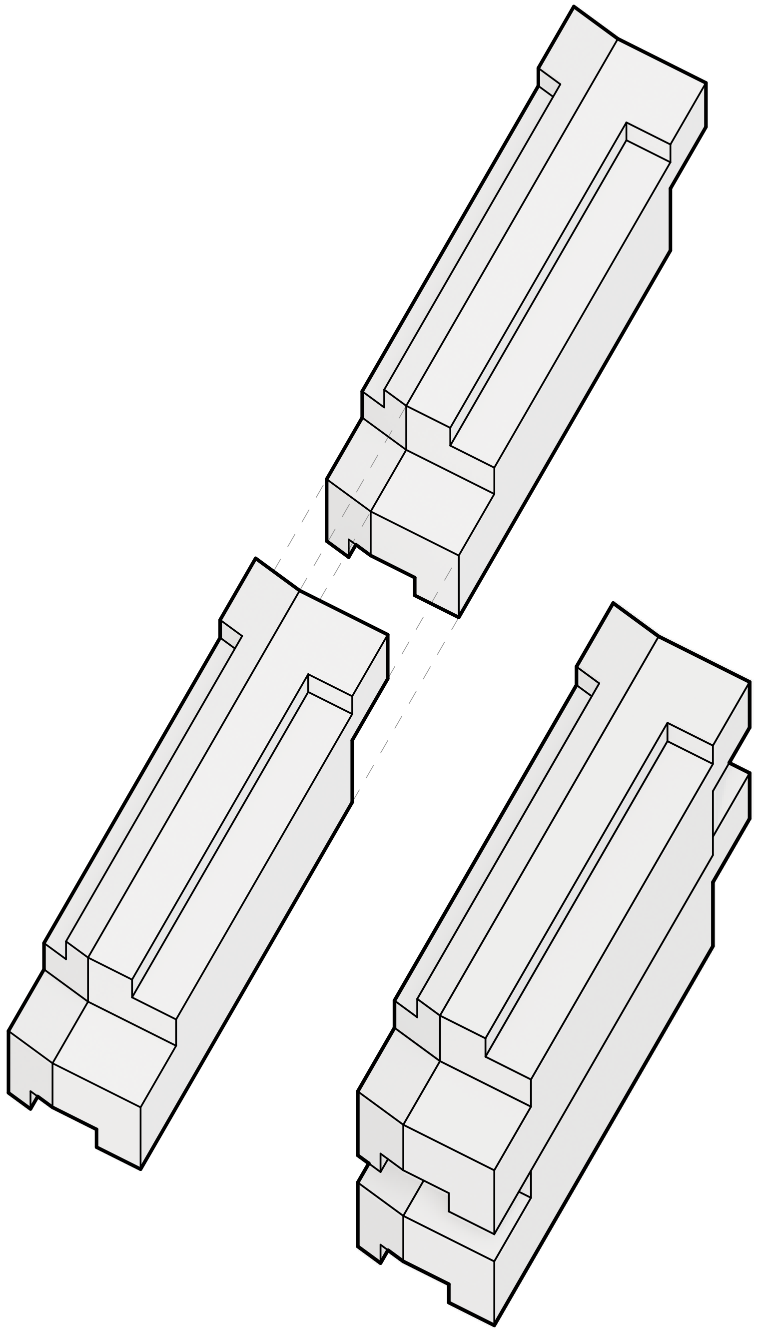






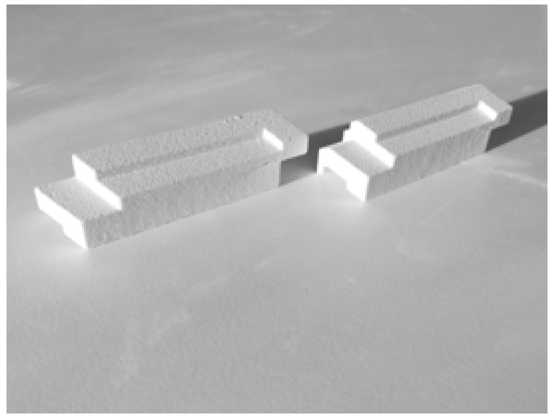
Iteration 4

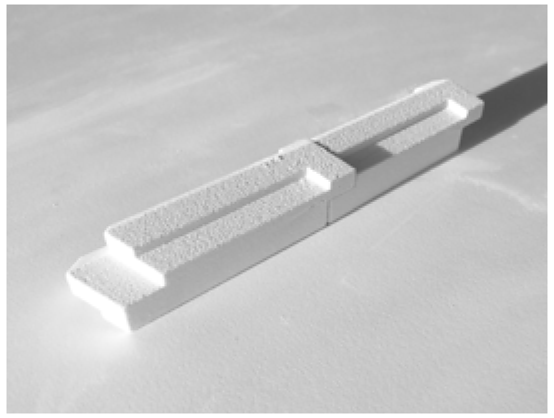


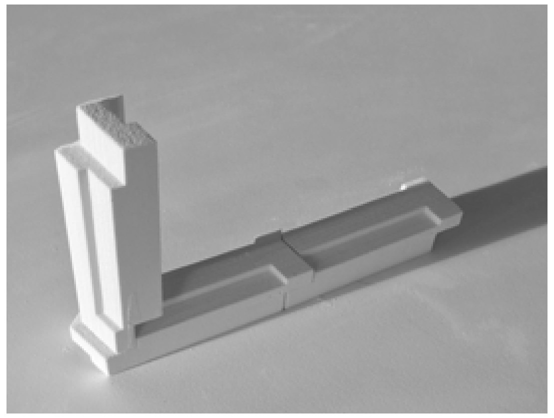


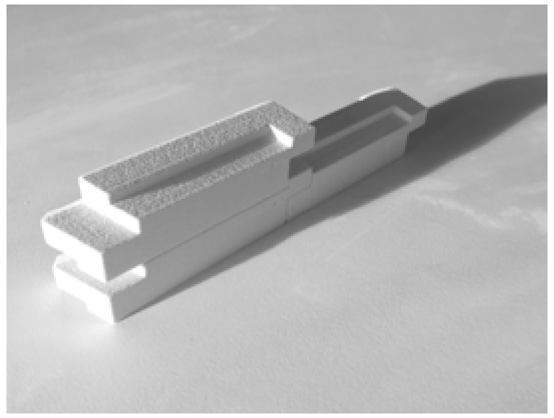
- Interlocking geometry manages the directional forces.
- Sliding when stacked is being handled in one direction.
- No degree of freedom in vertical stacking.
- Complex form rendering the construction from sheet material very hard.

MODULE STUDIES







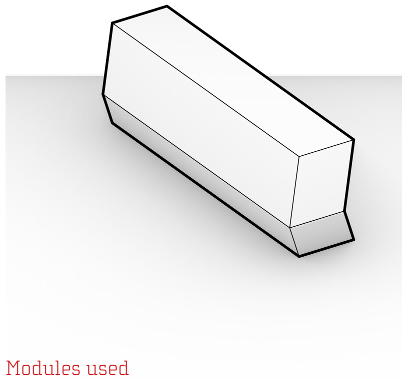


- The geometry of the of module of **Iteration 1** allows just a friction joint. In addition it does not allow the perpendicular stacking which is essential for the module to be able to be used as a column.
- **Iteration 2** has also a friction joint although the geometry allows the perpendicular stacking. The overall form is simple enough to be mass produced and assembled.
- **Iteration 3** provides some interlocking although its more complex geometry renders this module harder to mass produce.
- **Iteration 4** has more points of interlocking, but the fabrication in sheet material is very hard, while stacking is limited to specific placements due to the complex geometry.
- **Iteration 2** is chosen due to its simpler geometry that allows aggregation freedom, easier mass production and an initial joint that can be developed further later in the process.

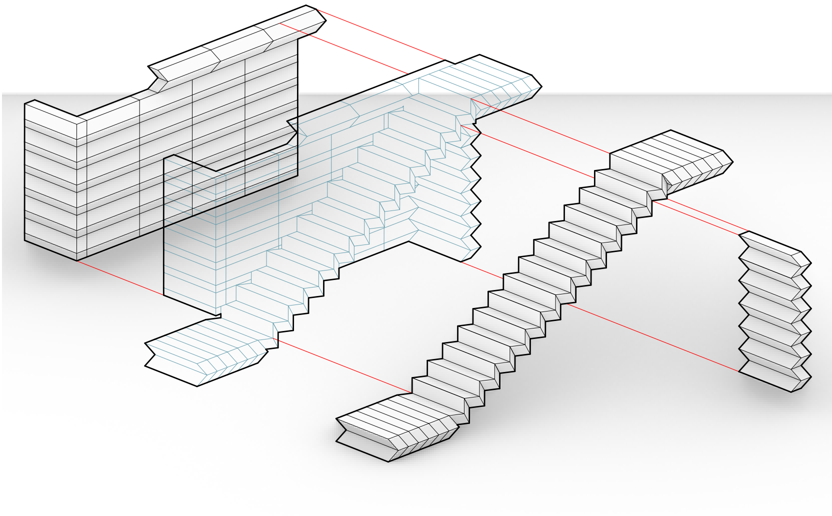
MANUAL AGGREGATIONS

MANUAL AGGREGATIONS

Iteration 1

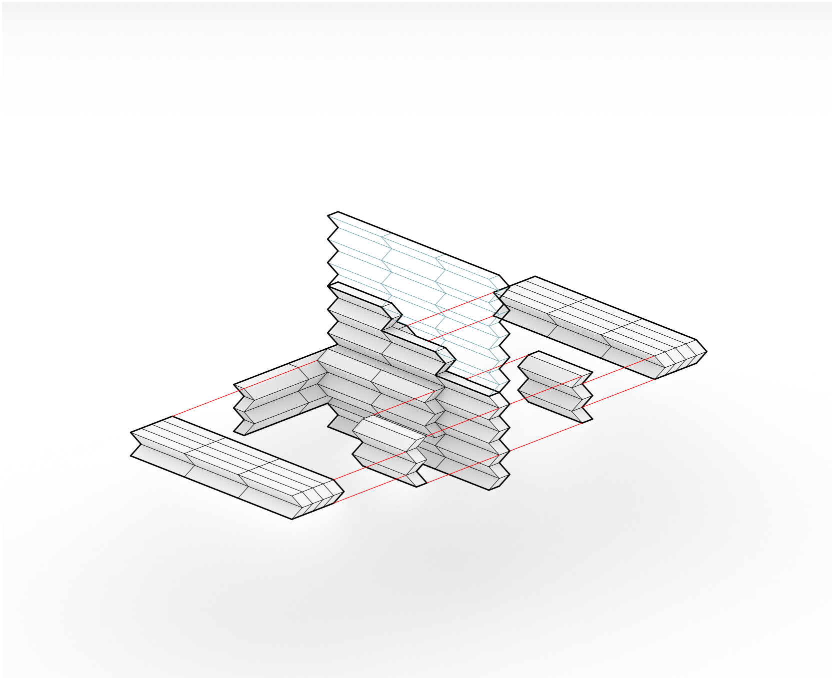


Modules used

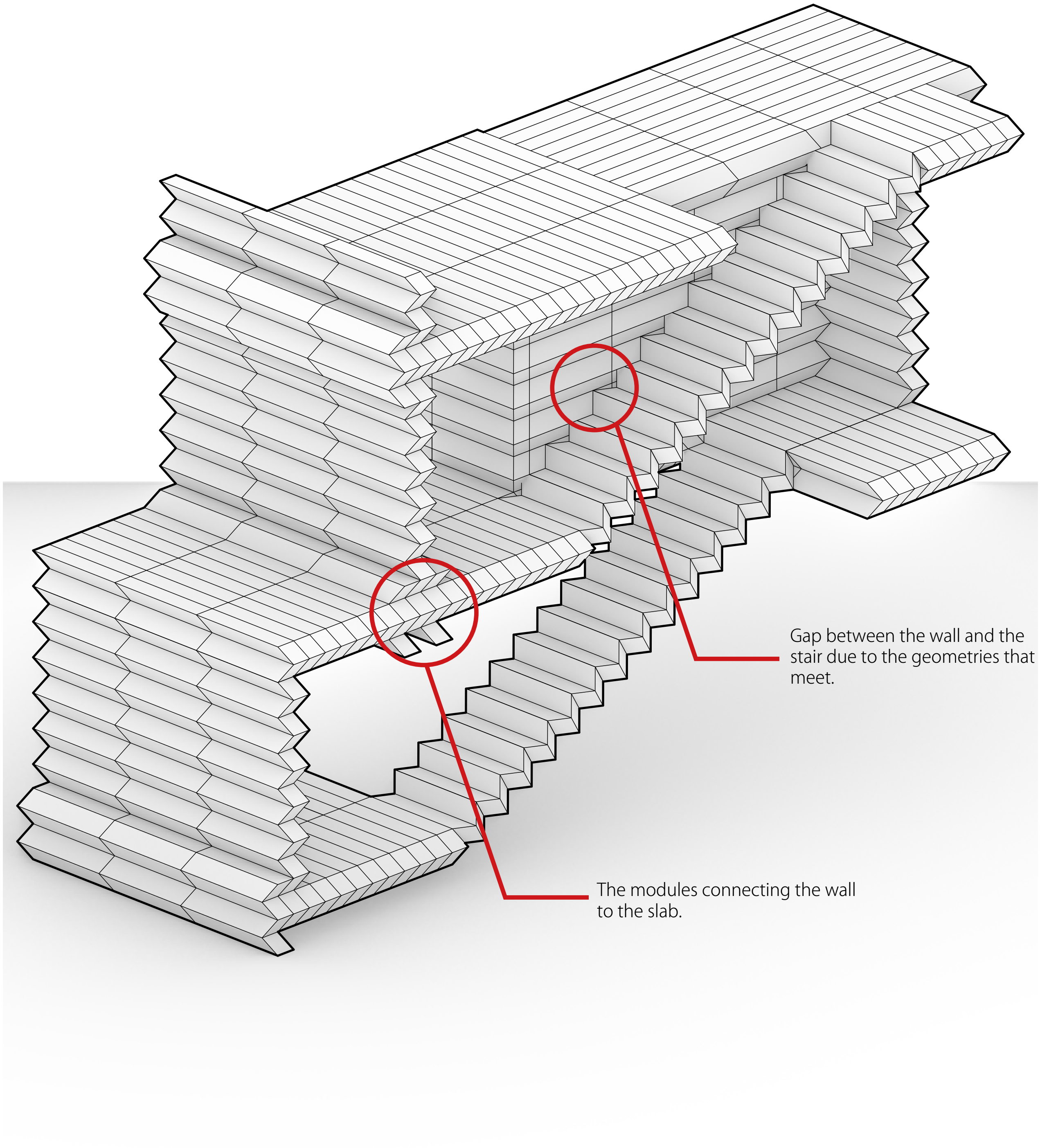


Stair 1

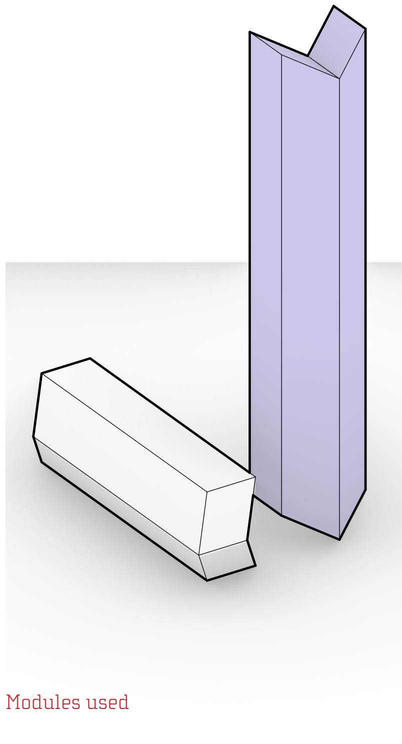
- Working with the most complex scenario for the stair, where it runs parallel to a different apartment, a wall is needed to isolate it. The angled geometries meeting create gaps.
- The slab and the wall are kept together with two modules on each side of the bottom of the wall, creating a sill on the upper floor as well as a .... on the ceiling of the storey underneath.



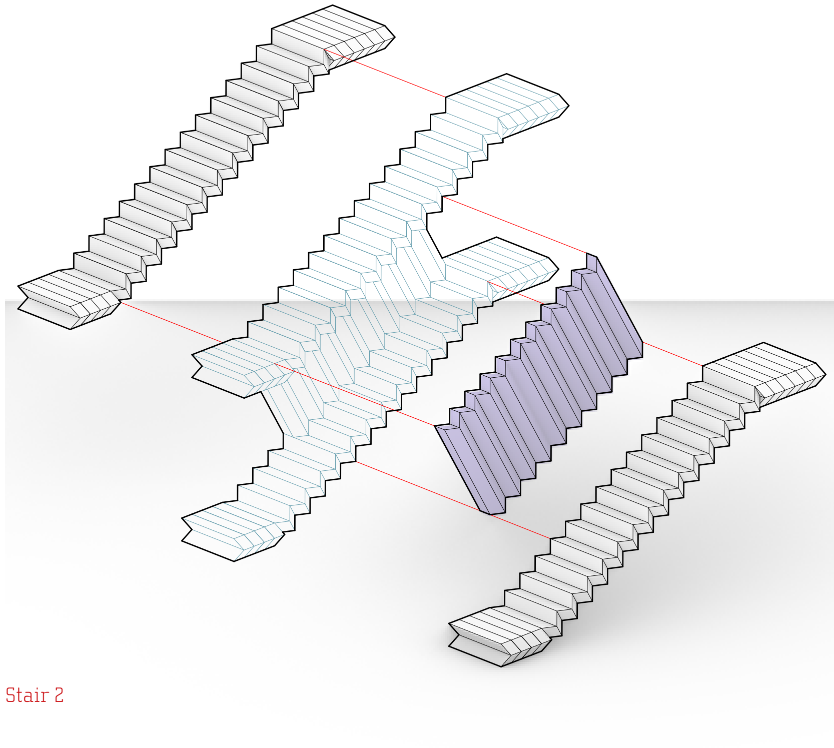
Slab-Wall connection



Iteration 2



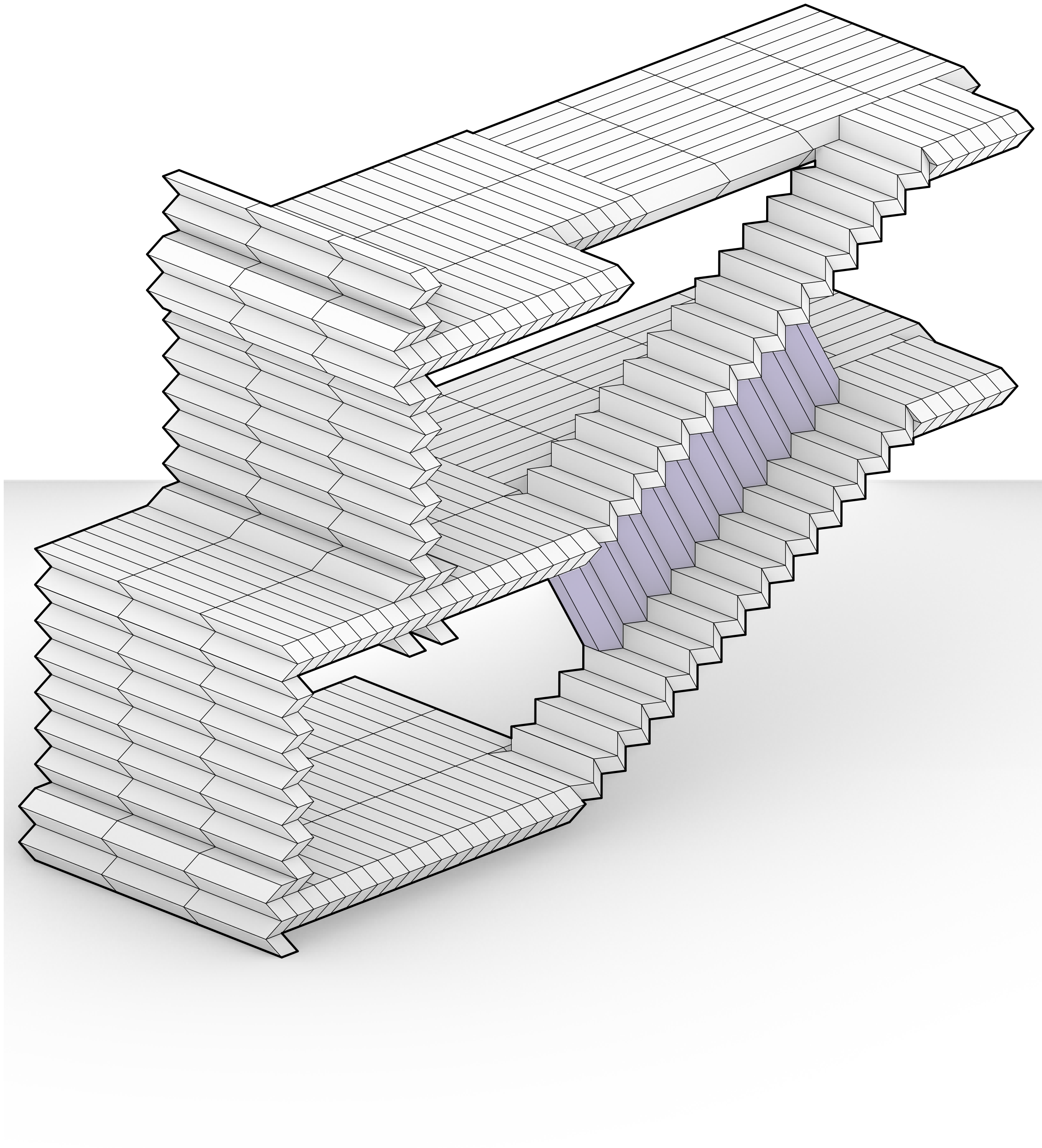
Modules used



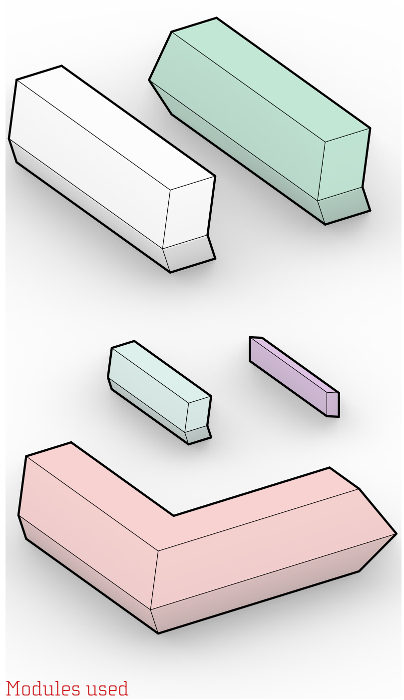
Stair 2

- In this iteration a different approach to isolate the stair is chosen. Instead of using a wall, a custom, longer, module is used to connect the stairs with each other. This approach works only when the stairs run underneath each other.

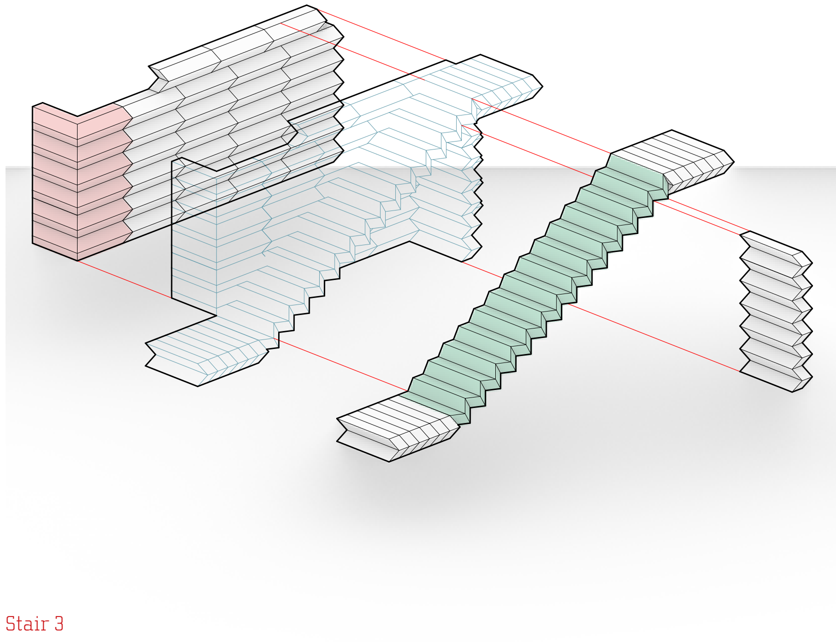
MANUAL AGGREGATIONS



Iteration 3

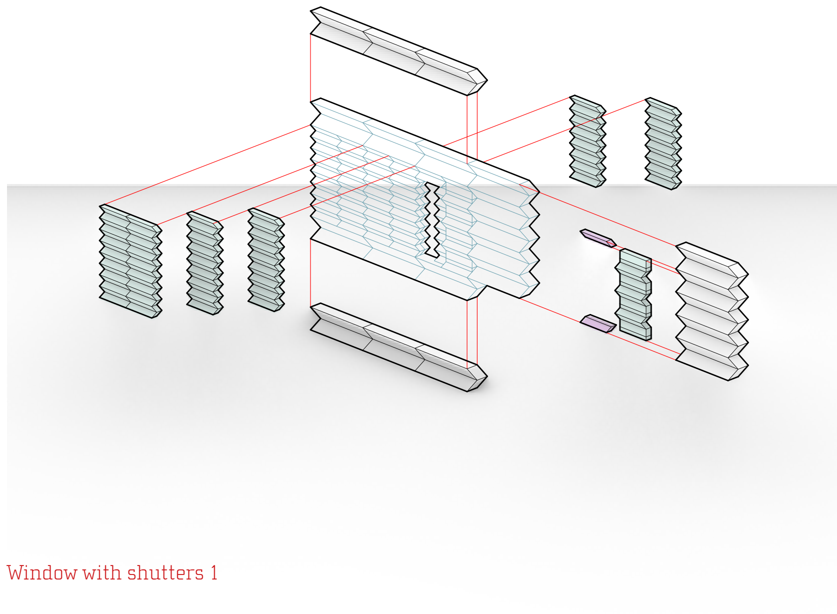


Modules used

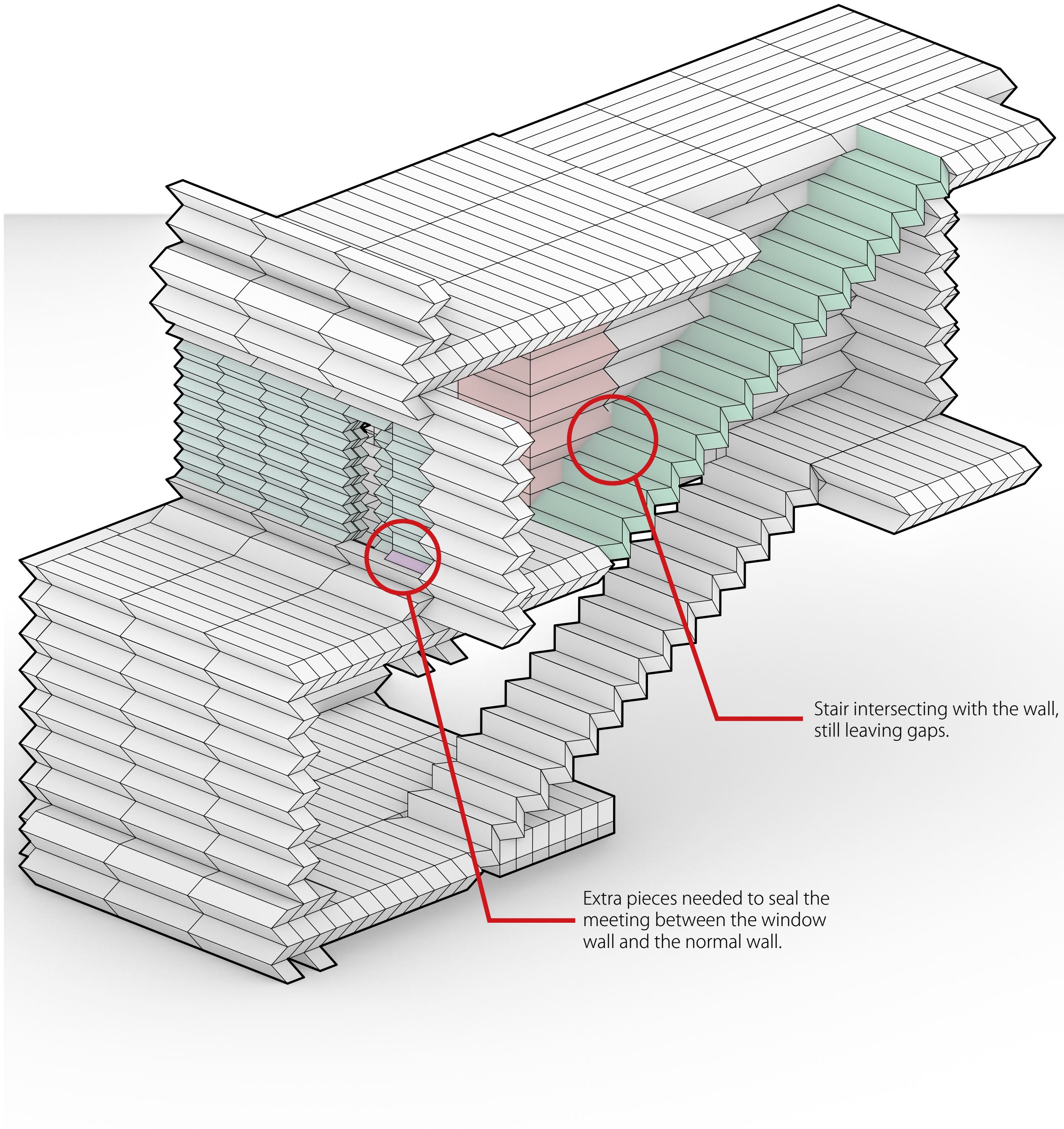


Stair 3

- The stair intersecting with the wall. Holes are still present.
- Putting a window opening in the wall. Modules half the size of the default module are used, creating the opportunity for additional detailing.
- Extra pieces are needed on the top and the bottom where the smaller modules meet the default modules of the wall.
- Sliding shutters built from the half-module are used to open and close the window.

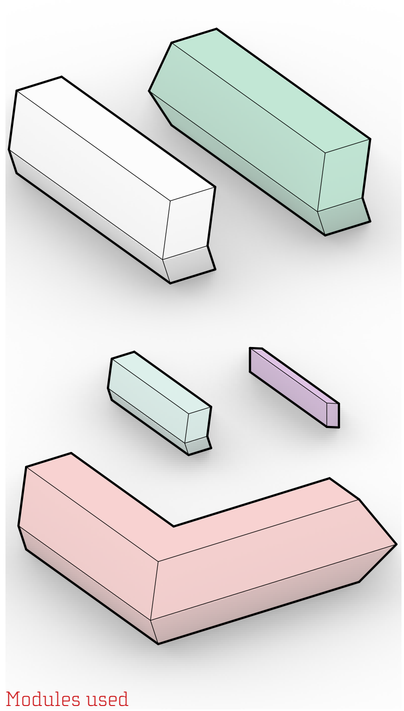


Window with shutters 1

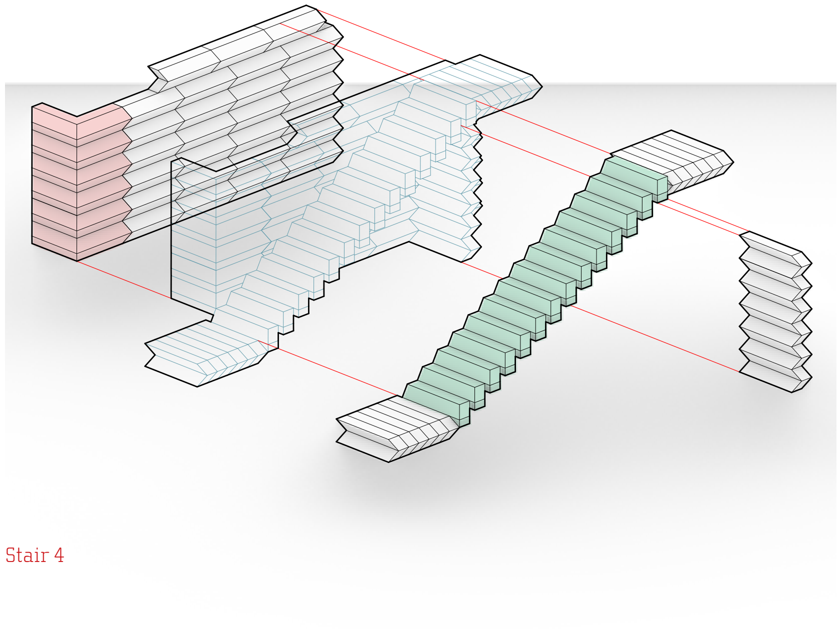


MANUAL AGGREGATIONS

Iteration 4

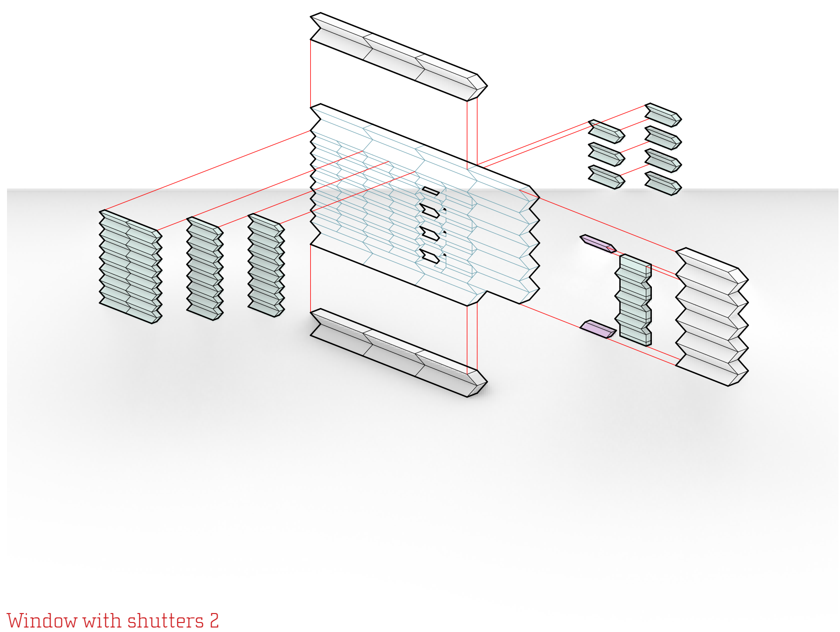


Modules used

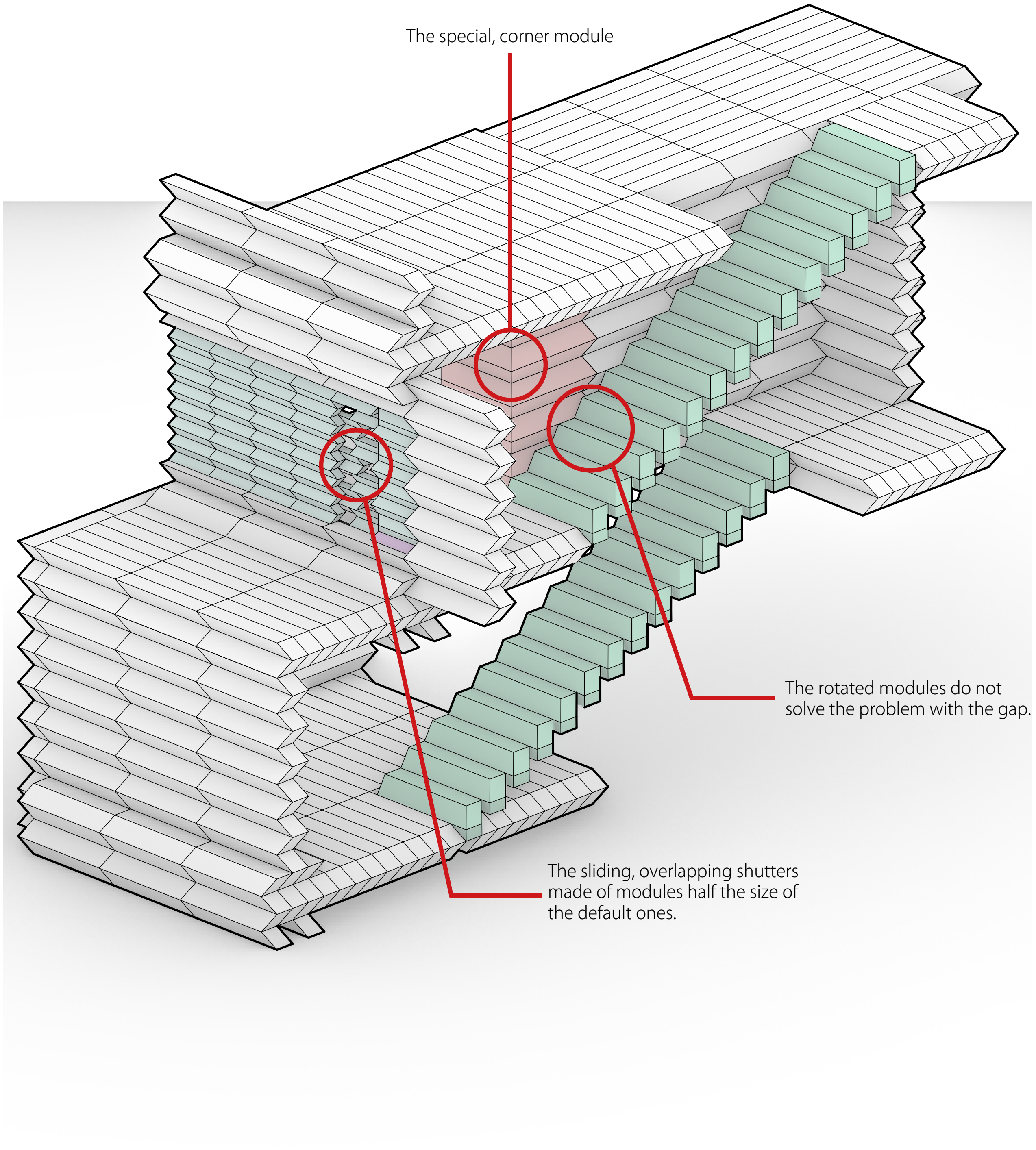


Stair 4

- The stair modules are rotated to examine the wall-stair meeting. Holes still present.
- The window remains the same and a shutter system where the shutters overlap is being used.
- A special module to handle the corner is used in order to have a sharper meeting.

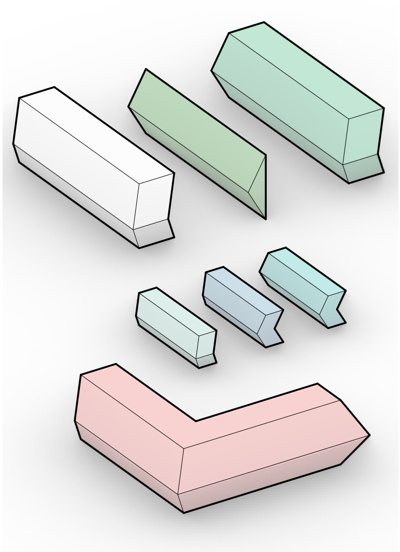


Window with shutters 2



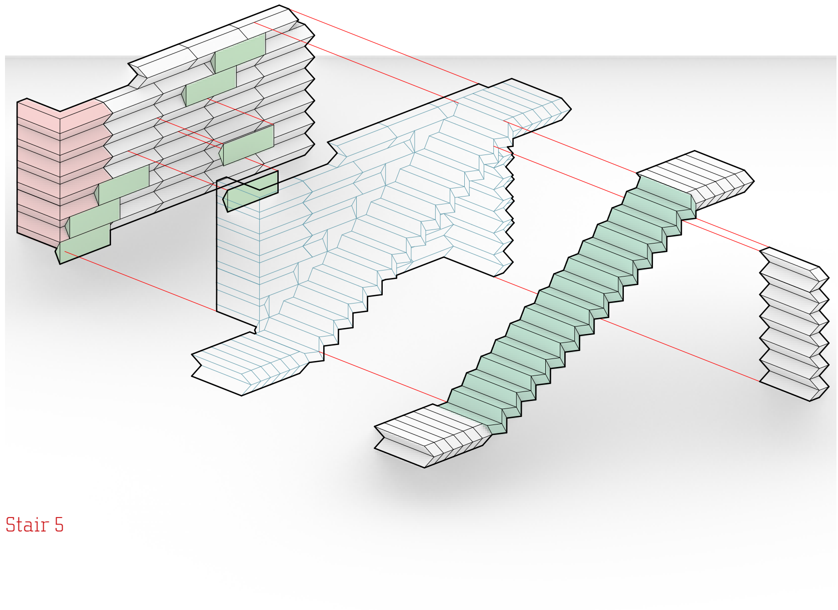
MANUAL AGGREGATIONS

Iteration 5

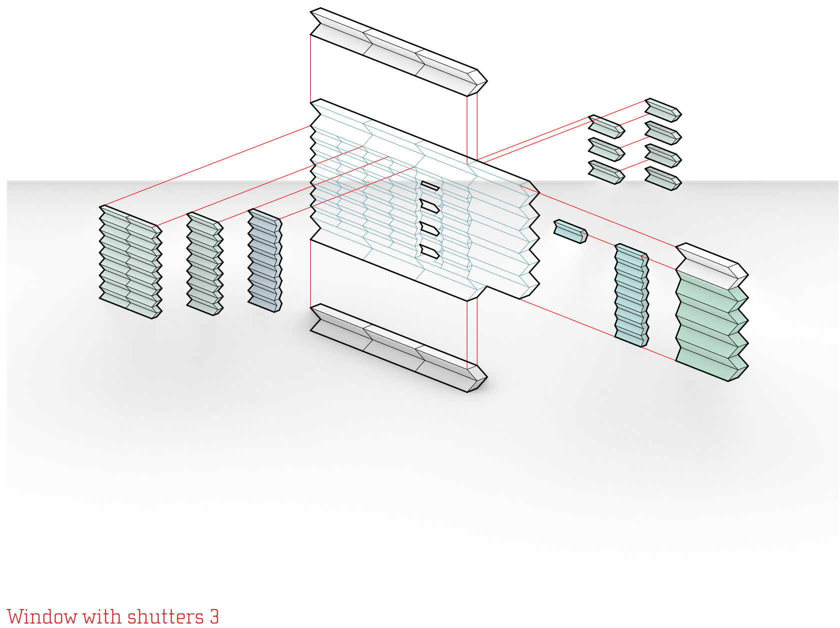


Modules used

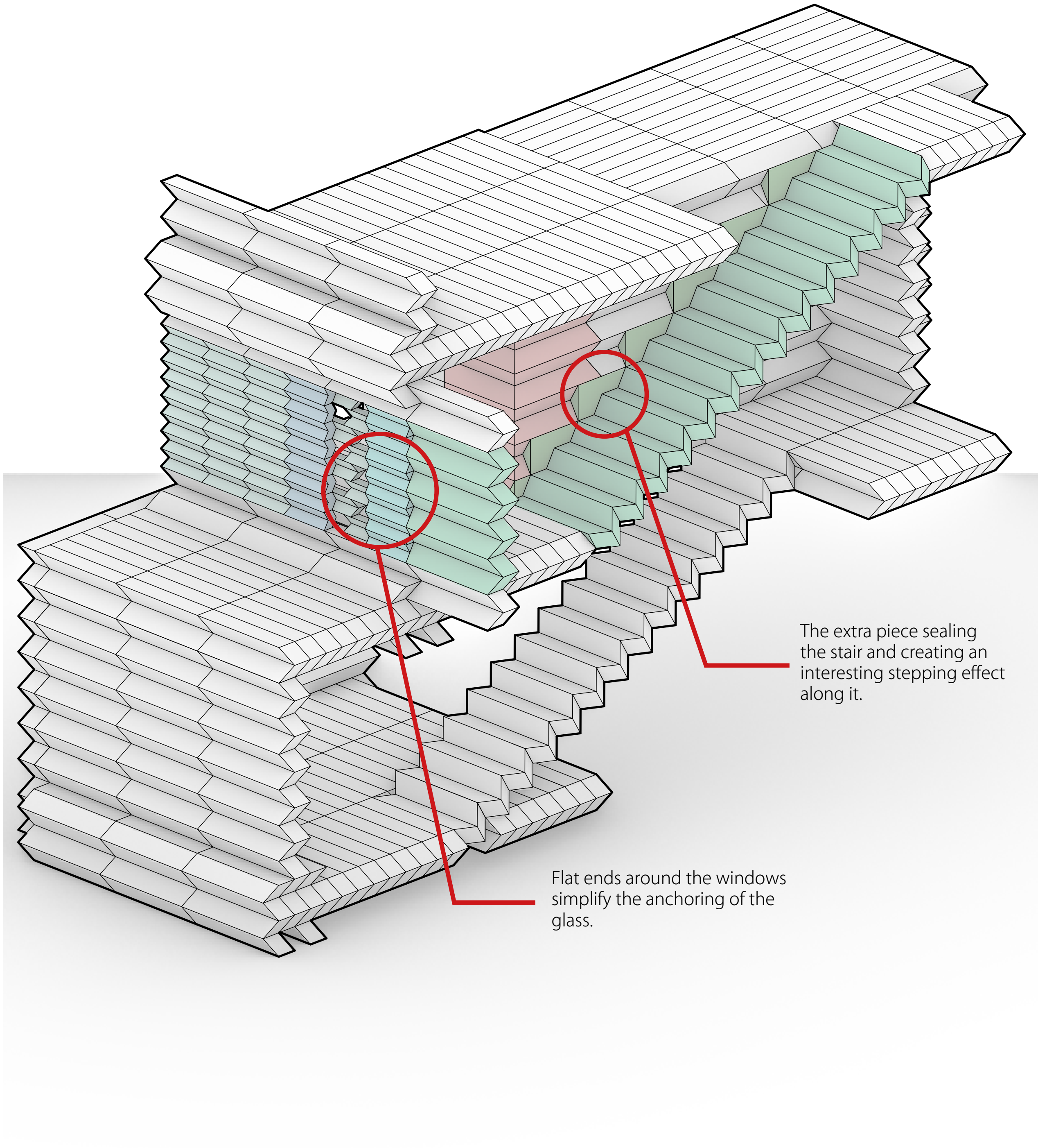
- The stair modules are rotated back to the original position and an extra piece is being added between the stair and the wall in order to seal the gaps.
- Three additional special modules are used for the window. One in the default size with a flat end, one half size with a flat end and one half size with both ends flat. That eliminates the need for the extra smaller module used in previous iterations as well as providing flat ends for the glass to anchor.
- The shutters are the same as previously.



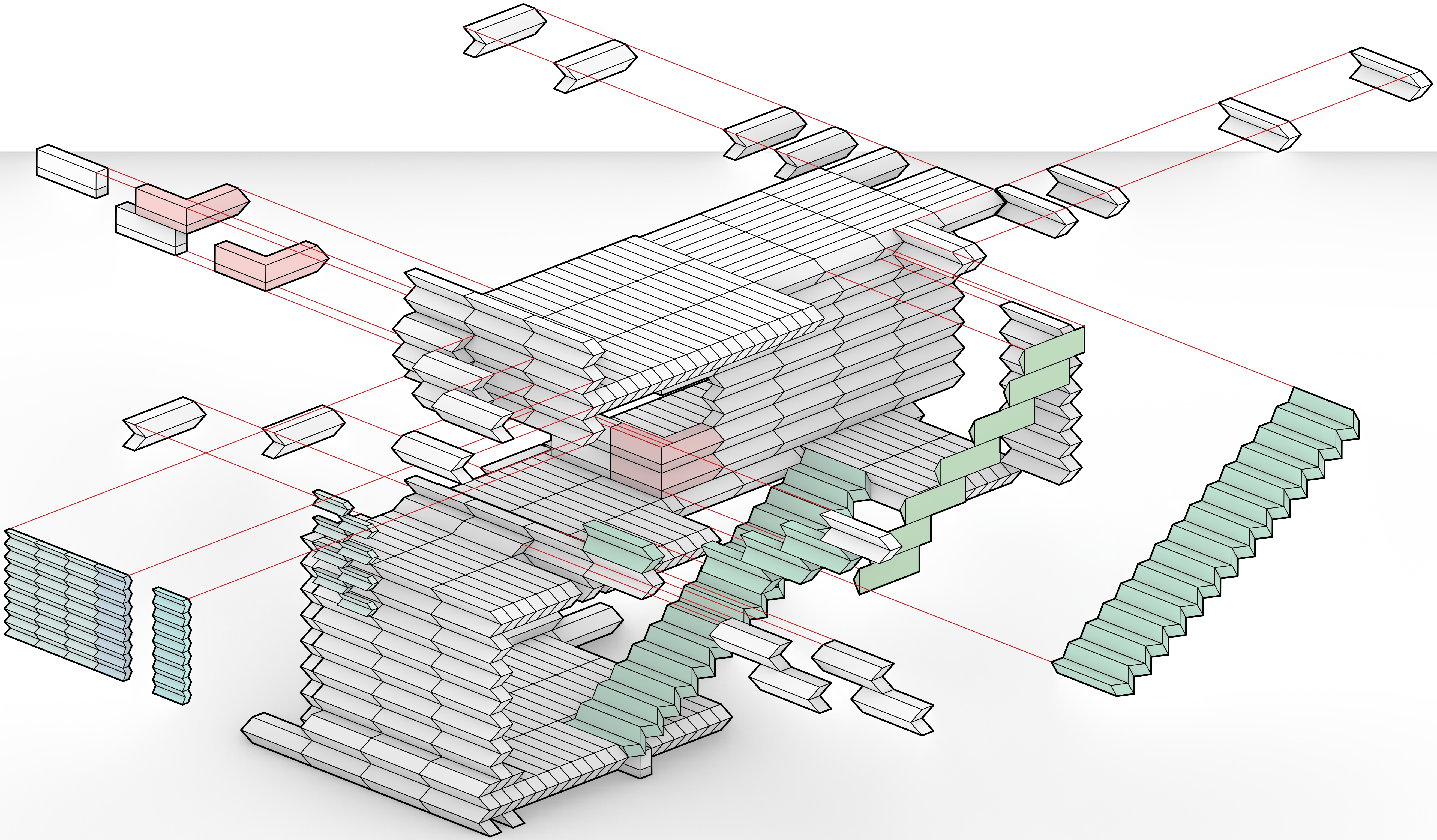
Stair 5



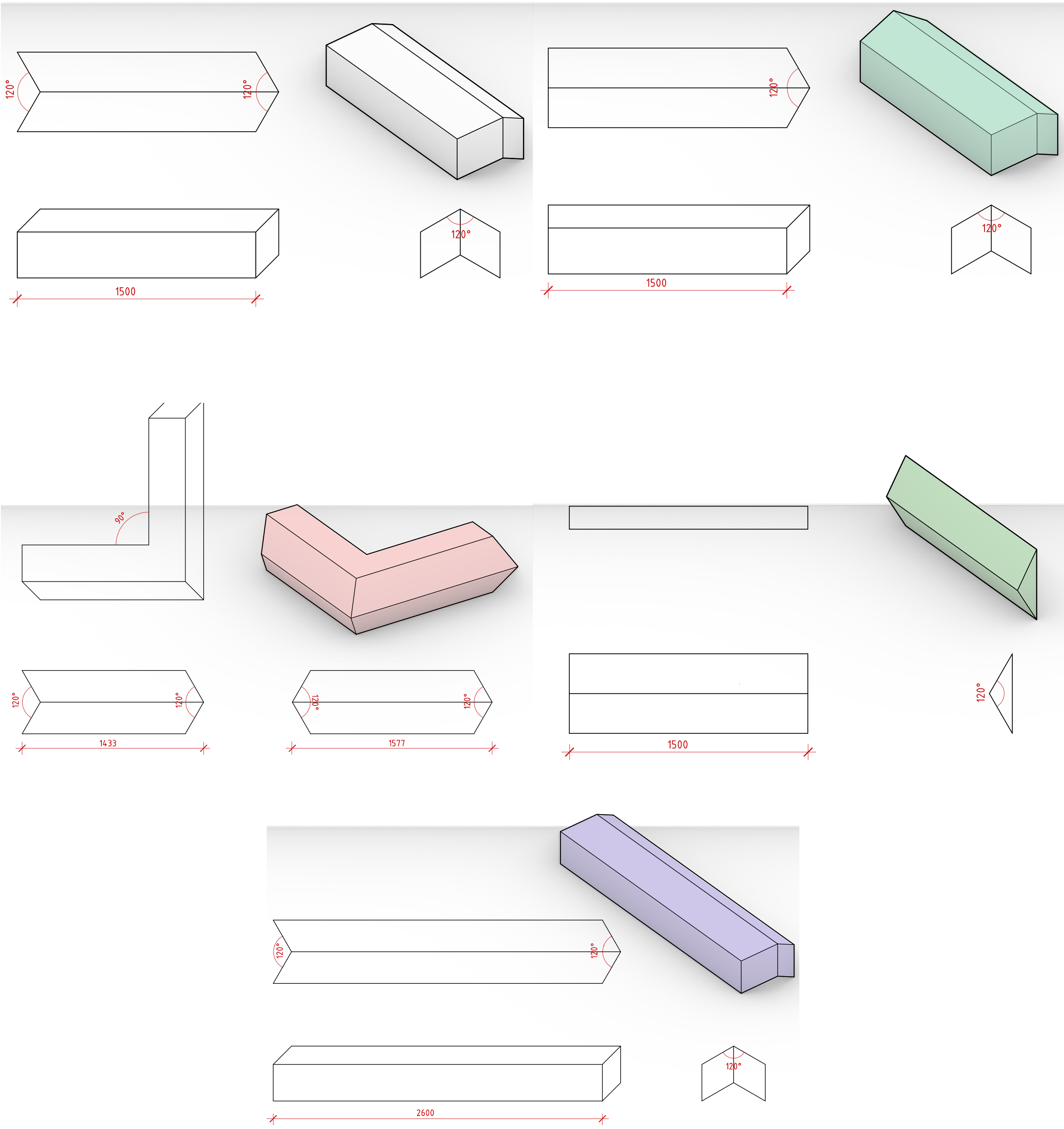
Window with shutters 3



MANUAL AGGREGATIONS

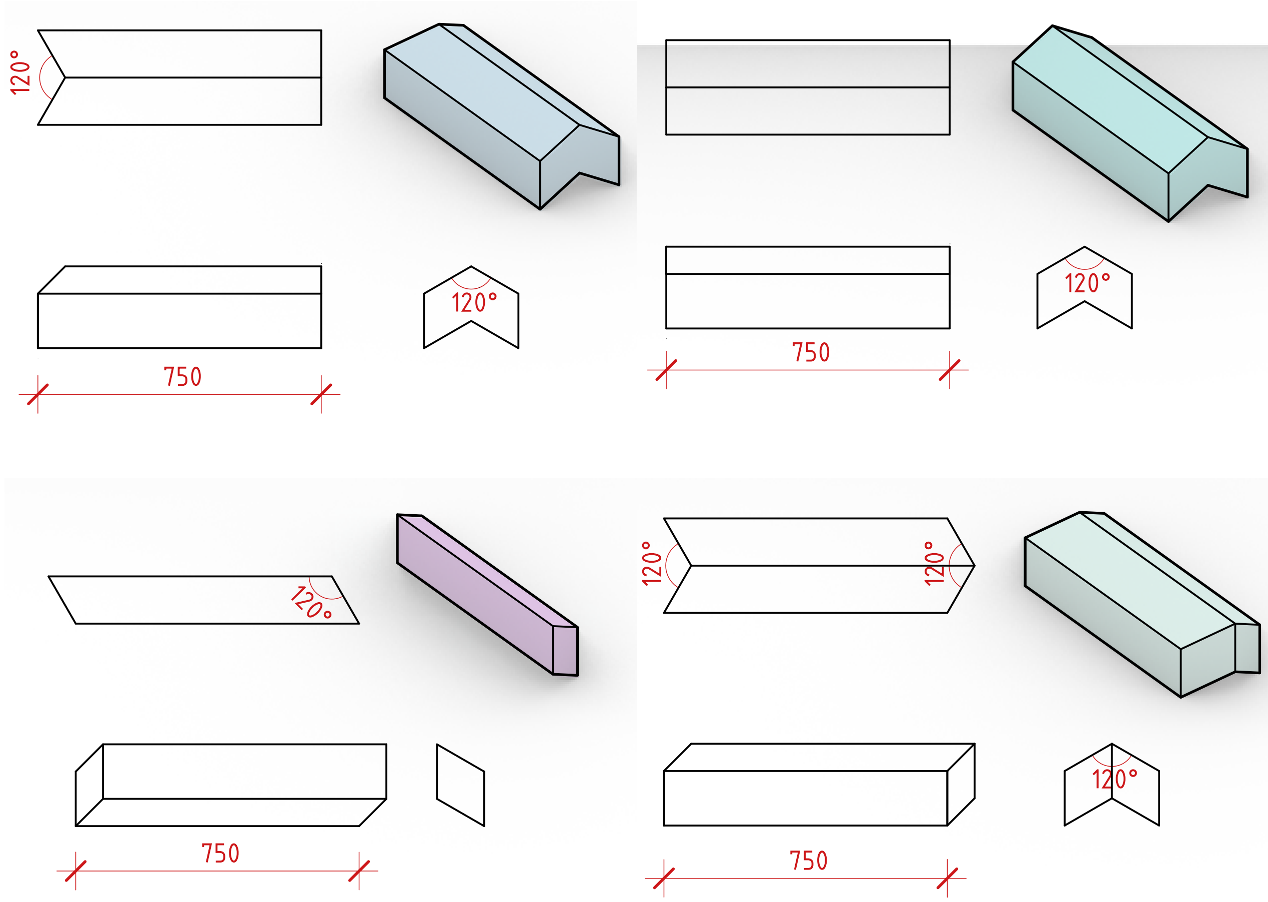


Drawings of the modules used in the iterations



MANUAL AGGREGATIONS

Drawings of the modules used in the iterations



"Genuine variety without monotony could have been attained if we had taken greater interest and influence in the development and design of... standardised, component building parts which could be assembled into a wide diversity of house types. Instead, the idea of prefabrication was seized by manufacturing firms who came up with the stifling project of mass-producing whole house types instead of component parts only. The resulting monotony further deepened the horror of nostalgic sentimental, unguided public of a prefabricated future."

-Walter Gropius

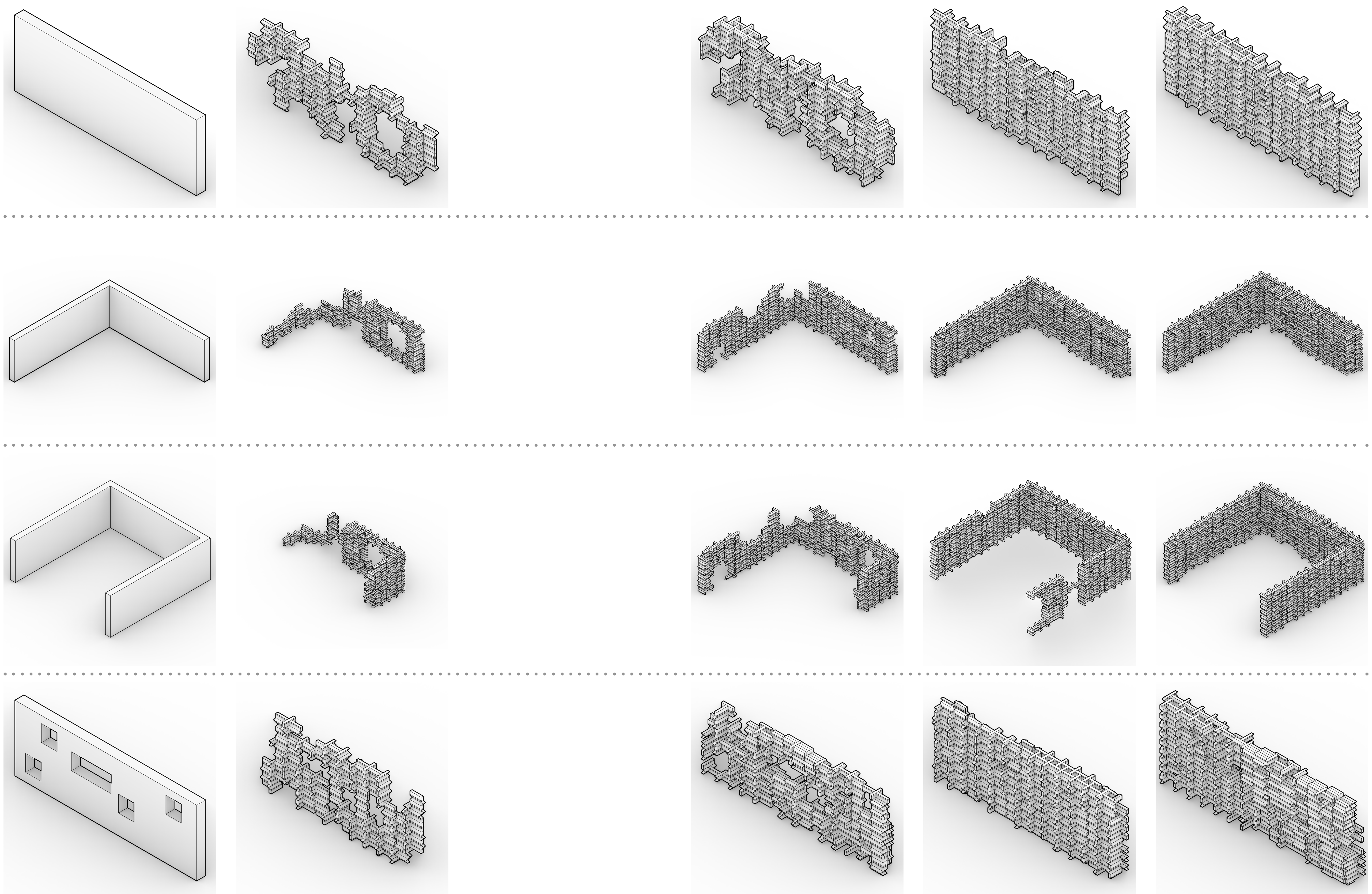
COMPUTATIONAL AGGREGATIONS

The computational aggregation script is based on the Grasshopper plug-in WASP. WASP is developed by Andrea Rossi in TU Darmstadt as part of his PhD.

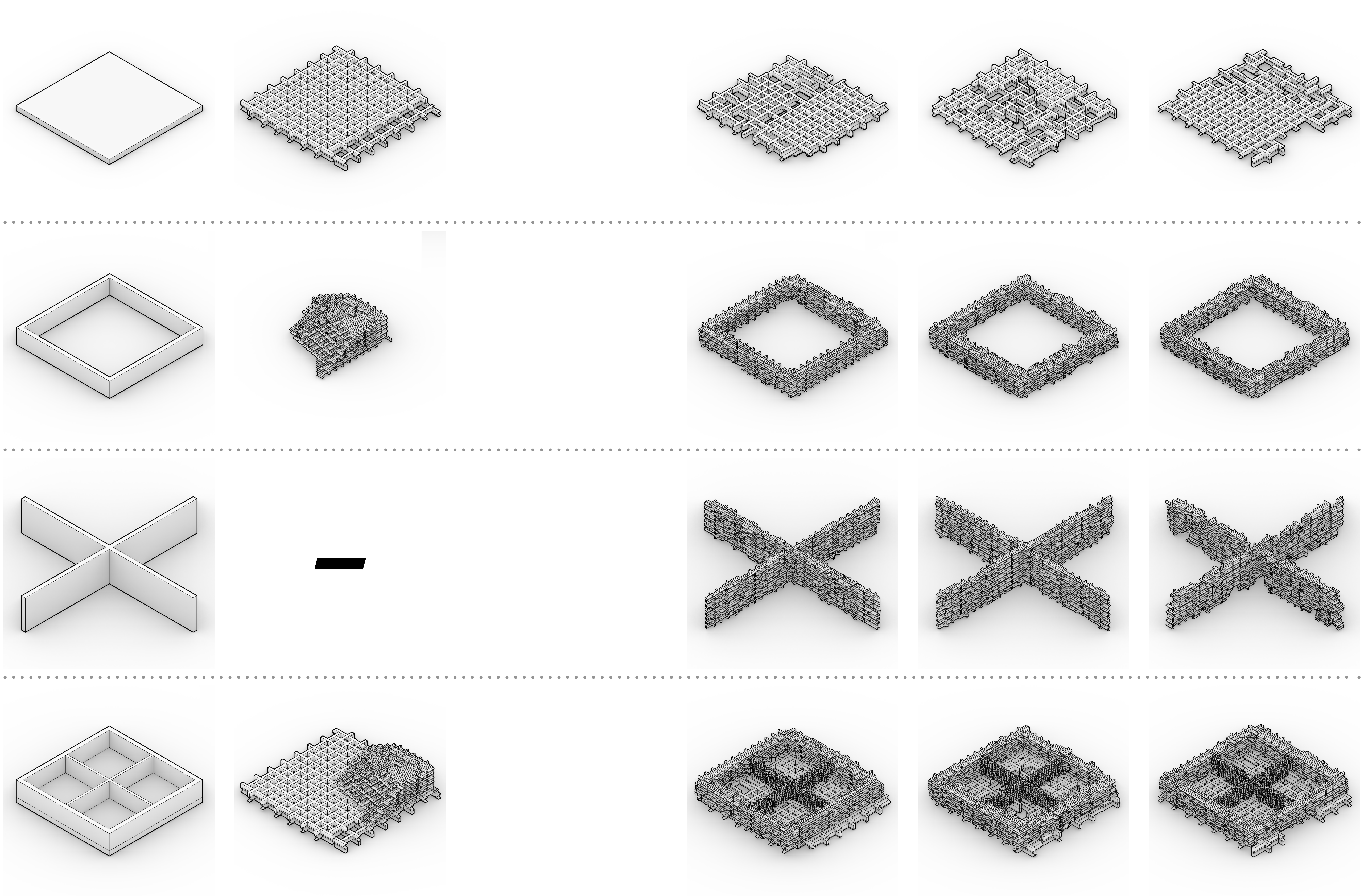
The script inputs are the geometry of the module, the ways the modules are being connected to each other, the desired number of modules to be used in the aggregation and the resolution of the aggregation. The resolution defines how accurate the aggregation will be.

While the geometry and the combinations are easy to understand, the way the number of modules and the resolution are interacting was not so straightforward. In order to get full control of the script, I put it to the test creating two matrices. In the first one the resolution is kept constant while the number of modules used was varying. In the second matrix, the amount of modules is constant while the resolution was varying.

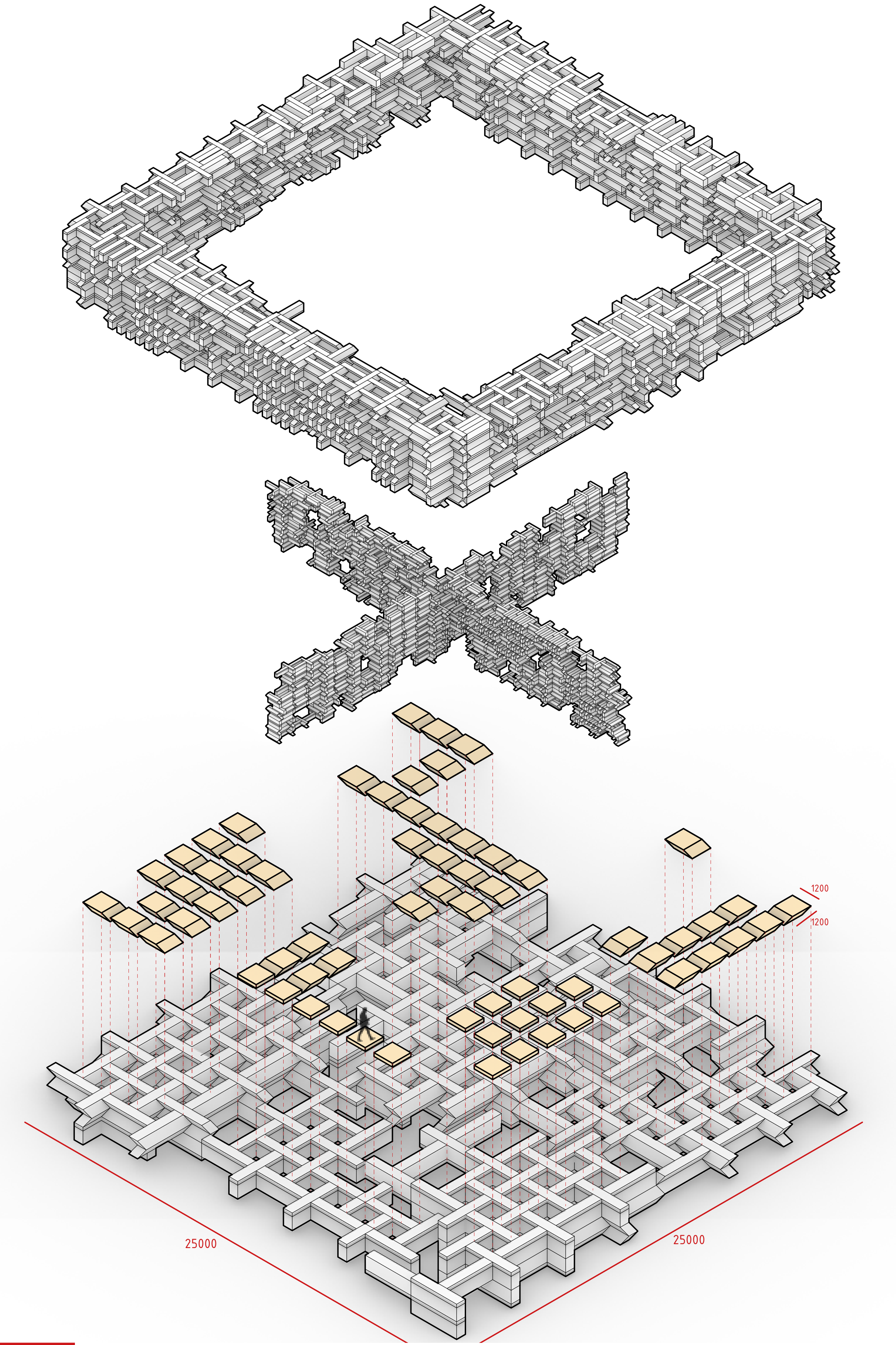
The result was to see the relation between the complexity of the boundary and the resolution. A good example of that is the case where a more complex boundary with low resolution in the aggregation resulted to an error not giving any output. In adittion, when the boundary is simple geometrically a lower resolution is required in order to achieve the desired result. That leads to significantly reduced computation times in later stages where the boundaries become bigger.



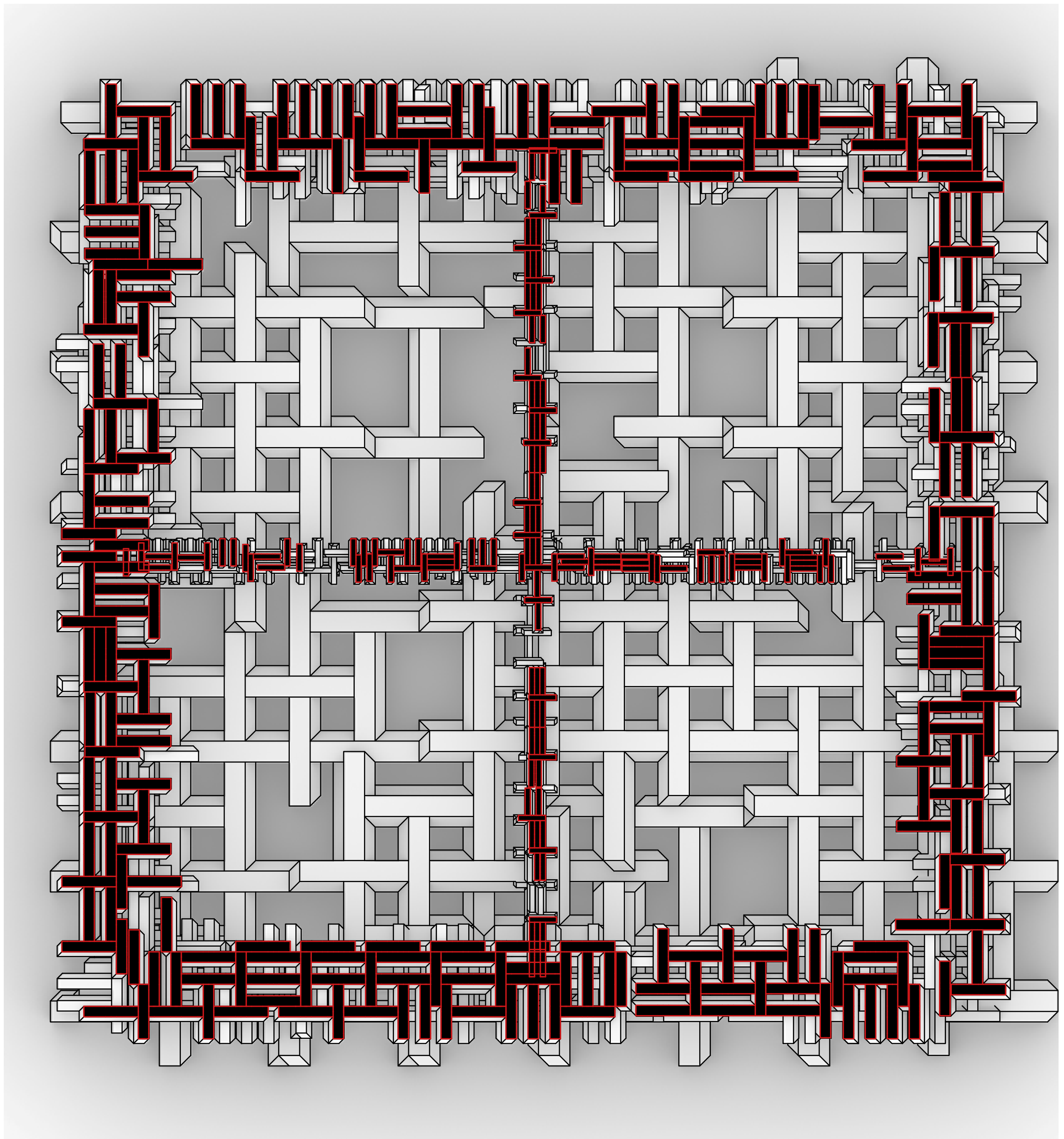
Boundary driven aggregations with varying number of modules and constant resolution

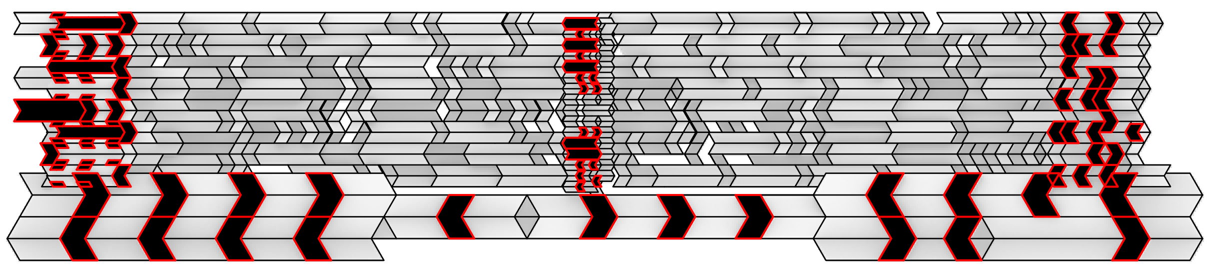


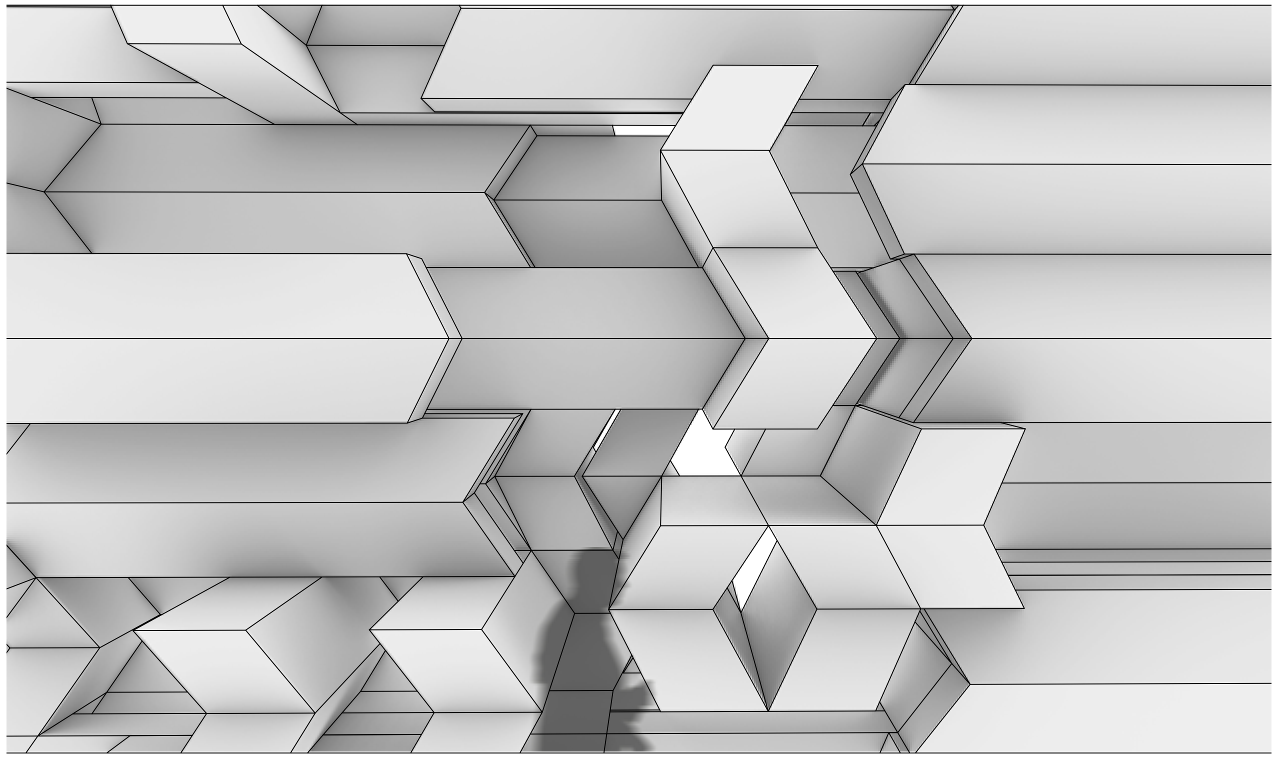
Boundary driven aggregations with varying
resolution and constant number of modules

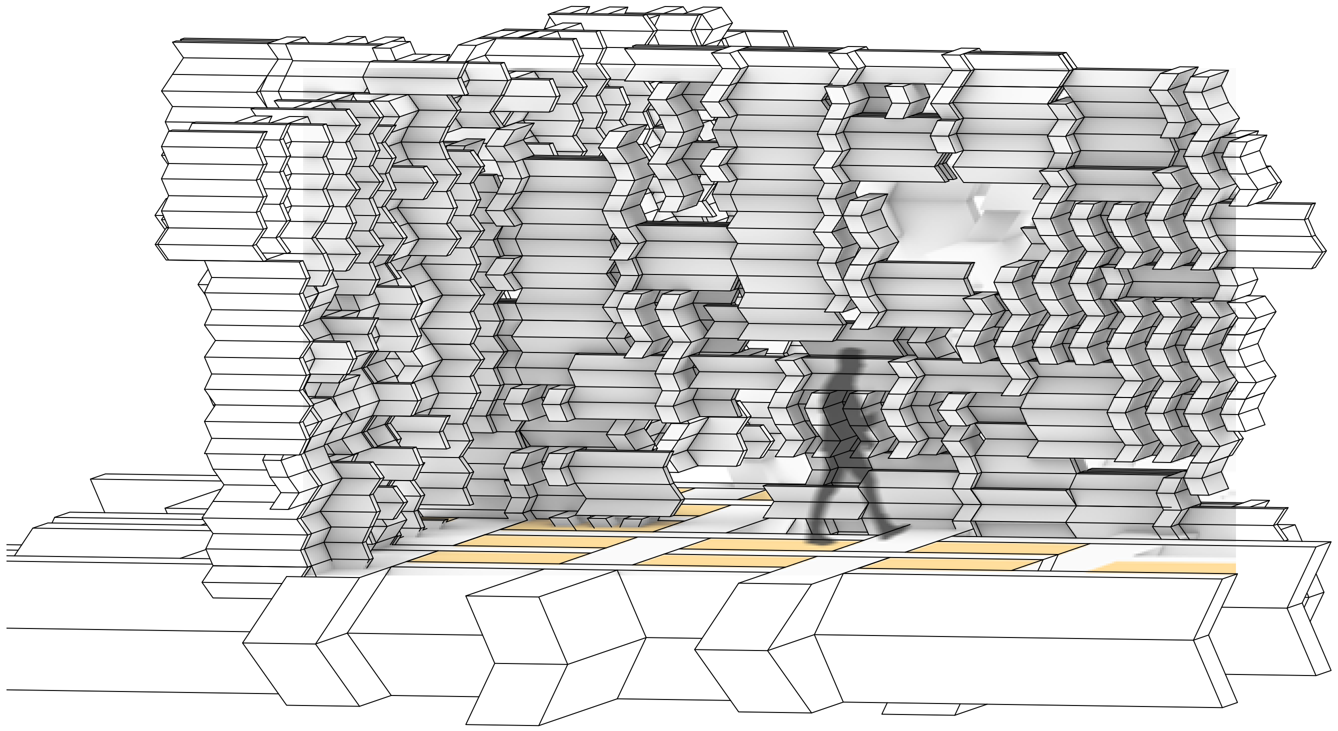


COMPUTATIONAL AGGREGATIONS









COMPUTATIONAL ITERATIONS

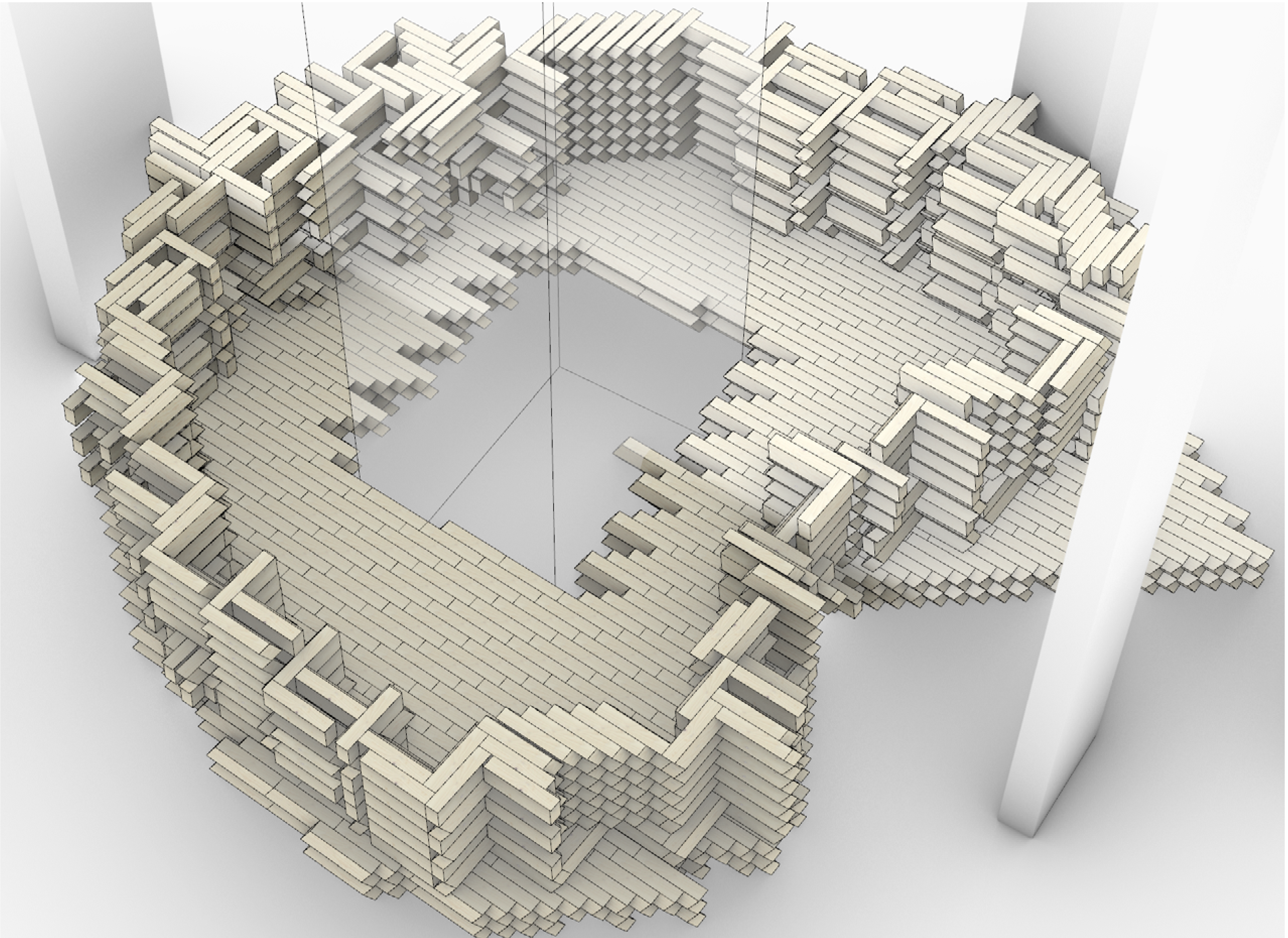
COMPUTATIONAL ITERATIONS

After taking control of the script, it was put to the test in some free form geometries in order to see how the module could be accommodated. At this point the flat vault approach is abandoned for the slab.

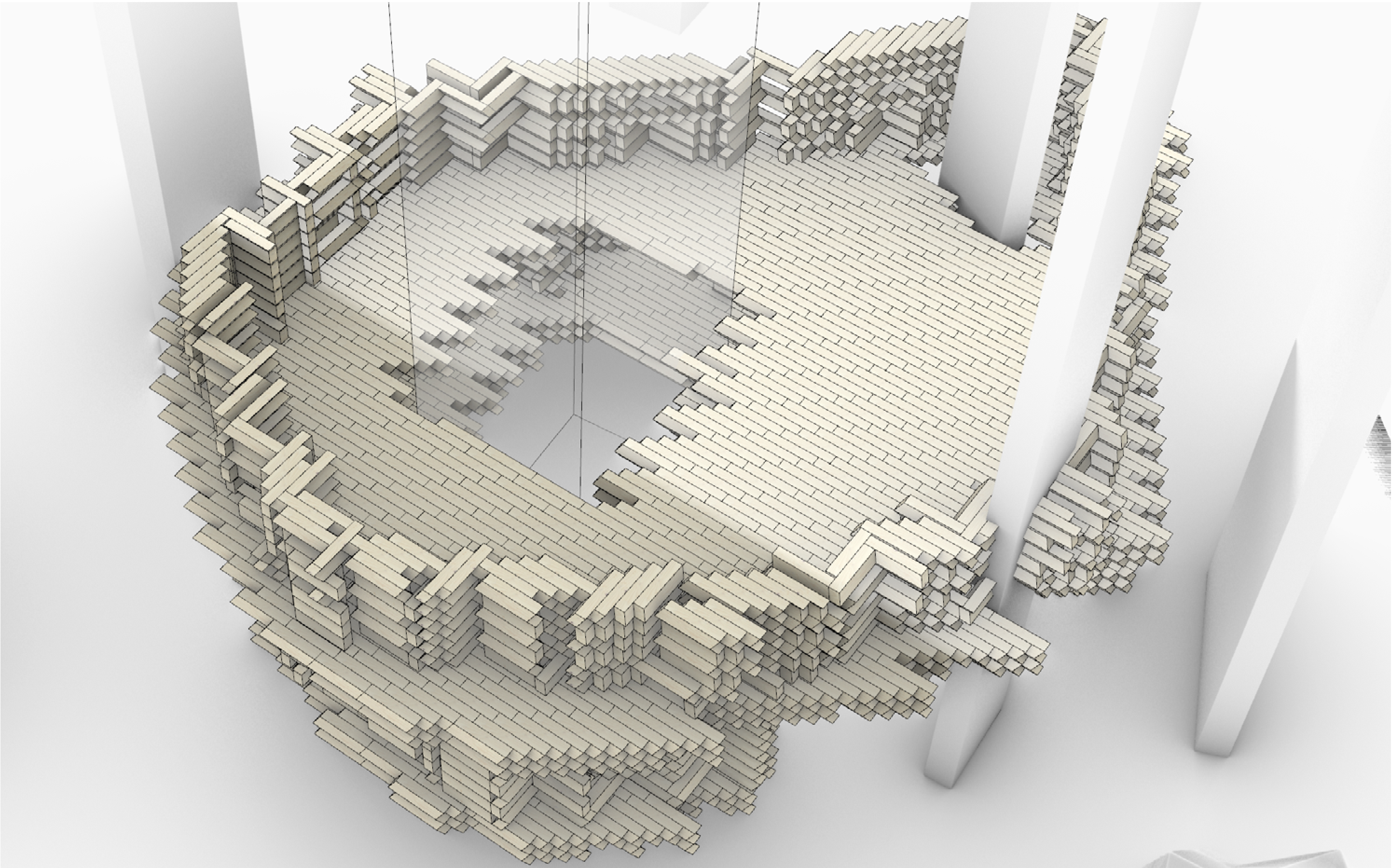
The combination of the module chosen creates always either 90 degree or 180 degree angles, leading to uncontrolled staggering and accumulation of the modules. This behaviour is not desired since the outcome is random.

These computational iterations showed the weaknesses of the module when trying to replicate free forms leading to the developing of the grid system used finally in the proposal.

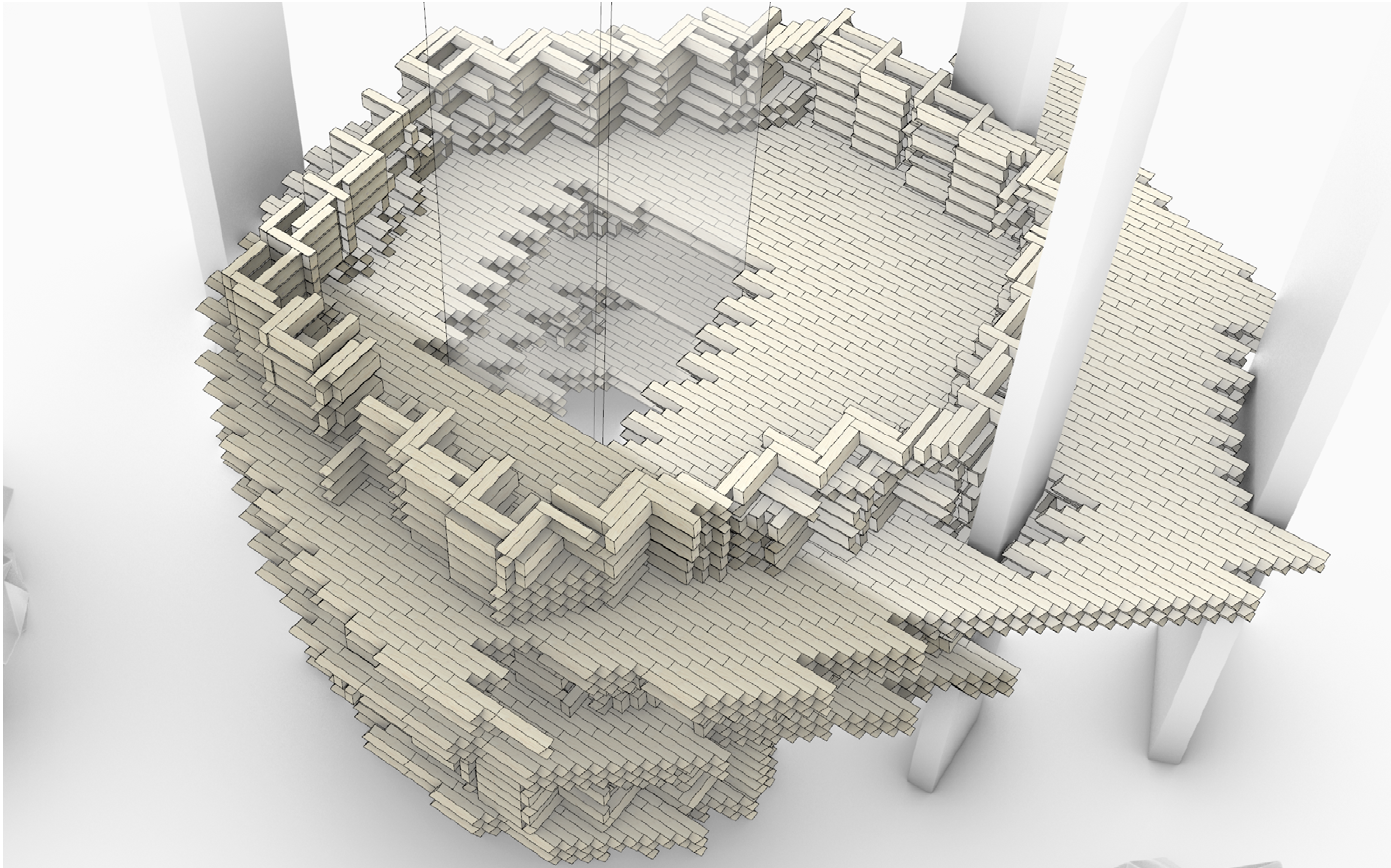
These aggregations, though, could be more controlled if the module was tweaked. The decision was to continue with this module at this stage of the research in order to reach a point where all the pieces (module, structure, aggregation system) are put together.



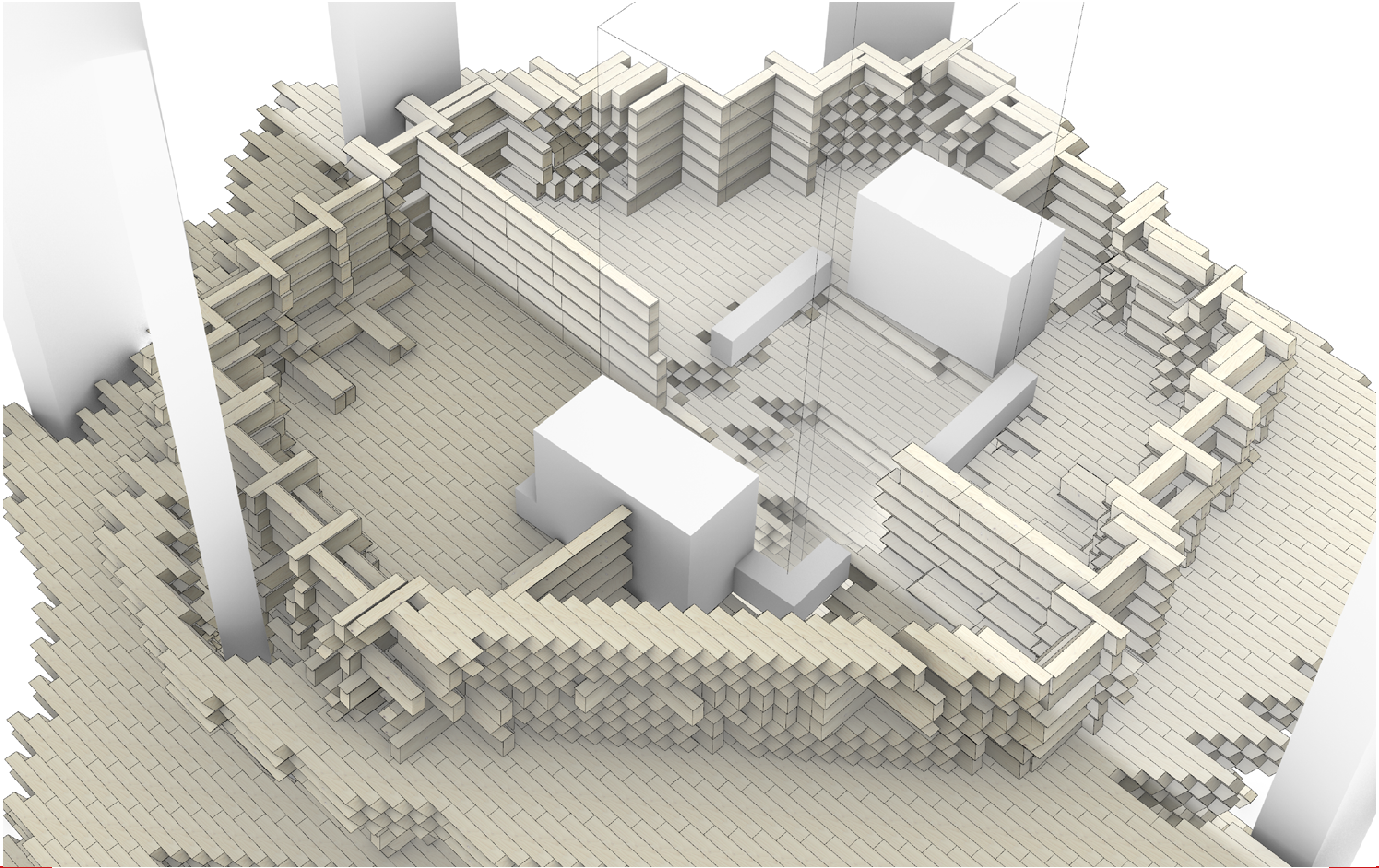
COMPUTATIONAL ITERATIONS



COMPUTATIONAL ITERATIONS



COMPUTATIONAL ITERATIONS



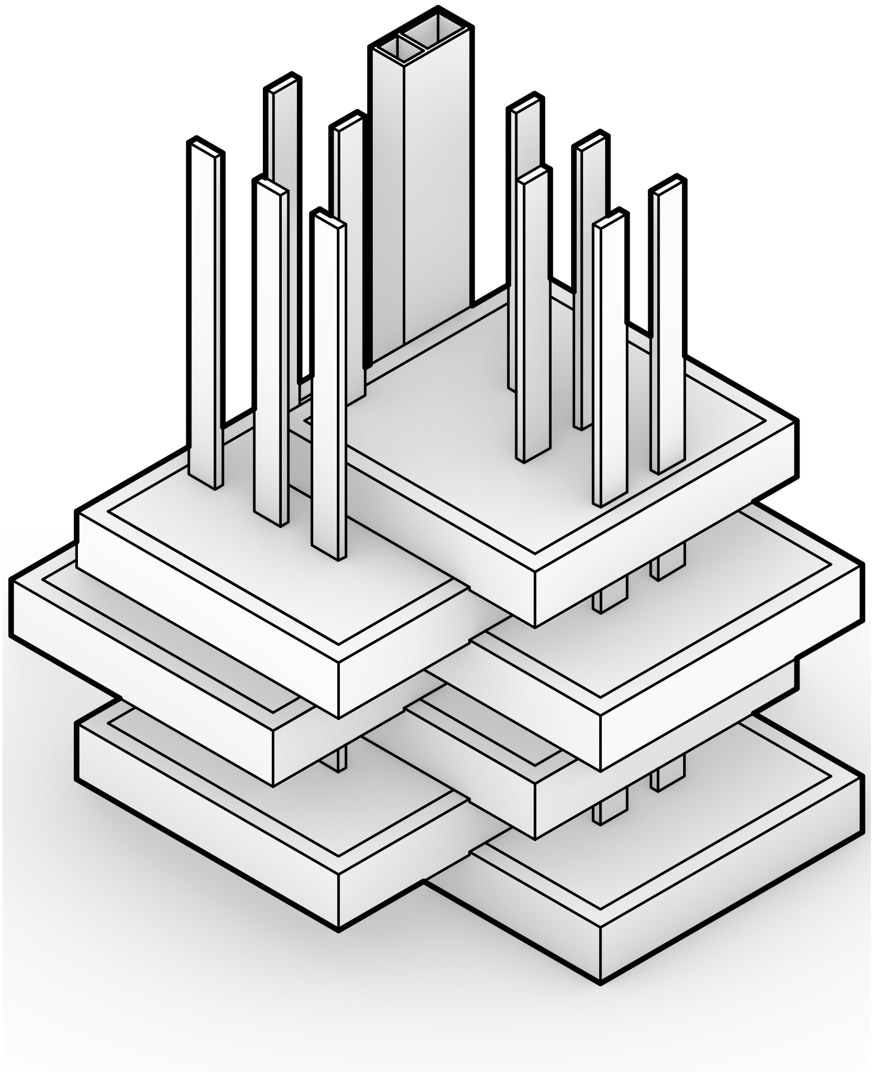
VOLUME STUDIES

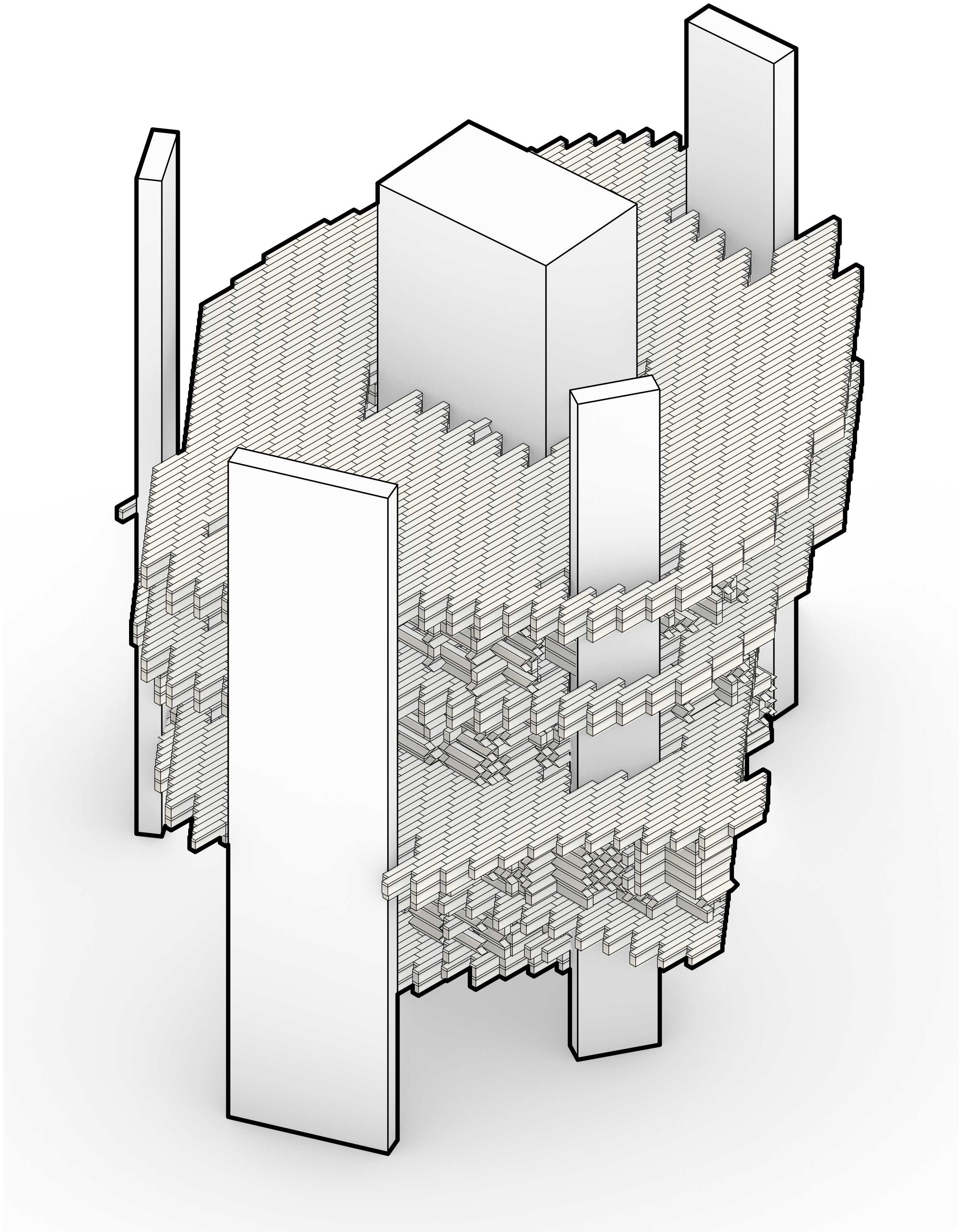
VOLUME STUDIES

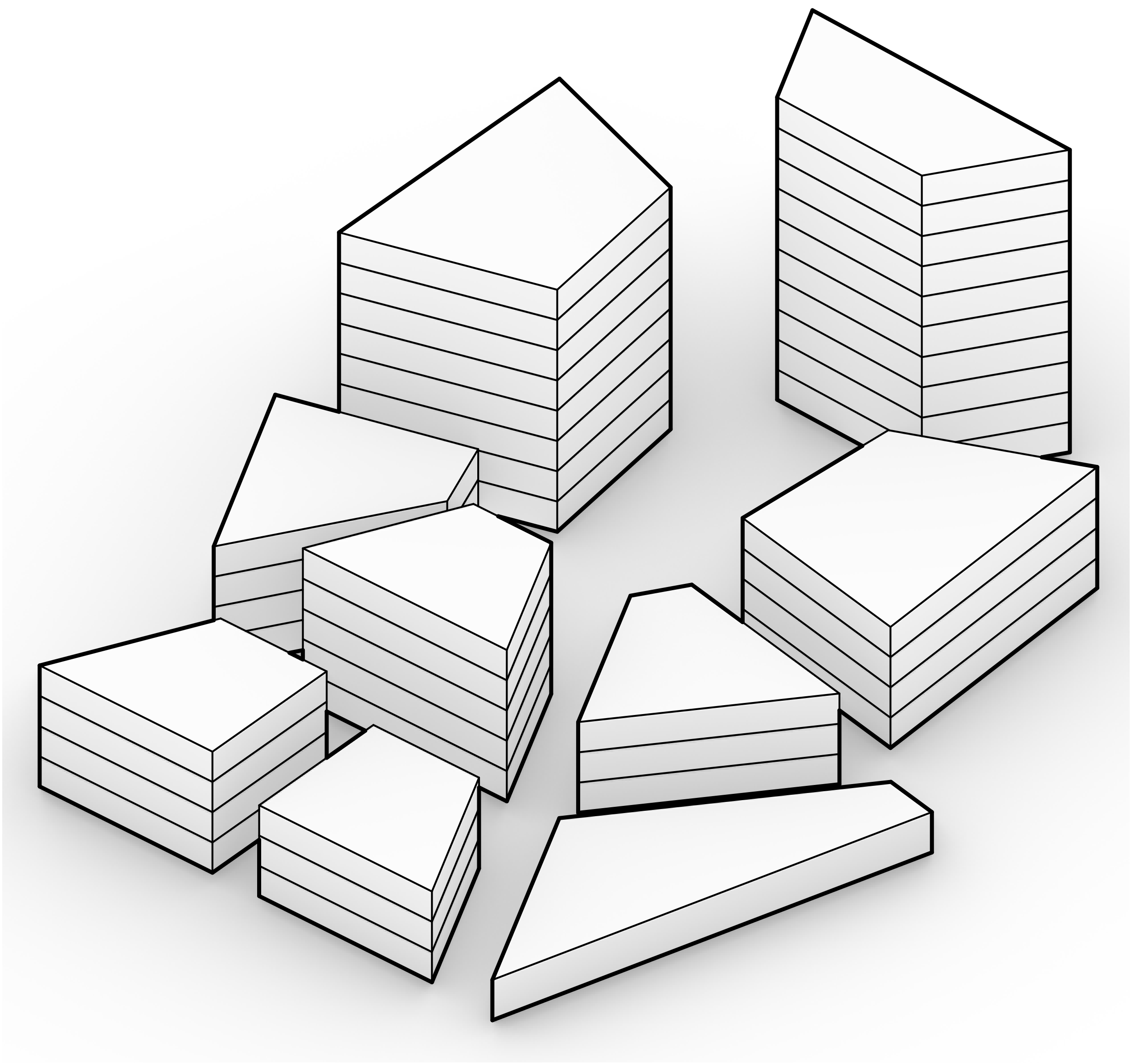
The volume studies were done in parallel with the computational aggregations. From the beginning the structural core was adopted as an approach although the lack of an underlying logic was prevalent.

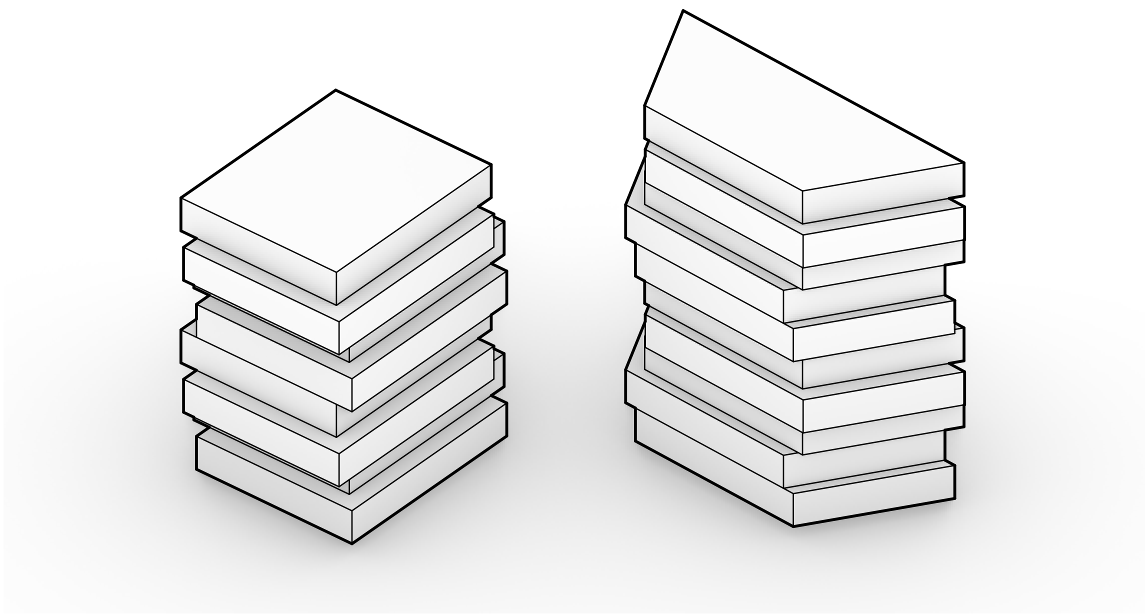
There have been attempts to have a freestanding building on the site as well as attempt to have a more urbanistic approach to the site. Although since the site was not the focal point of the research, such an approach would raise many questions.

When the logic of the grid was developed, during the structural iterations, the desired free form, pinpointing the flexibility and reversibility of the system as a whole, was easier to create. The final approach is rather a hybrid of the urbanistic and the free-standing approach of these studies, while the "forest of shafts" used in some of those, both for structural and practical reasons, was replaced by a single core in the centre of every building volume.

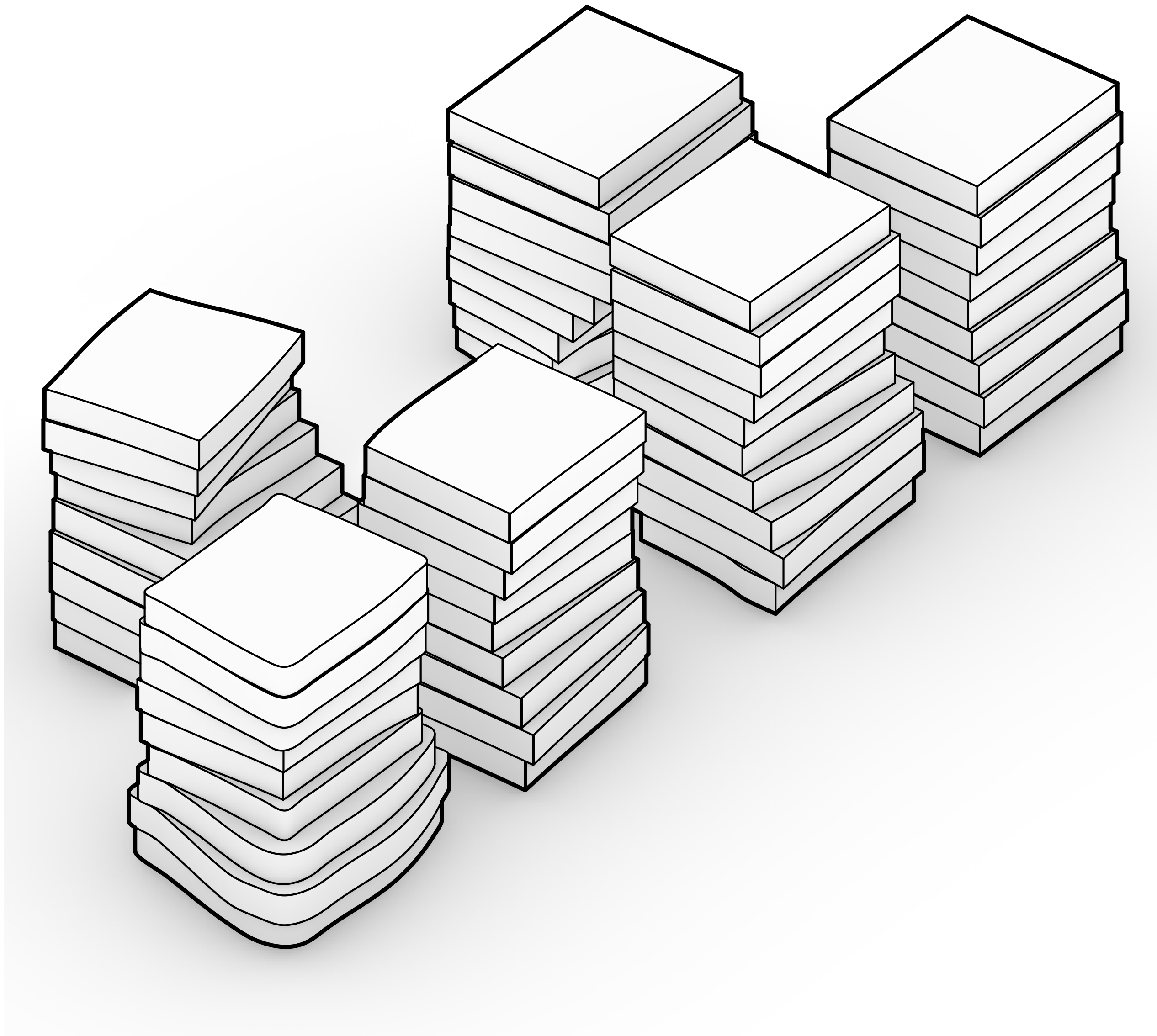








VOLUME STUDIES



STRUCTURE ITTERATIONS

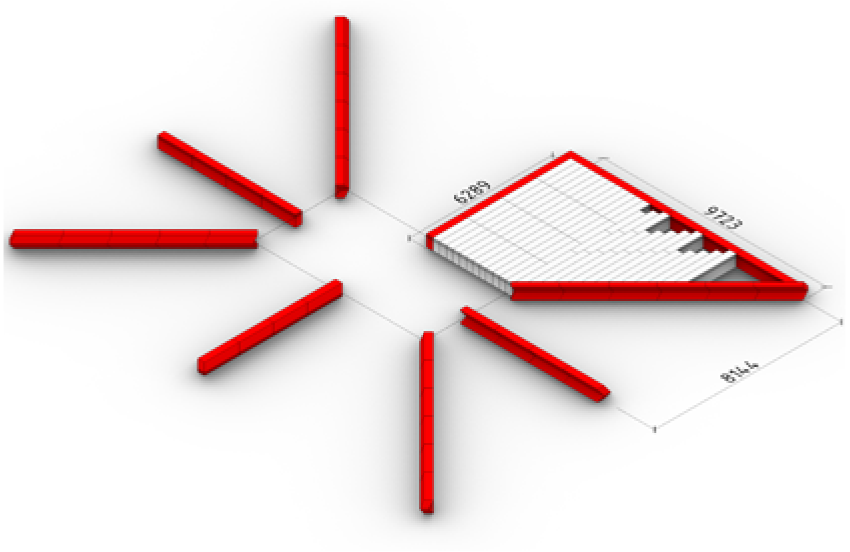
In the computational iterations a main issue was the structure of the slab. During the volume studies there were ideas about the structure behind the different steps although it was obvious that an undelying logic was needed.

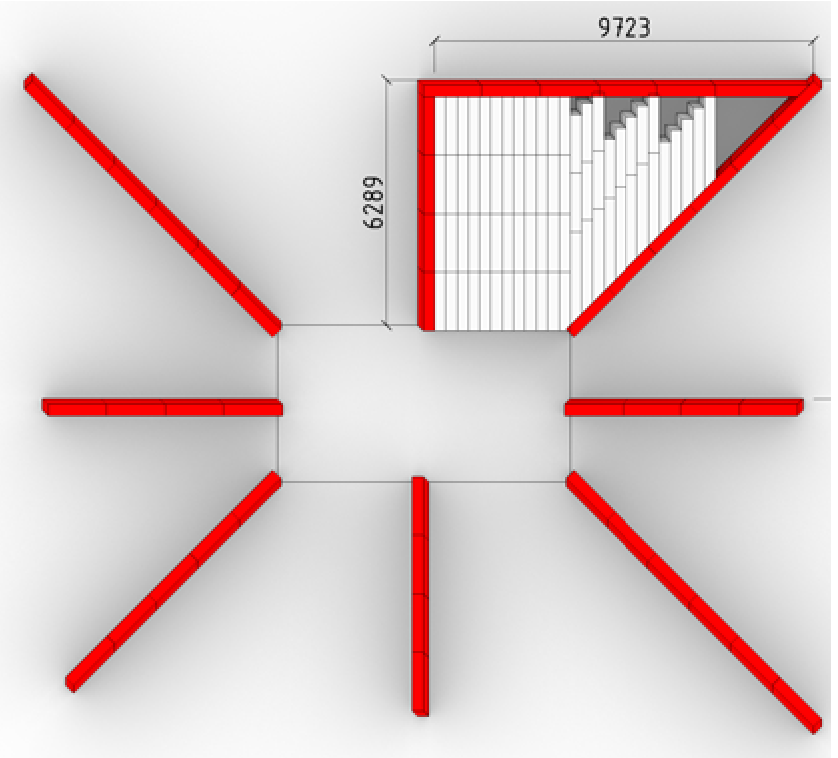
The first attempt to solve these issues was to create frames of beams, built up by the modules, in order to fit the slab inside. This approach limited the flexibility and the reversibility of the slab.

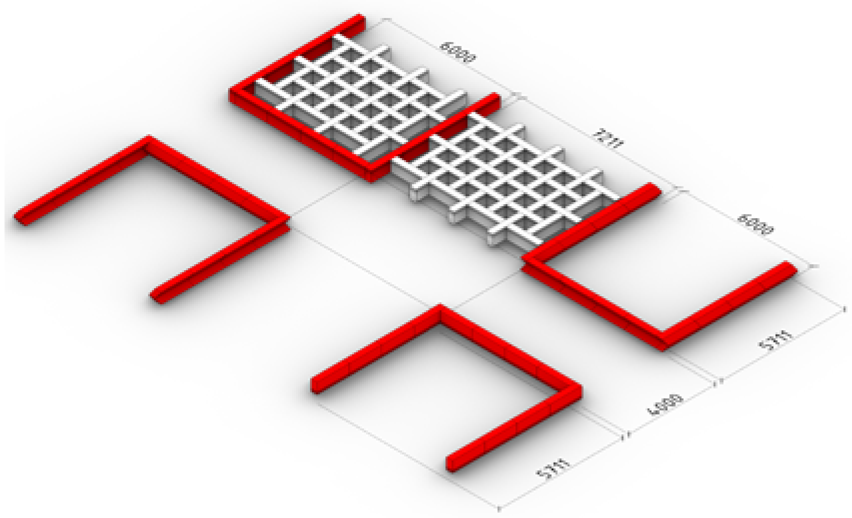
While developing the aggregation script, the pattern of the flat vault emerged. Its property of distributing the loads equally along its area as well as the idea of the stabilising core in the middle of the slab rendered its use ideal for this case.

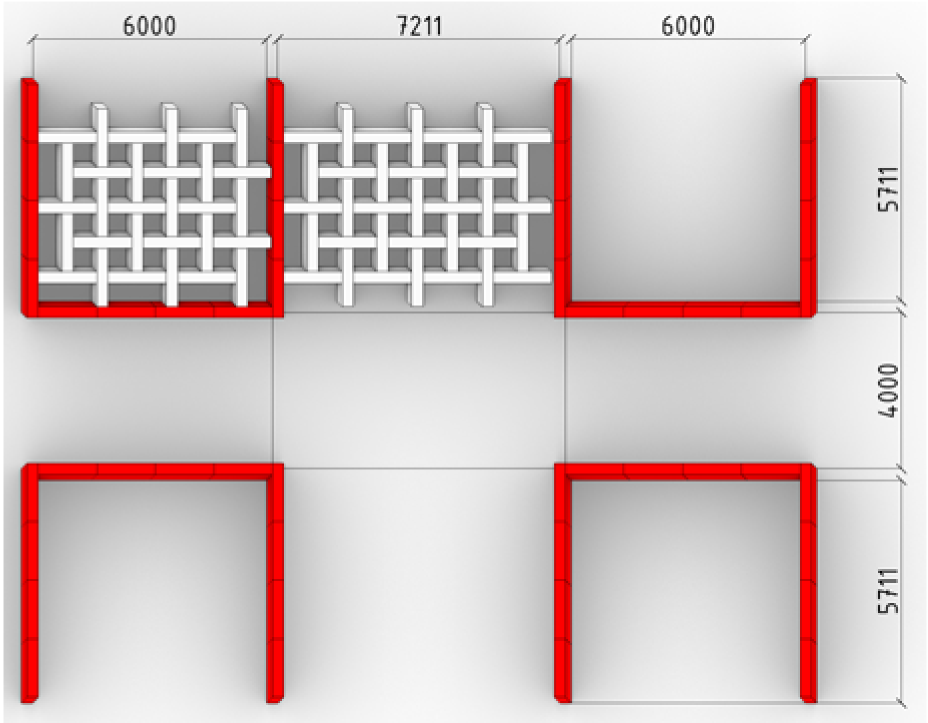
After many iterations and consultation with a structural engineer the "frame" approach was abandoned and the flat vault was placed on top of the beam frame, allowing for flexibility in the development of the slab as a flat vault. In addition it was confirmed that the joints work perfectly in order to create a beam out of the modules.

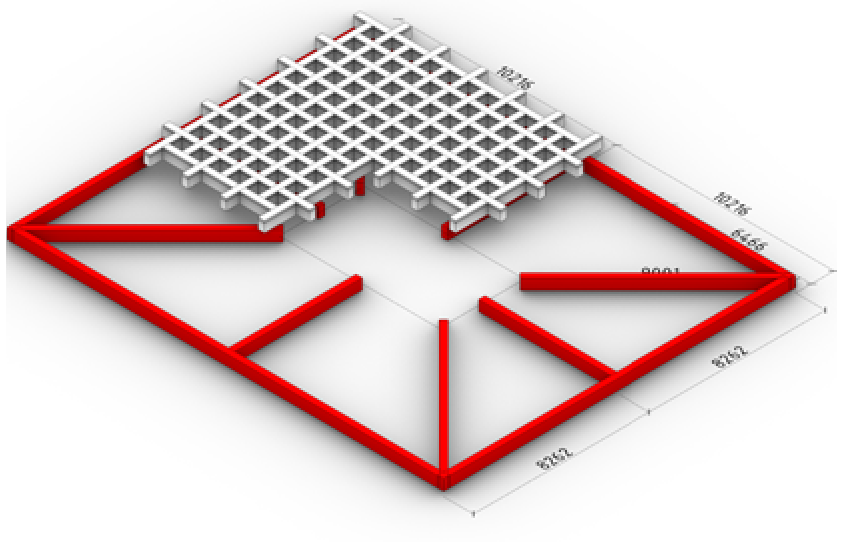
The approach that was chosen led to the development of the grid system that is the framework for the development of the proposal.







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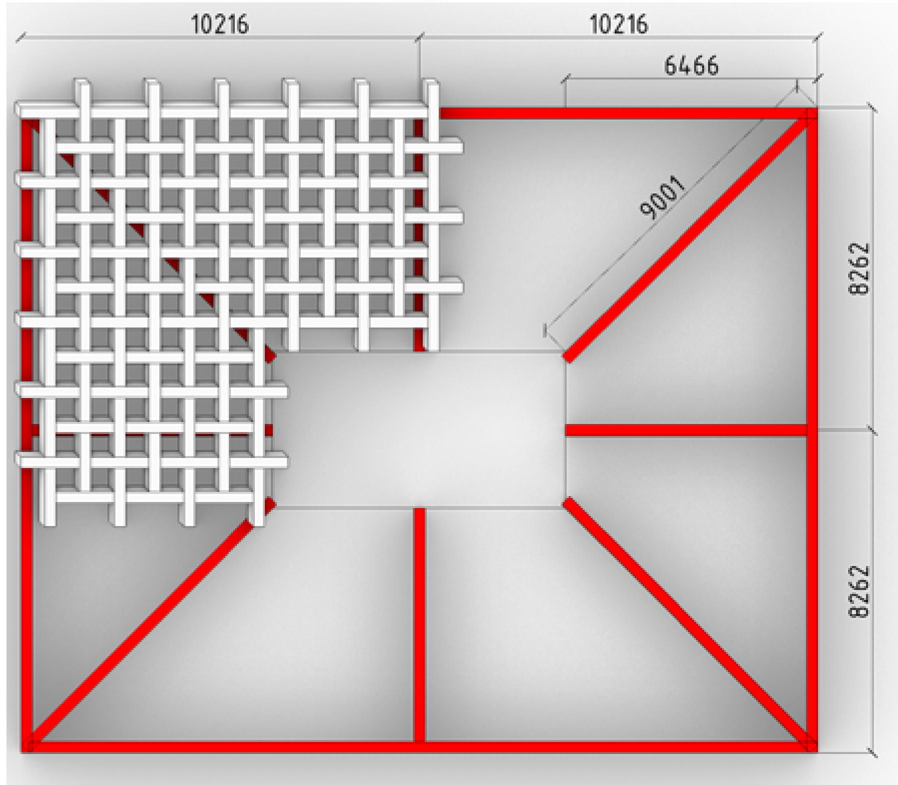
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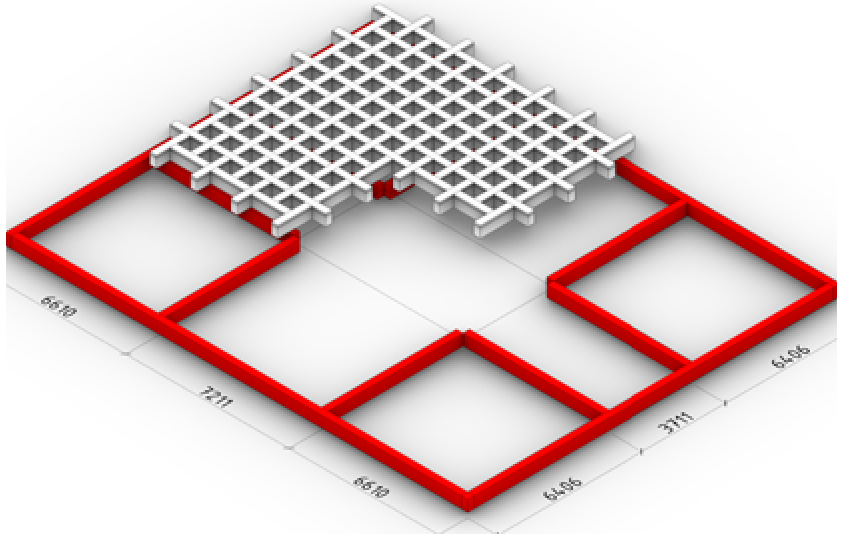
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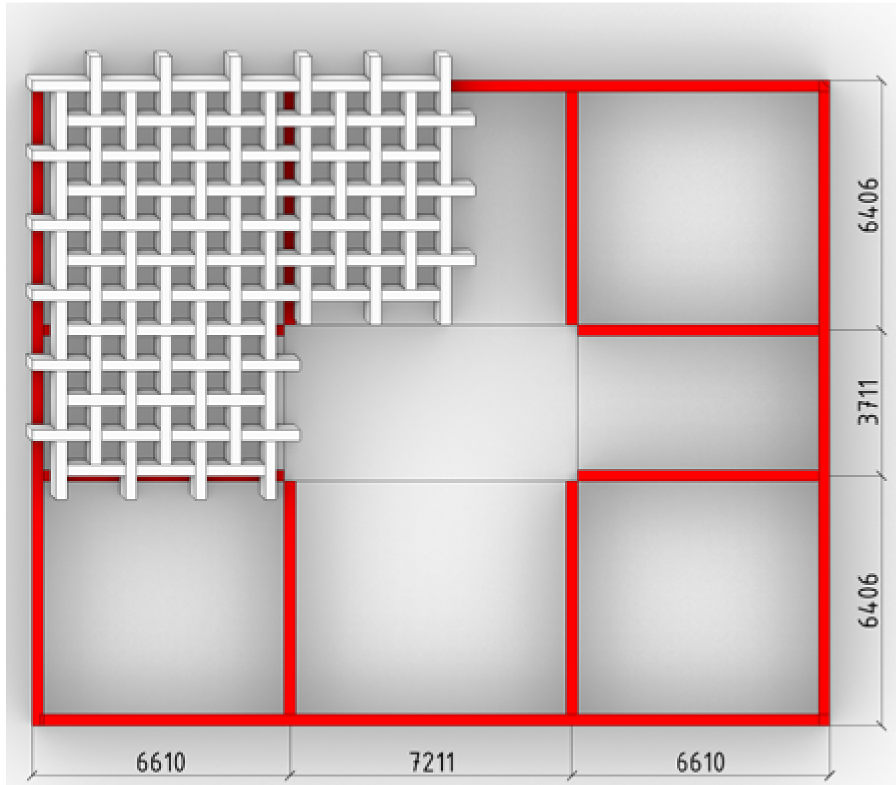
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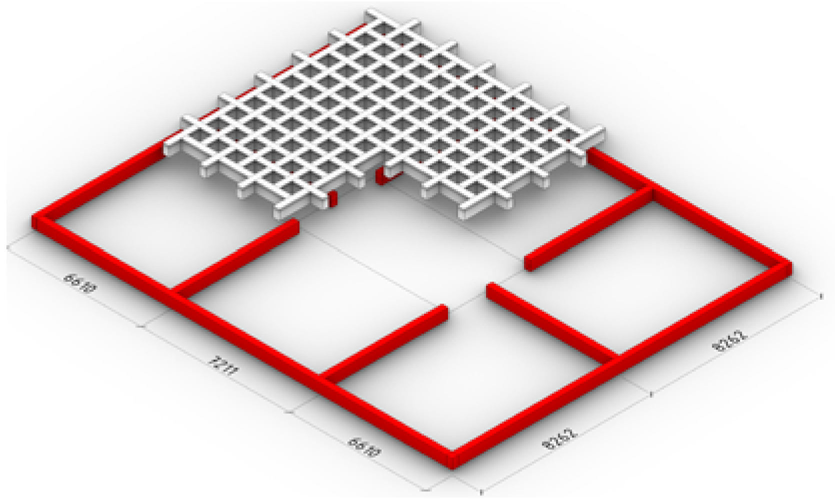
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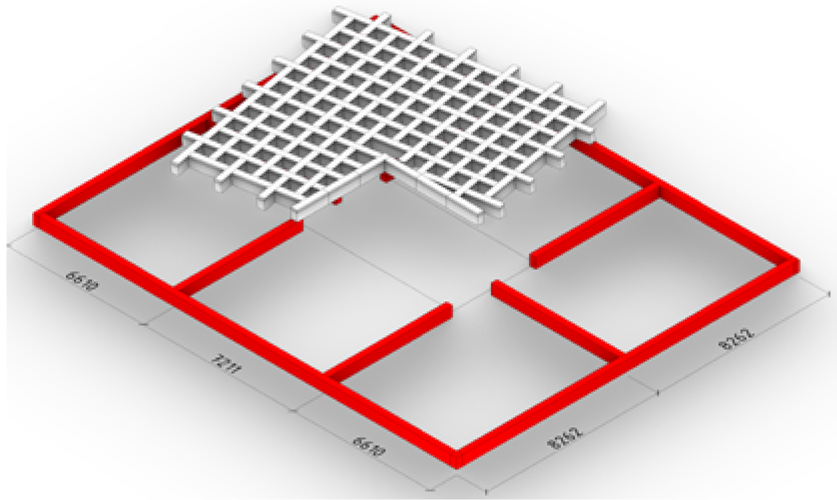
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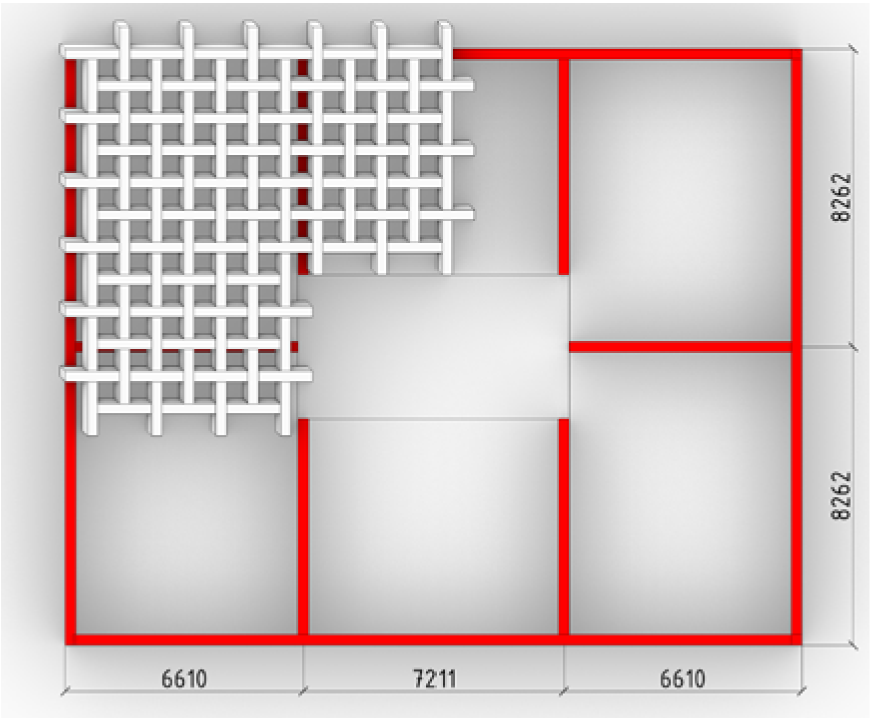
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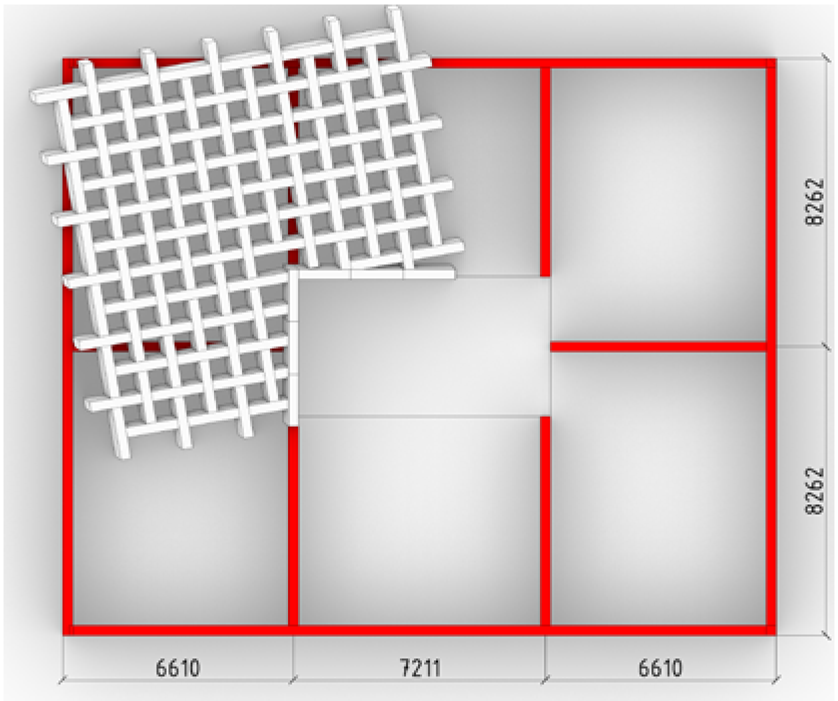
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DESIGN REFERENCES

Tallin Architecture Biennale Pavillion, Gilles Retsin

Fabrication
- CNC-cut Plywood, assembled in the factory.

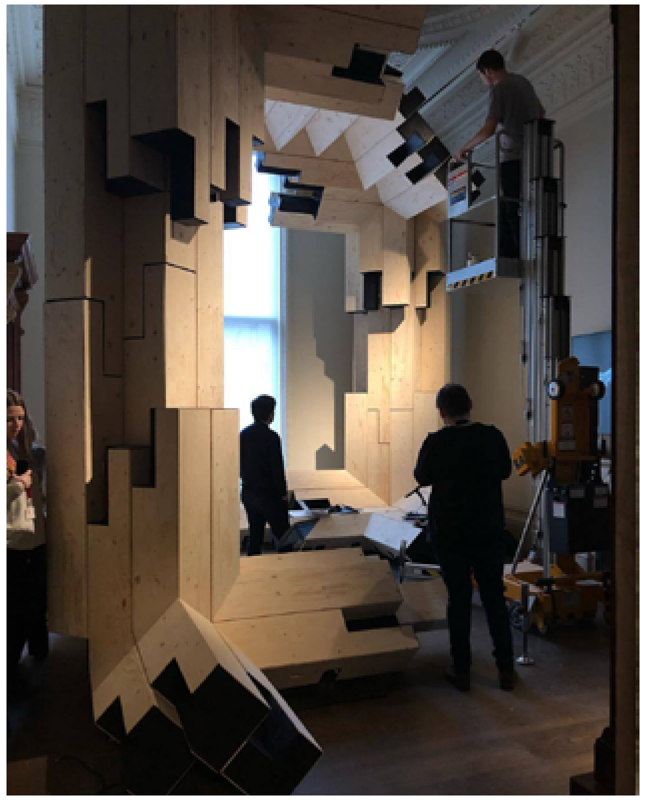
Size
- The straight modules are in almost human height.
- CNC-cut Plywood, assembled in the factory.

Weight
- Lightweight due to the material used.

Misc
- Easy assembly handled by one or two builders
- Multi-directionality
- Intricate tectonics

DESIGN REFERENCES

Real Virtuality, Invisible Landscapes Act III, RA, Gilles Retsin



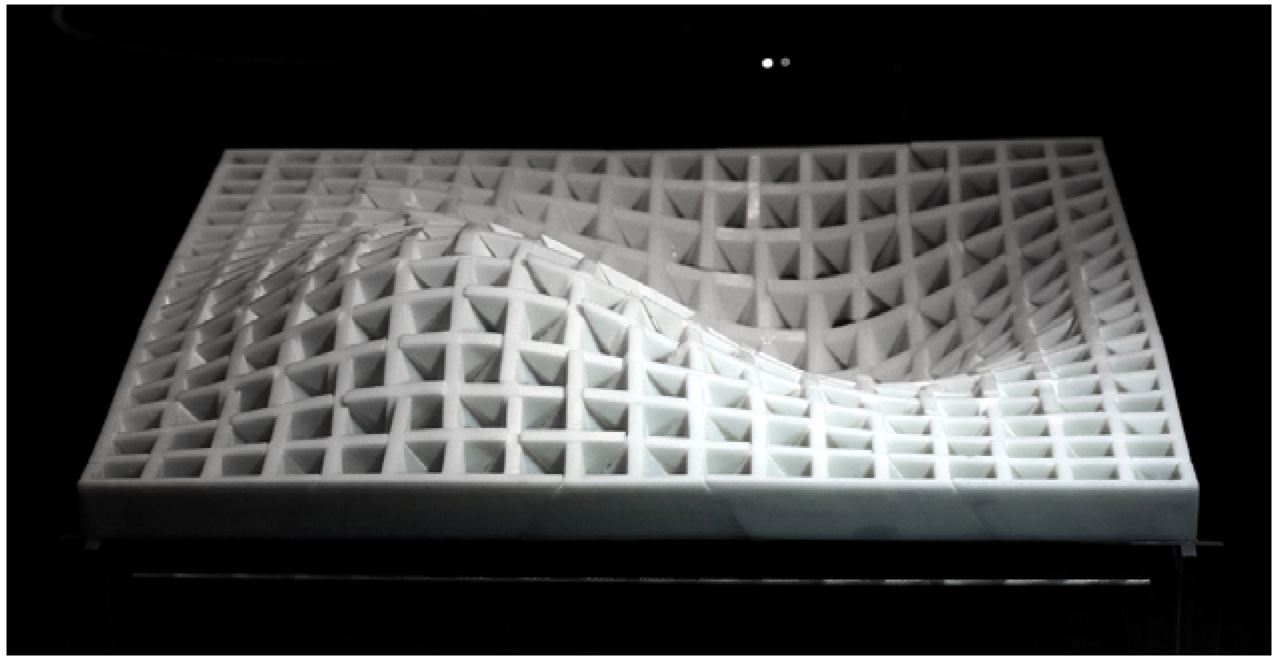
Fabrication
- CNC-cut LVL, assembled in the factory.

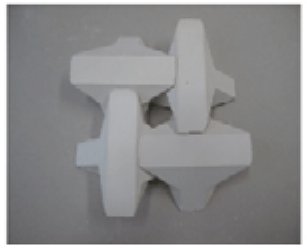
Size
- The straight modules are in almost human height.
- The angled ones are bigger although not higher.

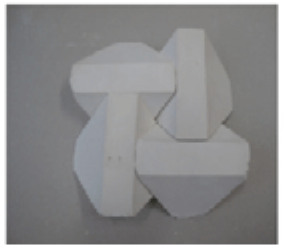
Weight
- Lightweight due to the material used.

Misc
- Easy assembly handled by one or two builders.
- Right angles that create collumn-like structrures.

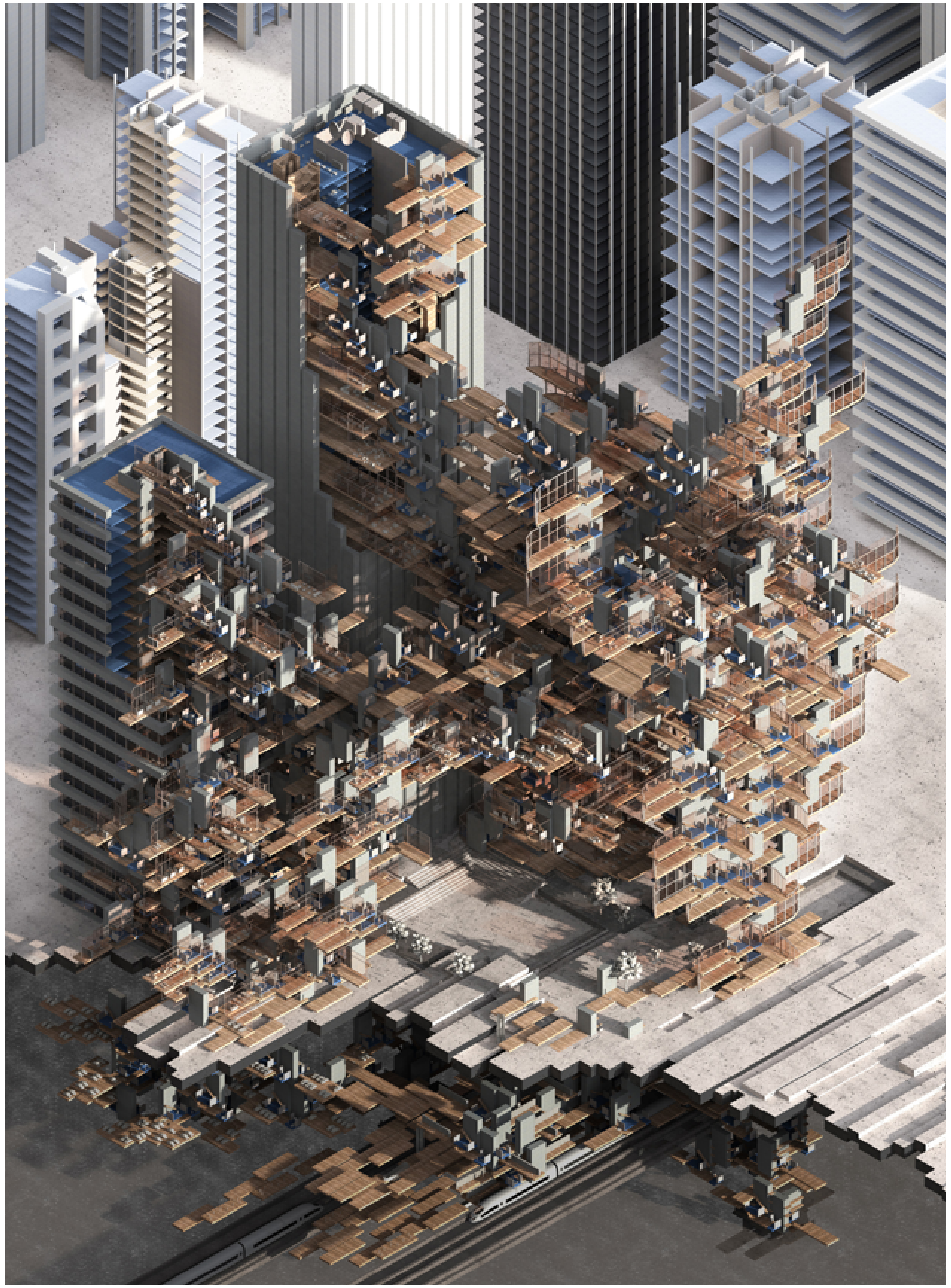
Topological Interlocking, Oliver Tessmann





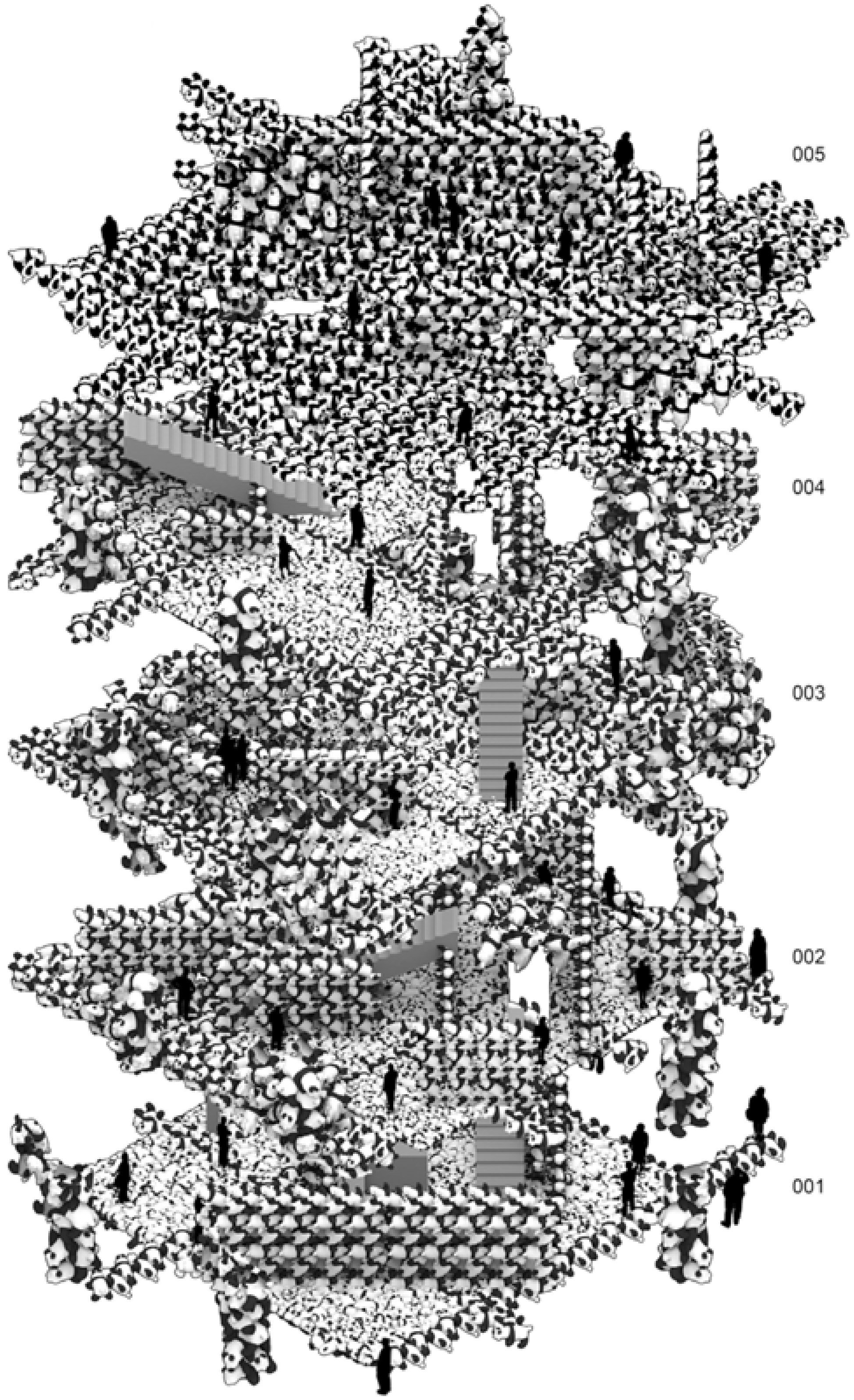


Blockerties, Daniel Kohler et al.



Habitat Puerto Rico, Moshe Safdie

Panda Hut, Ryan Vincent Manning, Fabian Partoll, Alexander Gasser



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ACKNOWLEDGEMENTS

I would like to thank:

My supervisors, Jonas Runberger and Karin Hedlund for their invaluable guidance through this thesis.

My examiner, Jonas Lundberg for pushing me to evolve the project further in every step of the road.

Kengo Skorick for the endless discussions before and during this semester.

Daniel Norell for his feedback throughout this semester.

Karl Gunnar Olsson for his input on the structural issues.

My family for their understanding and support.

Louisa for her patience.

Johan for the intensive discussions that helped me in the early stages of the project.

Michalis and Fritzi for their support.