Robotic High Rises No.02: Design Research Studio 2013 PART 1

Publication Date:
2014

Permanent Link:
https://doi.org/10.3929/ethz-a-010709472 →

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Robotic High Rises No.02

FCL Magazine Special Issue

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FCL MAGAZINE SPECIAL ISSUE

Robotic High Rises No.02

Design of Robotic Fabricated High Rises | Research Module of Architecture and Digital Fabrication | Gramazio & Kohler | Future Cities Laboratory

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Design Research Studio 2013

Foreword

The work presented in this special issue of the FCL Magazine focuses on work emerging from the design research studios conducted in Singapore by the architecture and digital fabrication team, lead by Profs Fabio Gramazio and Matthias Kohler. The design research studio is a hybrid research format that deals as much with the identifying, shaping and setting of research problems, as much as it does solving them. It is a form of research that shuttles between empirical investigation and creative proposition-making. The design research studio is also and effective and meaningful way of integrating masters students, PhD candidates and postdoctoral researchers into a collective inquiry.

The digital fabrication team have innovated around the design research studio format in the context of Singapore's famous high-rise and high-density built fabric. The format has enabled them to develop collaborative research and teaching platforms with colleagues and students from the National University of Singapore, and ETH Zürich. The distinctive features of the design research studio – interacting with more conventional modes of scientific inquiry – allows researchers to test, refine and develop compelling visions, and credible technologies and processes that sustainable future cities will require.

Stephen Cairns

Editorial

The Design Research Studio on Robotic Fabricated High Rises was conducted for the second consecutive year at the Future Cities Laboratory (FCL) in Singapore. The focus continued on high-rise mixed-use residential typlogies, since they dominate large parts of the urban landscape in South-East Asia. Although an unbroken demand for housing space coupled with decreasing availability of usable land resources continues to push the limits of vertical growth, the construction technologies are still rooted in a quite anachronistic industrial paradigm: efficiency and economic factors are the driving factors. The studio challenged established paradigms and investigated how contemporary computer-aided architectural design in combination with robotic fabrication could contribute to more differentiation in the context of large buildings.

The studio projects continued to investigate the potential impact of these technologies by creating robotically constructed 1:50 models of high-rises. Processes and components generated in the previous year served as the conceptual foundation for students in the second year. They were provided with a combination of a vacuum gripper and an elaborated feeder system, which allows them to pick building elements from laser-cut sheet material. Predefined programmes and a robotic control setup in Grasshopper directly linked geometric representation of the computer screen with a robotic building process. This initial setup enabled each group to work from the beginning on with an unlimited number of different parts, unlike to the year before when students had to start building tower models with geometrically very limited and similar elements. Hence the focus shifted away from overcoming technical challenges in the robotic fabrication process to a discussion of the implications of robotic fabrication on architectural design in general and the typology of a high-rise in particular.

The semester started off with a survey of high-rise typologies. Students were challenged to identify typological elements that can be translated into parametric design models and produce differentiation. After the initial analytical phase students developed computational design engines connected to the given robotic fabrication process and started to build iterations of towers. The built models were analysed and discussed leading up to the next iteration of model building, thus forming a constant feedback loop between computational design and robotic fabrication. In that working mode the Design Research Studio produced fourteen 1:50 models of up to 4.0 metres height.

In 2013 the studio was open to master's students from both ETH Zürich and National University of Singapore (NUS). A team of PhD researchers addressed robotic construction in a 1:1 scale, focussing on computational design, constructive systems and fabrication processes. Working in an interdisciplinary robotic test laboratory, the studio and PhD researchers greatly benefited from each other through constant knowledge and technology transfer.

Raffael Petrovic and Michael Budig

Guest critics and lecturers 2013:

Marcel Brülisauer
Jason Carlow
Stylianos Dritsas
Alexander Erath
Sawako Kaijima
Peng Beng Khoo
Christian Lange
Forrest Meggers
Achim Menges
Shinya Okuda
Norman Blank
Stamatina Rassia
Roland Schnizer
Yunn Chii Wong

Acknowledgements:
The studio in 2013 was conducted with administrative support of the National University of Singapore. The Dean of the School of Design and Environment Prof Heng Chye Kiang, Head of Architecture Department Prof Wong Yunn Chii, FCL director Prof Gerhard Schmitt, and FCL Managing Director Dr Remo Burkhard were involved and highly supportive to integrate the studio agenda in the NUS curriculum in order to allow NUS students to participate.

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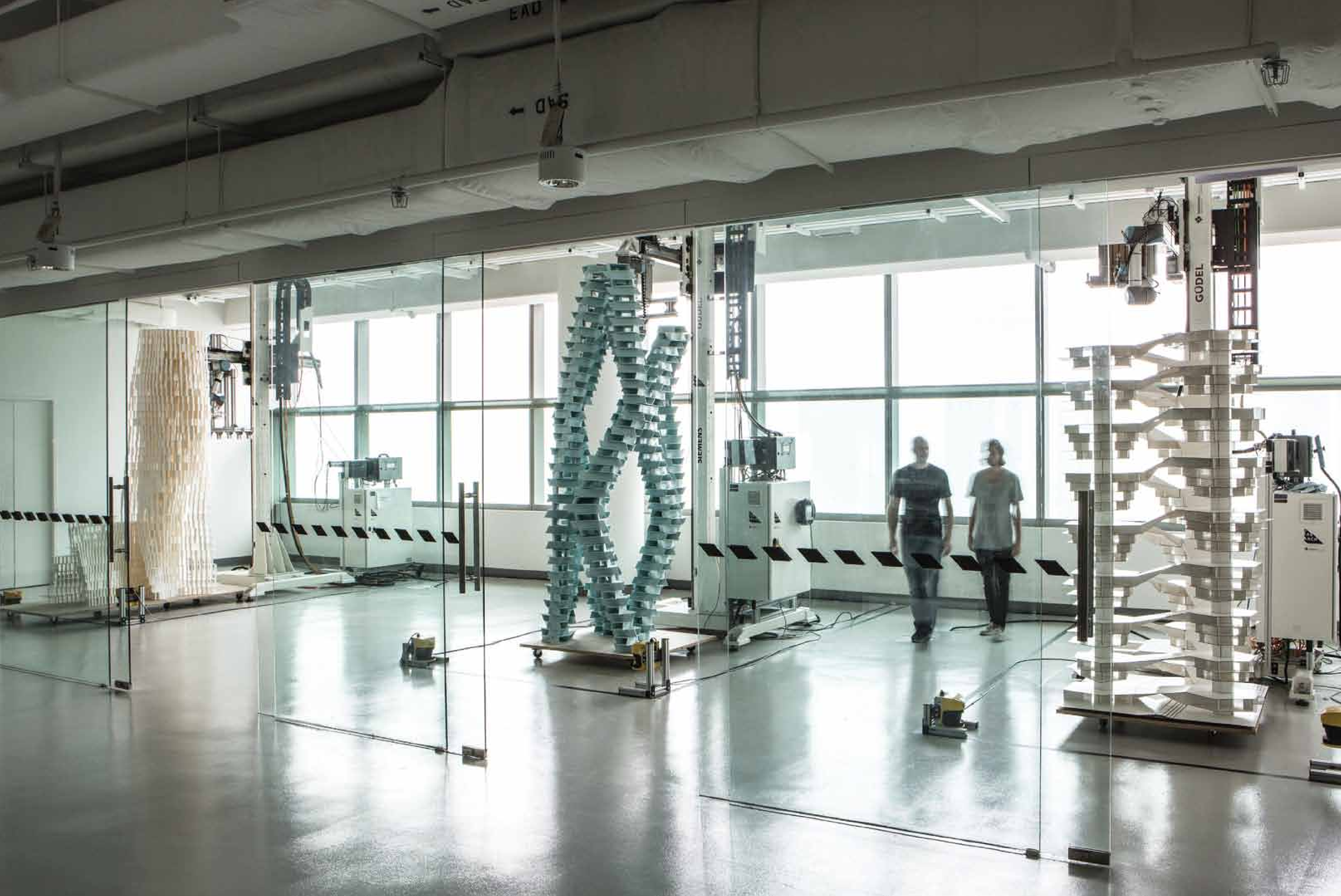
Future Cities Laboratory / Research Module of Architecture and Digital Fabrication

Robotic and automated productions have taken over large parts of many industrial sectors. Although highly ambitious and sophisticated, most attempts at using robotic processes in architecture remain exceptions, prototypes or even failures at a larger scale, because the general approach is either to automate existing manual processes or to automate the complete construction process. However, the potential of robotic fabrication is not fully exploited if used for the execution of purely repetitive mass fabrication processes. Robots can be controlled individually and thus offer the potential for variety and differentiated assembly – even at large scale. The challenges of diverse construction systems and changing demands for each project need to be taken into account, without limiting the range of design. Existing methods and processes have yet to be negotiated in this context. It is time to think about customised robotic processes, products and planning methods for architecture at large scale. At the SEC Future Cities Laboratory, our Chair of Architecture and Digital Fabrication has built up a laboratory to research the potential of robotic processes in architecture and to develop concrete scenarios for their large-scale application to the design and construction of novel high-rise typologies.

Fabio Gramazio and Matthias Kohler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Robotic High Rises

Integrating robotic fabrication in a design research studio

Michael Budig, Willi Viktor Lauer, Raffael Petrovic, Jason Lim

The methodology in the design research studio aimed for the reconsideration of the traditional architectural model by directly linking the digital design process with physical manufacturing and tools. As such, it established a strong correlation between computational design, material systems and robotic fabrication strategies. Since high-rises are strongly rooted in the industrialisation of building, with repetitive elements stacked along the vertical axis, they represent an interesting architectural typology to be challenged by this new design and fabrication paradigm. Some of the main strategies of both studio years are revisited and compared on the following pages.

High-rises dominate large parts of the urban landscapes in fast growing regions throughout Asia. In cities like Singapore a majority of the population lives in residential high-rises.[1] The construction of this typology is strongly rooted in a Modernist industrial paradigm – it is mainly driven by efficiency and economic criteria, with repetitive elements being stacked along a vertical axis. The questions inevitably arise, how contemporary computer-aided architectural design with the integration of robotic fabrication could contribute to a differentiated articulation and leverage more variety in the formal expression and functional capabilities of this widespread typology. The design methodology itself comes into the focal point of investigations, which is pursued in the context of a design reserach studio. The experimental design research studio investigates potential impacts of these technologies on the design and construction of novel high-rise typologies through the robotic fabrication of 1:50 scale models of mixed-use residential high-rises. It is run in close interaction with the PhD researchers of the Module of Architecture and Digital Fabrication, which serves as an experimental test bed for both digital design and fabrication research. Here, PhD research on constructive systems, on computational design processes and the development of software environments to control robots play a crucial role in the studio. The studio in return offers important test cases.

Within the design studio teams of two to four students develop their architectural concepts based on the integration of computational design strategies and bespoke robotic fabrication processes. The physical and the digital models are in constant negotiation with one another. Therefore constraints of the actually built model, e.g. in terms of material properties or manageable element dimensions, directly influence the computational design setup in a continuous feedback loop. The model scale of 1:50 requires a careful selection and abstraction of investigated aspects, but also demands a rigorous consideration of its tectonic logic. Up to four metre high models create their own constructive reality (Fig. 01). They oblige students to tackle problems of structural stability and the logical sequence of the construction process from the very beginning on. In what follows, we will describe a) the unique robotic system, b) the embedded mechanical tools such as the development of customised end-effectors, and c) the design research through architecural models by illustrating the conceived physical processes for their construction.

Fig. 01 Studio tower models that were built in several iterations

Robotic system

Students and researchers share three customised robotic units. Each one consists of a lightweight Universal Robots UR5 robot arm with six degrees of freedom that is mounted to an automatically driven Guedel axis configuration (Fig. 02).[2] This robotic system enlarges the working space of the robot arm from a range of 85 cm to a construction envelope of 4 m height, 1.7 m width and 2.7 m depth; due to its small operating diameter the robot arm can still reach very intricate locations. This allows for the digitally controlled assembly of complex physical models at the scale of 1:50. In addition, a high degree of modularity accommodates quick modifications of the robotic system, e.g. their height and thus the operating space can be adjusted without the need of additional special tools. Four adjustable base points enable the robotic tower to be levelled and transfer its 1.2 tons to the floor. Overall, this unique robotic setup offers flexible and extendable configurations, thus allowing for a rapid transition of digital designs from computation-only models to real-world robotic construction.

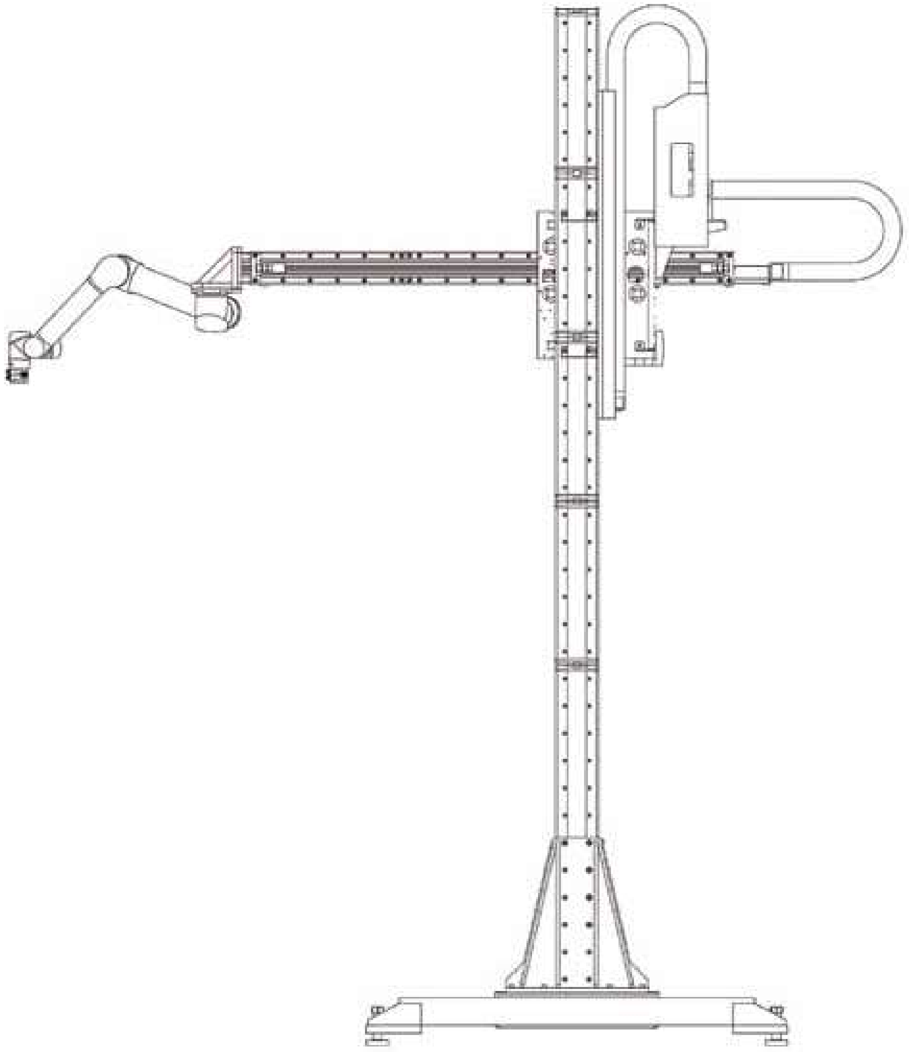
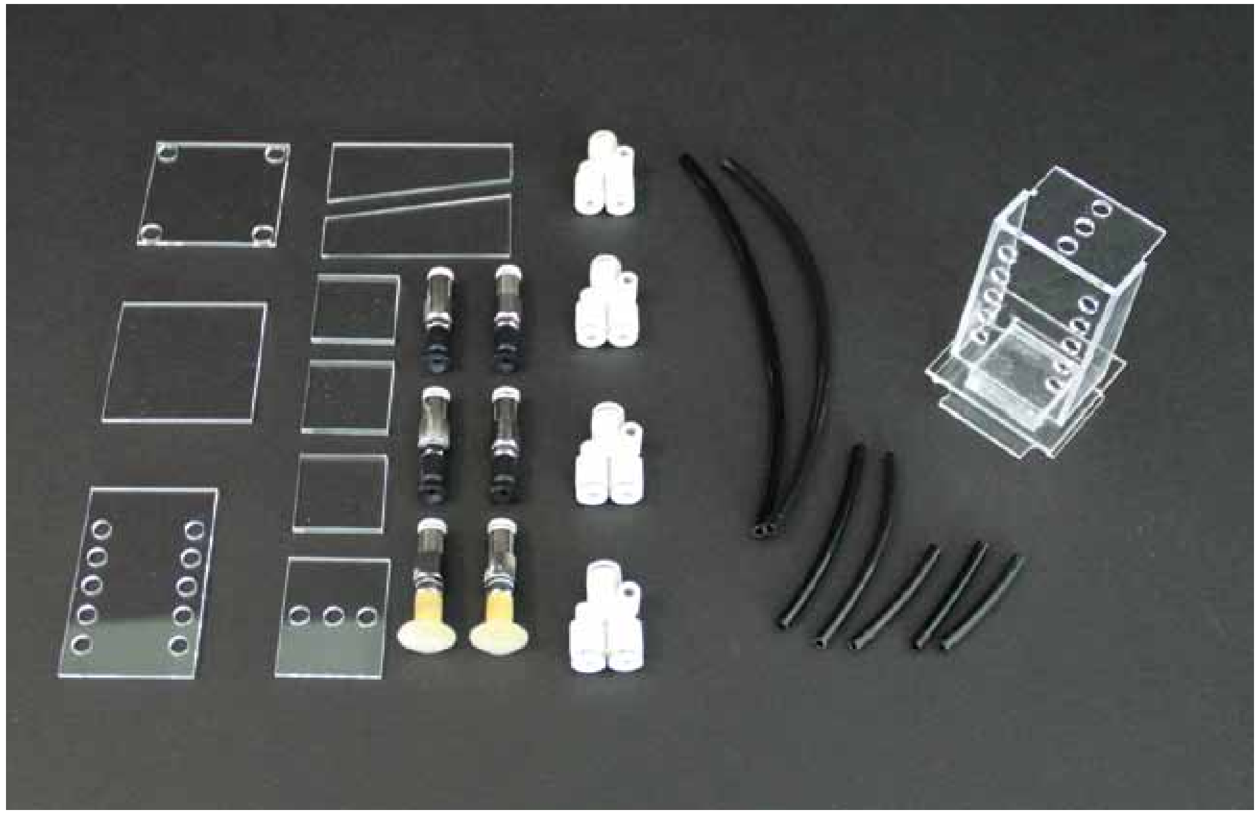


Fig. 02 Elevation of one of the robotic fabrication units, where a Universal Robot UR5 robotic arm is mounted to a Guedel axis system in order to increase the building envelope

Physical tools and end-effectors

For the development of a robotic fabrication process in the design research studio the robotic end-effectors become the most crucial physical components. Available mechanical grippers are mostly not flexible enough to grasp pieces of various sizes and geometries, and can hardly be adapted to different assembly concepts. To overcome these limitations a modular gripper system was developed to enable multiple options of mechanical and vacuum suction gripping. Students can design and produce these grippers easily and develop their own specific configurations for the model building process (Fig. 03). While the initial focus was put on the gripper geometries for controlled picking and placing routines, more elaborated concepts were eventually designed with higher functional integration, such as, for example, sensor equipment and high-resolution control valves for optimised vacuum suction grippers.

Fig. 03 Picture of a basic modular gripper setup that can be altered and amended by students



Since the previously developed grippers with suction cups restricted the building components' geometries, a second generation of vacuum grippers emerged from the idea to perforate a gripping surface with hundreds of small apertures. These grippers are built out of three layers of thin Plexiglas. The first layer is the perforated surface, with the air-feeding layer below and the third layer covering the feeding cavity from the backside. With this configuration grippers could easily be produced by a laser cutter and customised to the elements' intricate geometries. Due to the thin build-up of the grippers of only 5 mm, they were particularly well suited for dense assemblies at 1:50 model scale (Fig. 04).

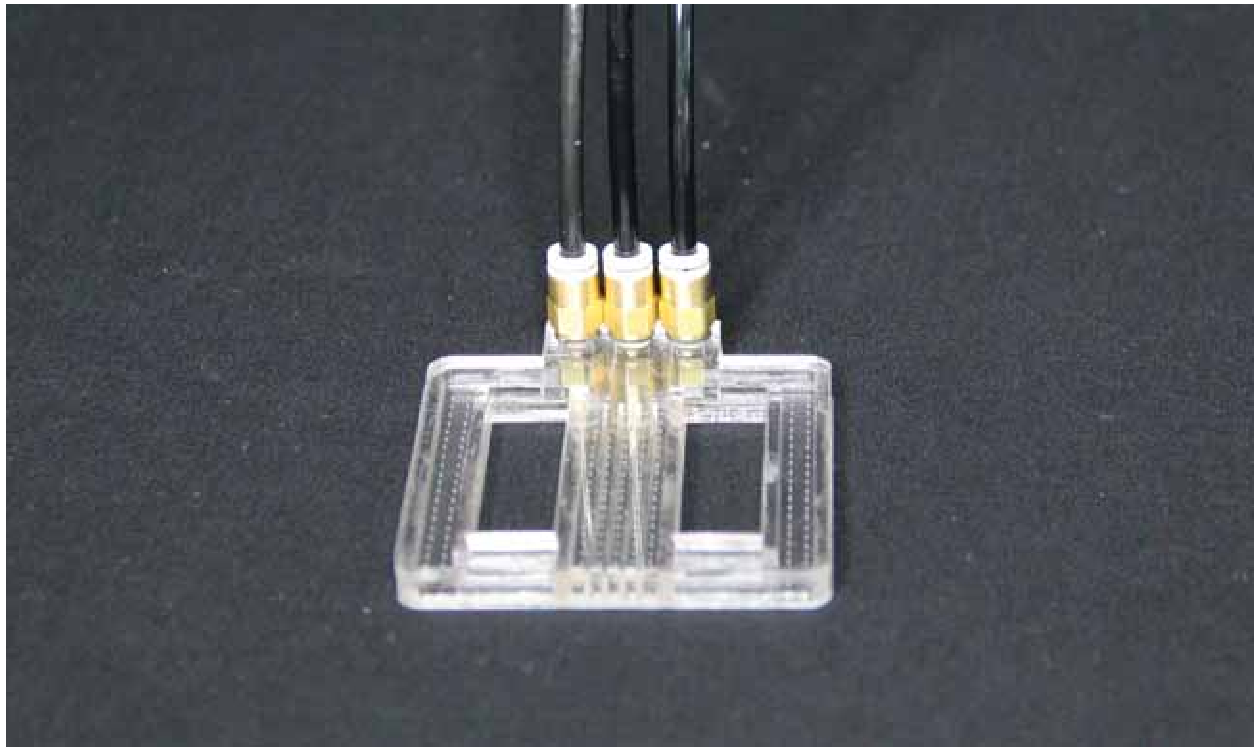


Fig. 04 The thin buildup of the gripper makes it suitable for dense assembly configurations

As the lightweight robotic arms employed in the design research studio are equipped with built-in safety systems, they do not need to be sheltered in a safety environment like their industrial counterparts. This feature opens the possibility for immediate human-robot interaction, which, in turn, allows a direct, intuitive and continuous process of refinement and adaptation of the end-effectors by the students. As such, the operating paradigm of the robotic towers is to combine the highest possible level of accessibility, human intervention and safety in the laboratory environment.

Software Tools

In a similar vein to the customisable hardware components, a custom robot programming library called YOUR and a corresponding toolkit of Grasshopper[3] components that are open to end-user modification were developed. These software tools aim at making robot control accessible to students without prior specific knowledge or programming skills. Either students use the toolkit from the Grasshopper visual programming environment or they start from the script editor in the McNeel Rhinoceros 3D Modeler; the former is geared towards those without any programming experience while the latter suits experienced programmers. In either case, students are able to control the robot directly from their computational design environment. By directly assembling components from the Grasshopper toolkit, students are able to set up and control their custom robotic fabrication sequences. This visual programming approach facilitates students in quickly prototyping processes, as they only need to learn how a few essential components work and can then connect them in different ways. Since the text based code defining these components is accessible, students become able to modify them once they acquire more experience in programming and knowledge in robotics. This allows them to introduce more complex assembly logics and more intricate robot motion patterns for material manipulation.

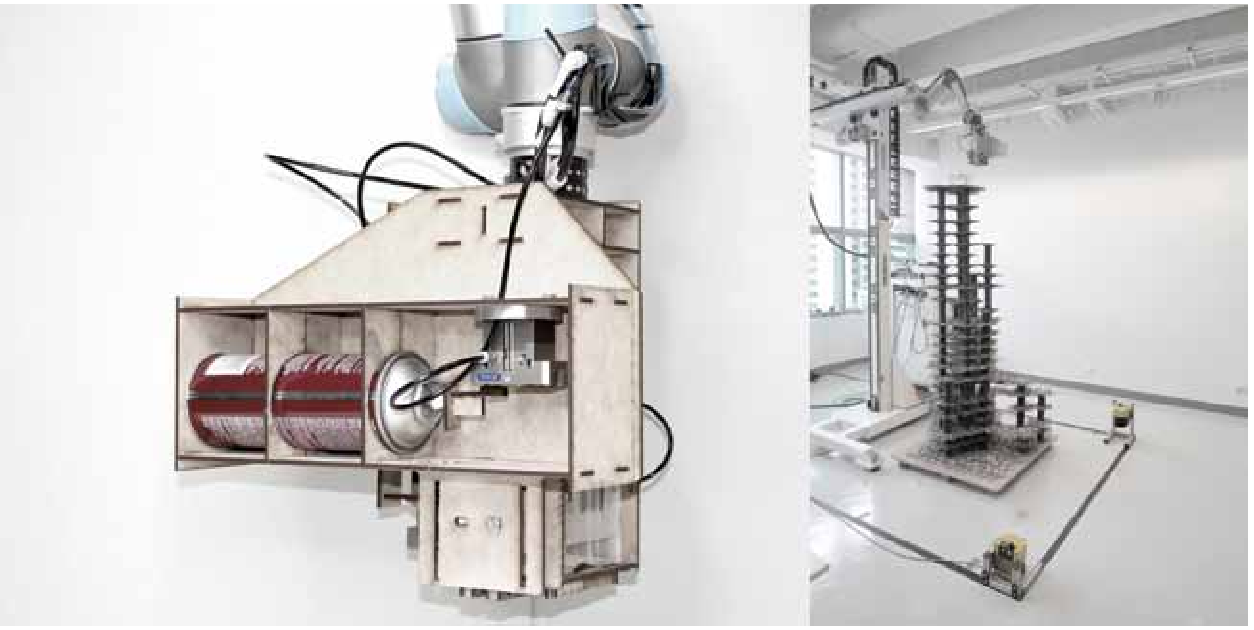
Fabrication techniques

The first aim of the design research studio was to build models as high as possible to gauge the limits of the robotic facilities. Initial towers were stacked configurations and fabricated with simple pick and place fabrication processes, for which the students developed different vacuum gripper systems to glue and place cardboard elements. The design of these grippers had to consider essential fabrication parameters, such as material thicknesses, drying times, and height deviations caused by the applied layers of glue. In the beginning the negotiation between the absolute precision of a computer model and the approximation of the material reality mediated by the robot had been the major challenge. Later phases led to the emergence of fabrication strategies, which utilised the robots inherent manufacturing potential as unique drivers for the architectural design.

Picking and placing

One early concept deployed in the design research studio investigates how models can be built through the robotic aggregation of a very large number of small identical components resembling a "constructive 3D printing" process. In order to achieve this goal in an efficient manner, a custom end-effector incorporating a feeder system as well as an automated gluing device have been developed. Using spray glue, this system can hold several hundred pieces at a time and consequently speeds up the construction process by minimising the distance the robotic arm has to travel for placing each individual piece. One of the towers produced with this process consists of more than 15.000 cardboard pieces of two different geometries. Here the challenge is to realise structural systems that are able to cantilever outwards from a vertical core system (Fig. 05).

Fig. 05 Customised gripper system that glues and places small building components in one step



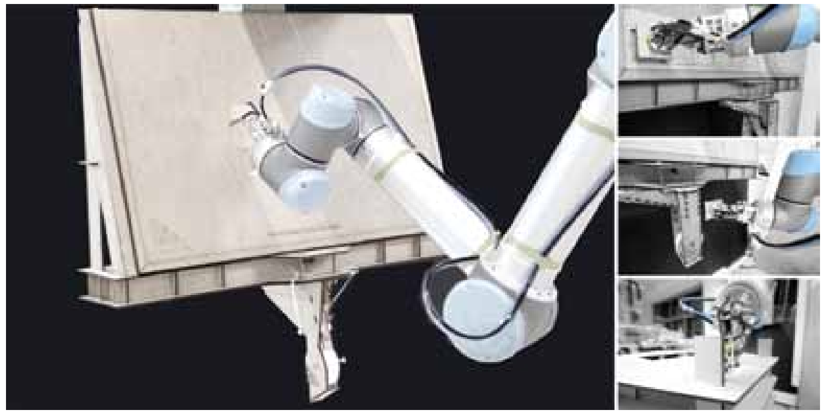


Fig. 06 Picture of a combined feeder and end-effector system; the feeder allows the students to directly place prepared laser cut sheets for the assembly process

Another fabrication concept focuses on the seamless integration of the laser cutter, allowing students to produce and assemble elements with different sizes and geometries within an efficient workflow. Since the picking point varies for each piece, a corresponding feeder system and visual programming setup are developed. The cardboard containing the prefabricated elements gets constrained to fit into the robot's workspace. The individual sheets are then placed directly on the feeder that contains a gluing station. Algorithms are used to generate the layout of the elements on the laser-cut cardboard sheets, and to coordinate the picking, gluing and placing movements of the robot (Fig. 06).

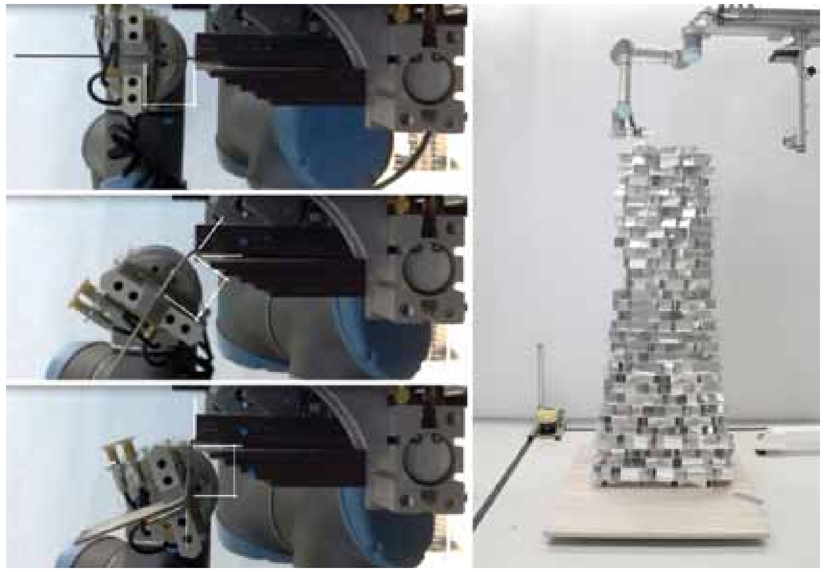


Fig. 07 Picture of cardboard folding process and tower model made of more precise aluminum sheets

Material deformation processes

Beyond picking and placing strategies the integration of material deformation processes further explores the potential of the robot in its unique capacity to produce bespoke parts departing from identical, mass-produced elements. In a first step, the implementation of a folding process allows to enhance the picking and placing of cardboard pieces by enabling the production of large numbers of geometrically differentiated elements. The next iteration of this process uses thin aluminium sheets, which are bent to more precisely defined angles. The process makes use of two mechanical grippers, one holding the piece in place while the other, mounted directly to the robotic arm, grips the sheet and rotates it around the stationary one – thus controlling the geometry of the folding process (Fig. 07). As a result, by robotically bending each piece in two opposite directions, each sheet becomes a structurally stable wall element. The subsequent picking and placing process of the folded wall elements in layers is controlled by an algorithmic process, which ensures the continuous vertical load transfer by specifically defining the horizontal intersections between the different layers. This proves to be a powerful strategy to exploit the robot's potential of complex spatial movements to integrally inform the applied material's geometry as well as its assembly. In contrast to simple picking and placing, the robot plays an active role in the form-giving process of the individual component.

Three additional projects enhance the geometric freedom of the form-giving capacity of the robotic arm by integrating a heat gun into the process. One concept involves bending acrylic stripes at multiple points to create a tower's primary structural system. After the thermal deformation, the pieces are cooled down with pressurised air in order to avoid retraction and increase assembly speed (Fig. 08). A similar process is used in another project for twisting acrylic sheets and producing a geometrically complex facade louver system. To integrate the previously developed picking and placing process with the material deformation, a combined mechanical and vacuum suction gripper was developed (Fig. 09).

Fig. 08 The acrylic stripes are fixed in a linear rail and pulled forward to their designated bending position. The material gets heated up for 10 seconds and allows the robotic arm to bend the material to any angle between 0° and approximately 160°. After the deformation the material gets cooled down with air pressure

Fig. 09 Combined gripper for picking identical building elements and deforming them with an integrated heat gun

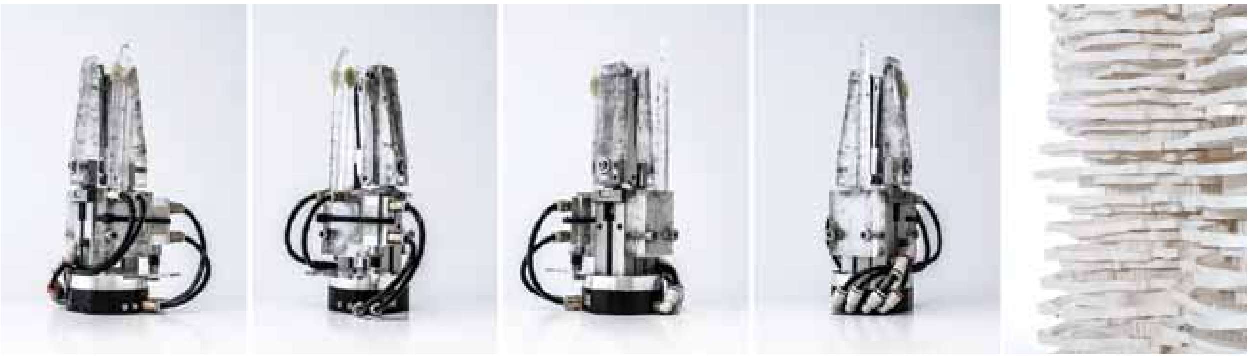


Fig. 10 Tower made out of paper stripes and stapling process, which uses the paper's intrinsic properties in the material deformation process

An entirely different approach to robotic material deformation is showcased by a project using generic paper strips as main building material. By connecting two overlaid paper strips at one point and then sliding their relative position before connecting them again, it is possible to produce geometrically highly differentiated building components with undulating geometries (Fig. 10). This process includes the development of a gripper that can pinch two stripes of paper and then staples them together to fixate their final positions. The resulting wall elements are self-stabilising and can be layer-wise assembled into an expressive high-rise structure. As the produced component geometries are a direct result of the material's intrinsic capacities, the process is parameterised in order to seamlessly connect the digital to the physical model, and to enable adjustments in multiple feedback loops.

Fig. 11 The tower is made out of paper elements that are manually cut and then robotically folded, glued and placed onto the model

Integration in architectural concepts

The second studio year builds upon previously designed fabrication concepts and revaluates these processes in correlation with algorithmic design strategies. The initial setup allows students to start building physical models from the beginning on – thus shifting the focus of the investigation away from digital fabrication experiments towards the development of specific computational design engines, which maximise the potentials of the previously developed robotic fabrication methods and techniques.

Connecting algorithmic design and robotic fabrication

By robotically building physical models and analysing aspects such as structural behaviour, material performance and overall architectural qualities, the students were able to materially inform and specifically adapt their computational design engines in iterative steps, whereby the empirically gained results were further used to rethink and to advance the fabrication process itself (Fig. 11). As an example, some processes demand for the integration of optical sensors that would enhance fabrication precision and allow the implementation of particularly complex manipulation sequences. Sensor technology also enables the integration of human-robot cooperation in a seamless manner as the process could autonomously stop when a manual intervention would become inevitable (Fig. 12). Other projects question the fabrication suitability of a given material system and design a completely new robotic fabrication method that optimises the robot capabilities to become the key driver to their design (Fig. 13).

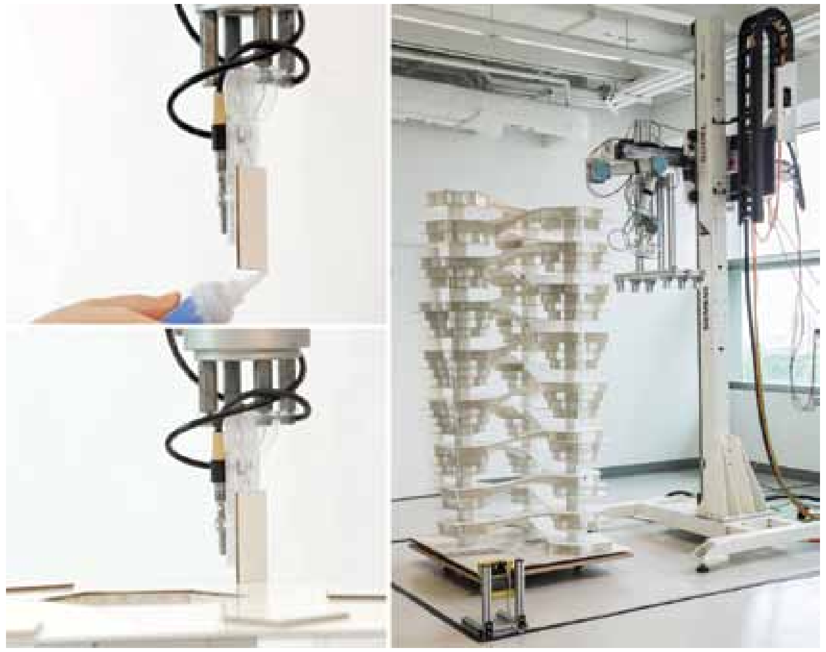


Fig. 12 With sensor integration into the gripper system the fabrication process becomes more reliable and faster; the pieces are 'handed' over to the robot, that assembles them onto the model

Fig. 13 The robot picks extruded Styrofoam cubes and moves them through the hotwire along a computed path, thus utilising the robot's potential for performing spatially programmed fabrication tasks

Outlook

The design research studio offers a unique experimental test bed, giving the physical architectural model a new meaning and revaluing its importance in the combination with digital design tools. The empirical developments of the designs in correlation with the physical artefact obliges students to deeply and creatively engage with robotic fabrication logics, which become, in turn, a crucial part of the design. The iterations of high-rise models involve continuous feedbacks between physical result and digital design concept. Beyond that, the models reach a complexity (both formal and structural), which could not be manually achieved. The robot thus catalyses new design explorations and avoids conventionally split design and fabrication sequencing, where the final design data gets handed over to a completely separated fabrication process.

Within this scope of directly linking the digital design process with robotic manufacturing as well as with its computational and physical tooling, twenty-seven 1:50 models were produced in total in the studios 2012 and 2013. Here, the consistent interaction with the robotic process leads to a direct and sensual understanding of the tectonic qualities in the model. This exposure to the process of making also requires a profound understanding of the tools and their effects on material and geometric shapes. The role of the architect is challenged here, where design opportunities become sustained in physical space through the adaption and even invention of novel tools and techniques. This design research methodology proves to be a valuable experiment on the way towards a deeper conceptual integration of robotic fabrication paradigms in the design process of novel large-scale architectural typologies.

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Endnotes

[1] In Singapore more than 80% of the population lives in high-rise and high-density flats built by the Housing Development Board (HDB).

[2] The Universal Robots UR5 robot arms are integrated in Guedel 2-axes linear modules type ZP-3.

[3] Grasshopper is a visual programming plugin for the widely used McNeel Rhinoceros 3D modeling software.

Credits

This text is an excerpt of a paper that was originally published in Mc Gee, W. and Ponce de Leon, M. (eds) *Robotic Fabrication in Architecture, Art and Design 2014*. New York: Springer. p. 111-130.

Project Sites

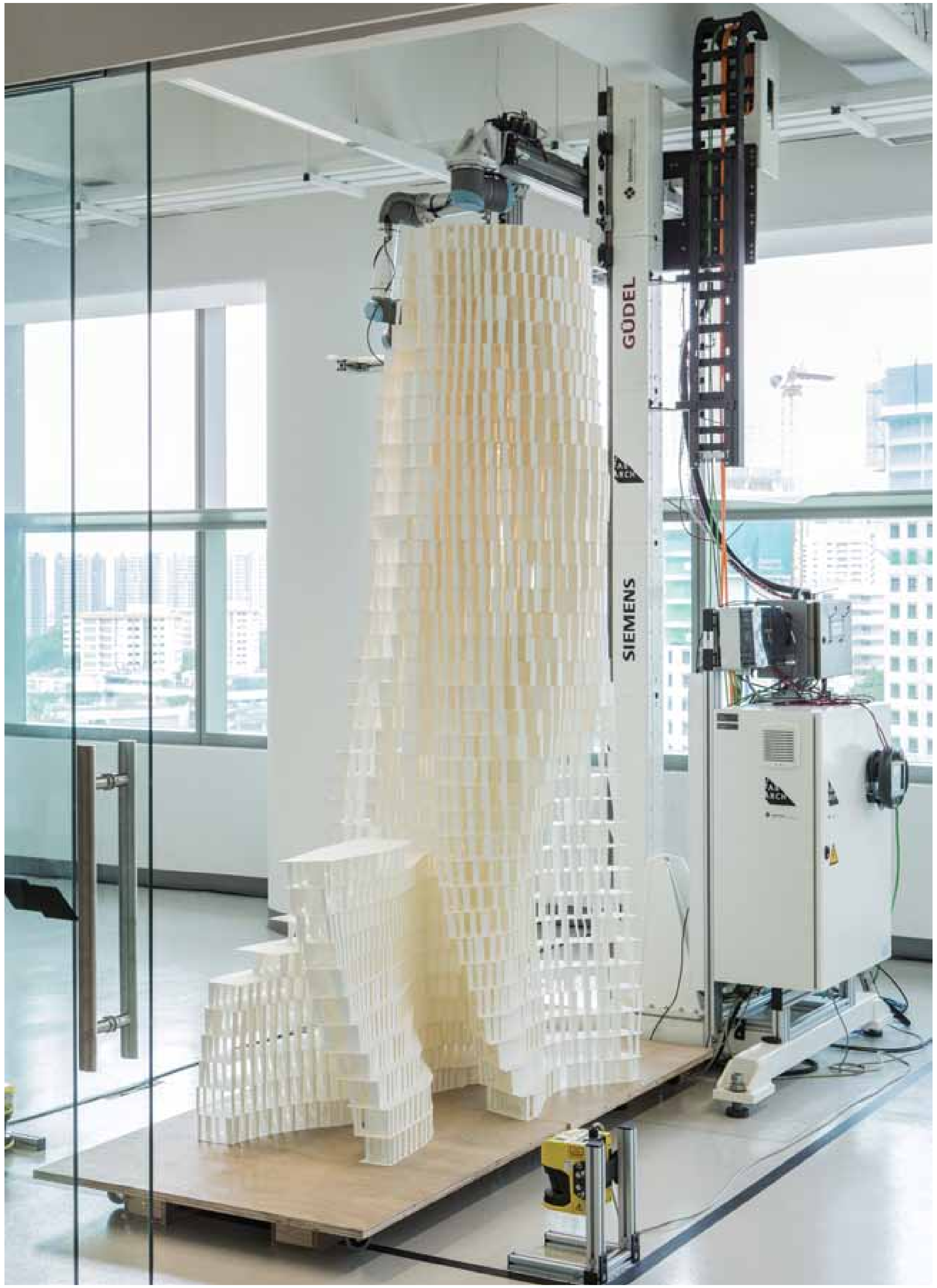
Project 1

Sequential Frames

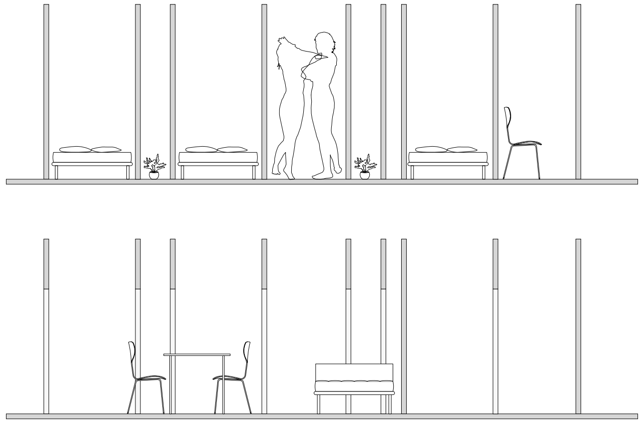
Bedok Area

Students: David Jenny
Jean-Marc Stadelmann
Yuhang He (1st term)

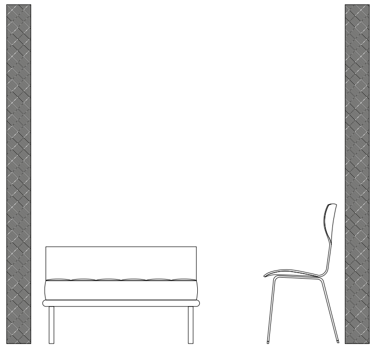
The project Sequential Frames defines the interior spaces of a high-rise not by enclosure, but by computationally programmed cut-outs in a sequence of densely placed shear walls. Here, a computational design process defines these cut-outs by negotiating between force flows, calculated from top to bottom, and the desired architectural typologies for the mixed-use programme of the tower. The 5.200 wall elements are made from paper stripes that are robotically cut after having been placed into a vacuum clamp at specific angles. The robot then folds the cut piece, applies glue and places the wall onto the model. Despite the assembly of supposedly geometrically simple elements, this approach towards fully integrated computational design and robotic fabrication routines allows highly articulated designs with a large variety of interior spaces.

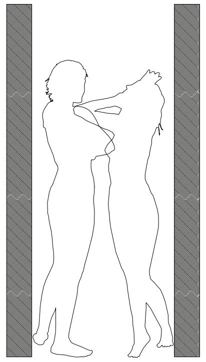


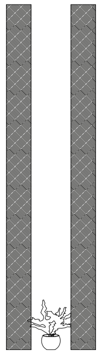
Design Concept

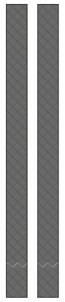


The resolution of the primary load bearing structure is increased, while the individual wall thickness is decreased. Walls no longer frame a room but only an architectural programme. Interior spaces are not defined by enclosure, but by programmed cut-outs in a sequence of densely placed walls









Design Iterations

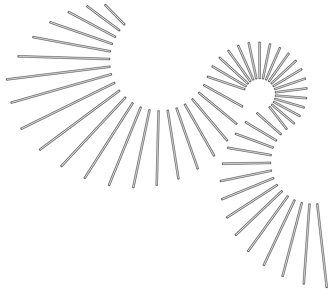
Tower 1

Tower 2

Tower 3

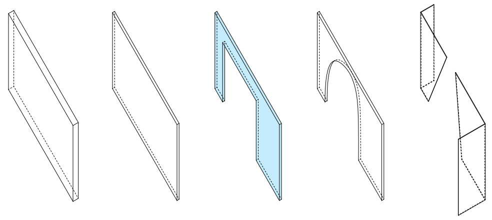
Final Tower

Tower 1

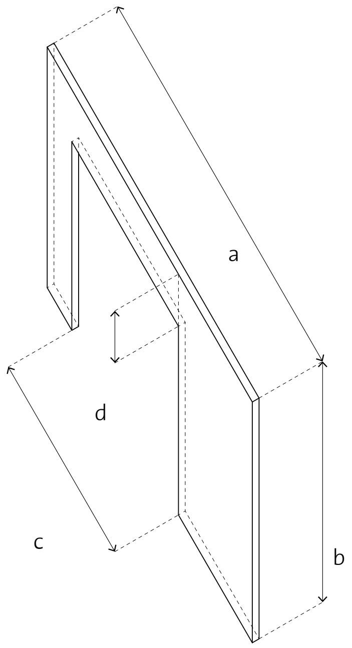


Tower 1 Multiple connected and curved open shapes turned out to be the optimal solution, combining the behaviours of the previous two models (above). Tower 1 consists of 1.200 wall elements and measures 1.6 metres in height.

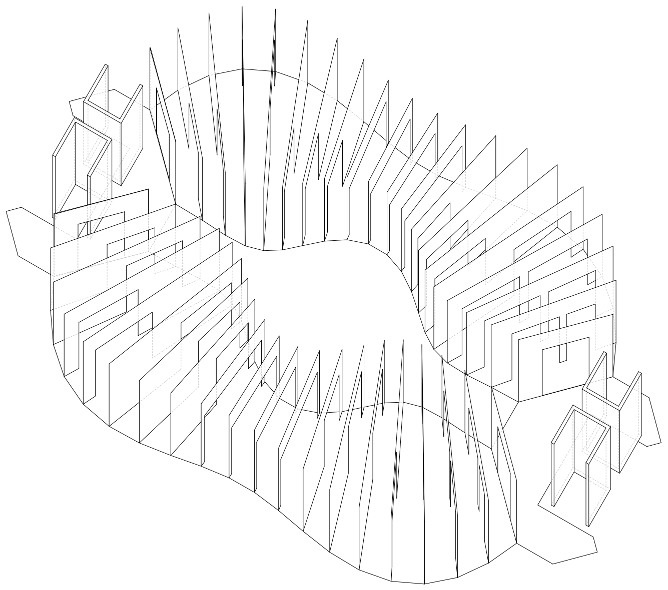
Tower 2 – Computational Design

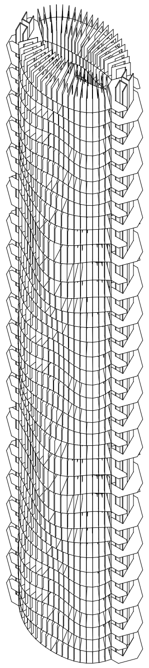


The design is based on the following wall parameters: a) length, b) height, c) cut-out length, and d) beam height



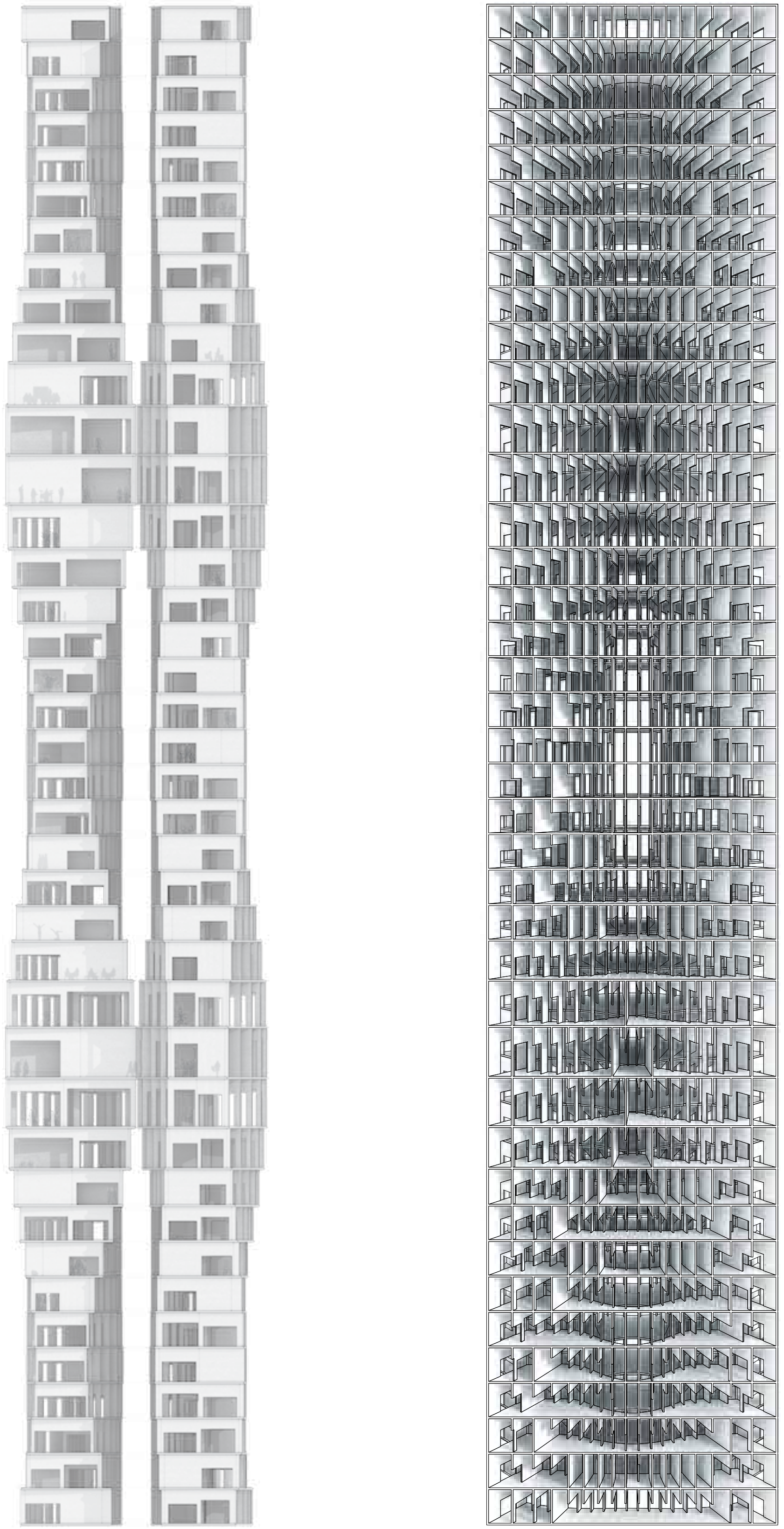
Computational degrees of design freedom of tower 2





Tower 2 The second tower was built to investigate strategies for the design of multiple housing configurations in a shear wall system by a sequence of wall cut-outs. The wall system was further parametrised by adding a cut-out shape, defined by a specific cut-out length and a beam height (right page, top). These cut-out walls were populated on curved floor plans, following a simple random distribution pattern. The floor plates vary slightly over the height of the tower, giving the tower a sinuous silhouette.

Tower 2



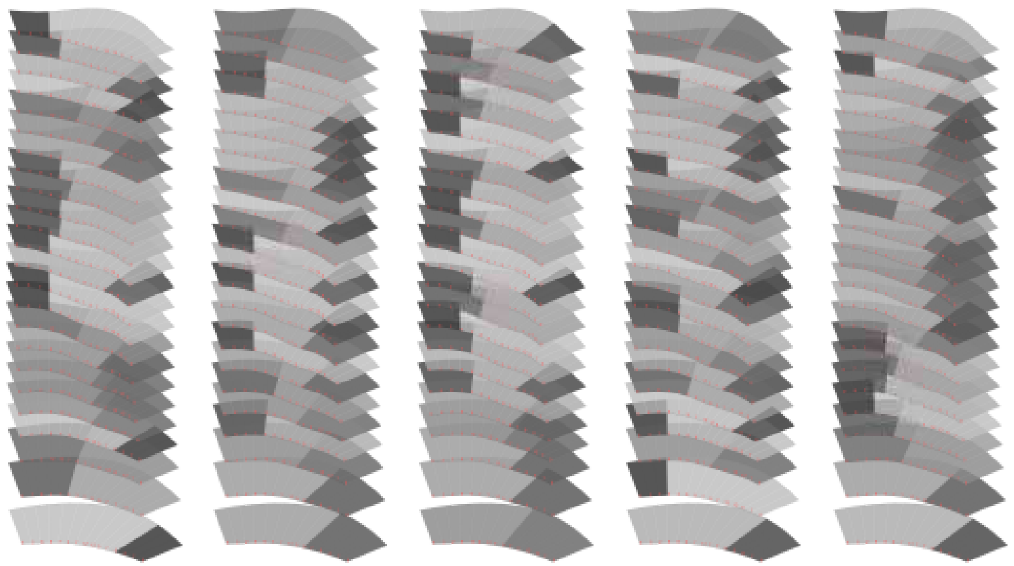
Cross section and longitudinal section of tower 2

The tower consists of 1.440 walls elements and 82 floor elements and measures 3.4 metres in height

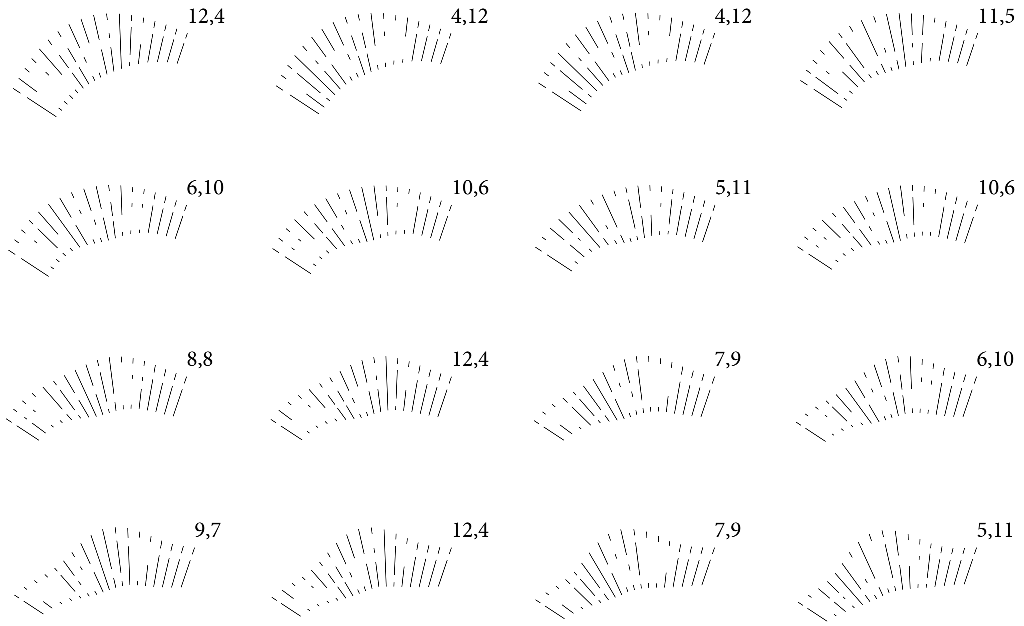
Tower 3 In the third tower the group optimised their organisational design script. Floors are no longer filled up randomly but with a set of predefined flat types. A flat type consists of a sequence of specifically cut out walls (right page, top). These flat types can have different lengths resulting in different room configurations – from a studio to a four bed apartment (right page, bottom).

Regarding the vertical organisation logic, the continuous force flow around the wall apertures is calculated from top to bottom. Each wall adjusts its opening's geometry, negotiating between the required structural performance and the desired cut-out for the flats. This makes the appearance of each flat different even if they are of the same type.

Tower 3 – Computational Design

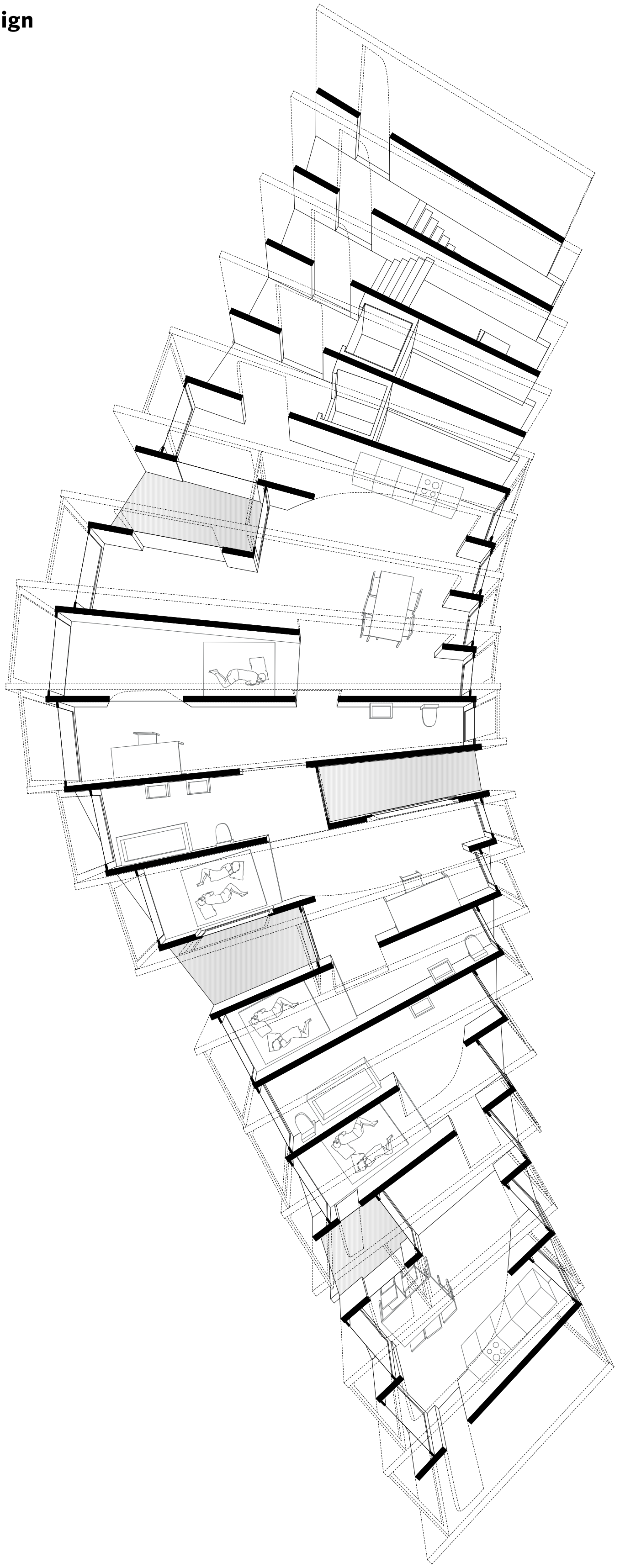


Five different versions of flat type distribution in the tower

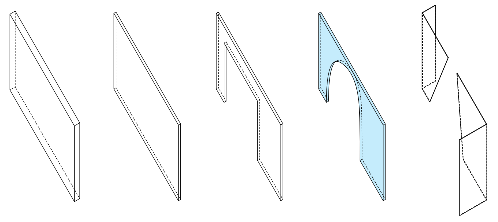


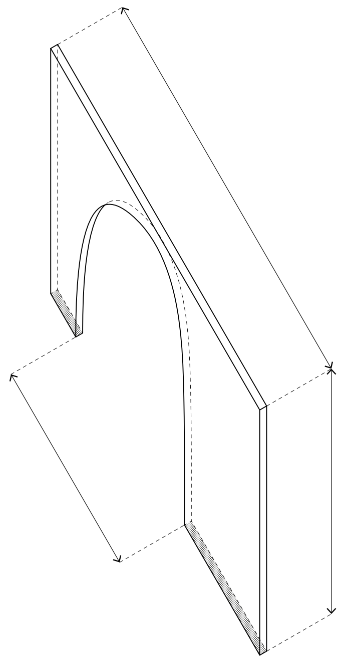
Each floor plan in the tower is unique. The numbers indicate the flat type of each apartment on the floor. The different flat types are generated by the same computational design engine

Tower 3 – Computational Design



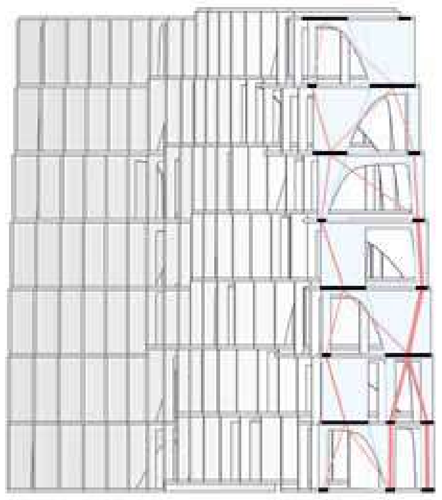
The floorplan shows, how the distance between the shear walls is minimised according to specific functions

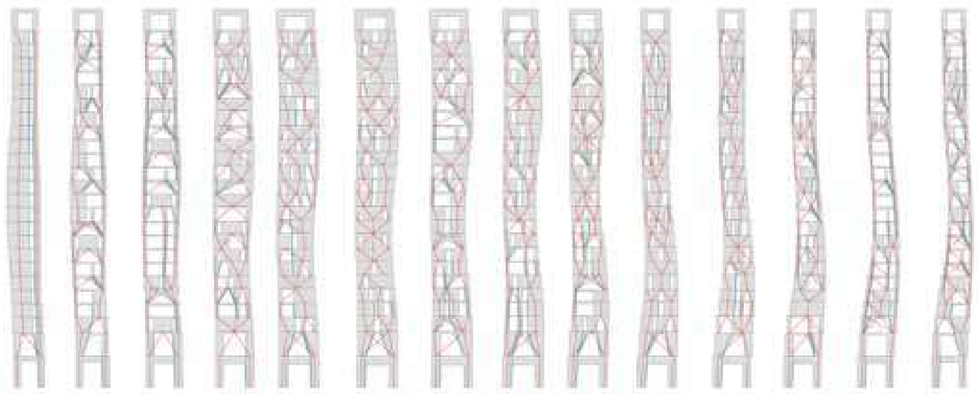




The design is based on the wall parameters for length, height, type, and is additionally adjusted to load-bearing (position, length and force impact) and opening parameters (length and geometry)

Computational degrees of design freedom of tower 3

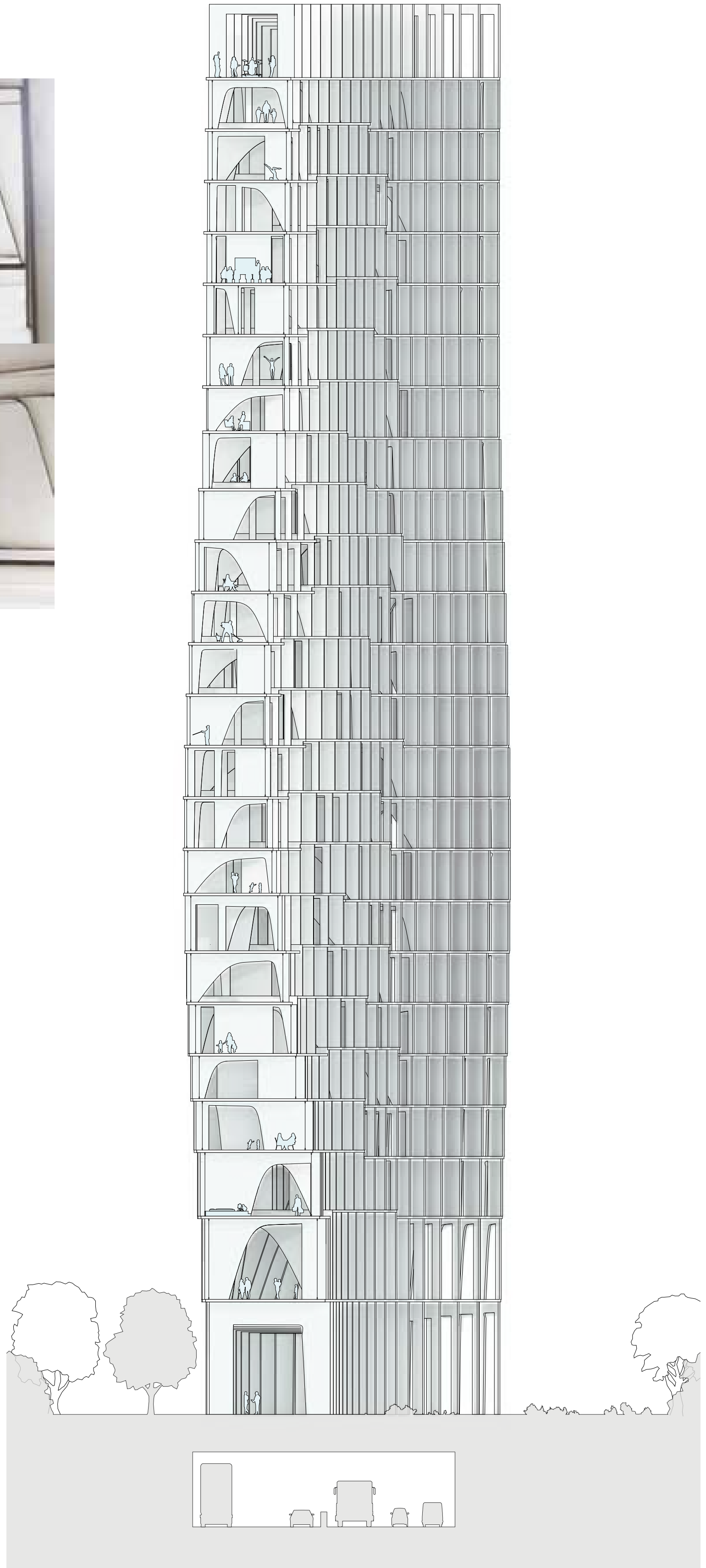




Sections of tower 3, showing the relation between the force flow and the wall geometry

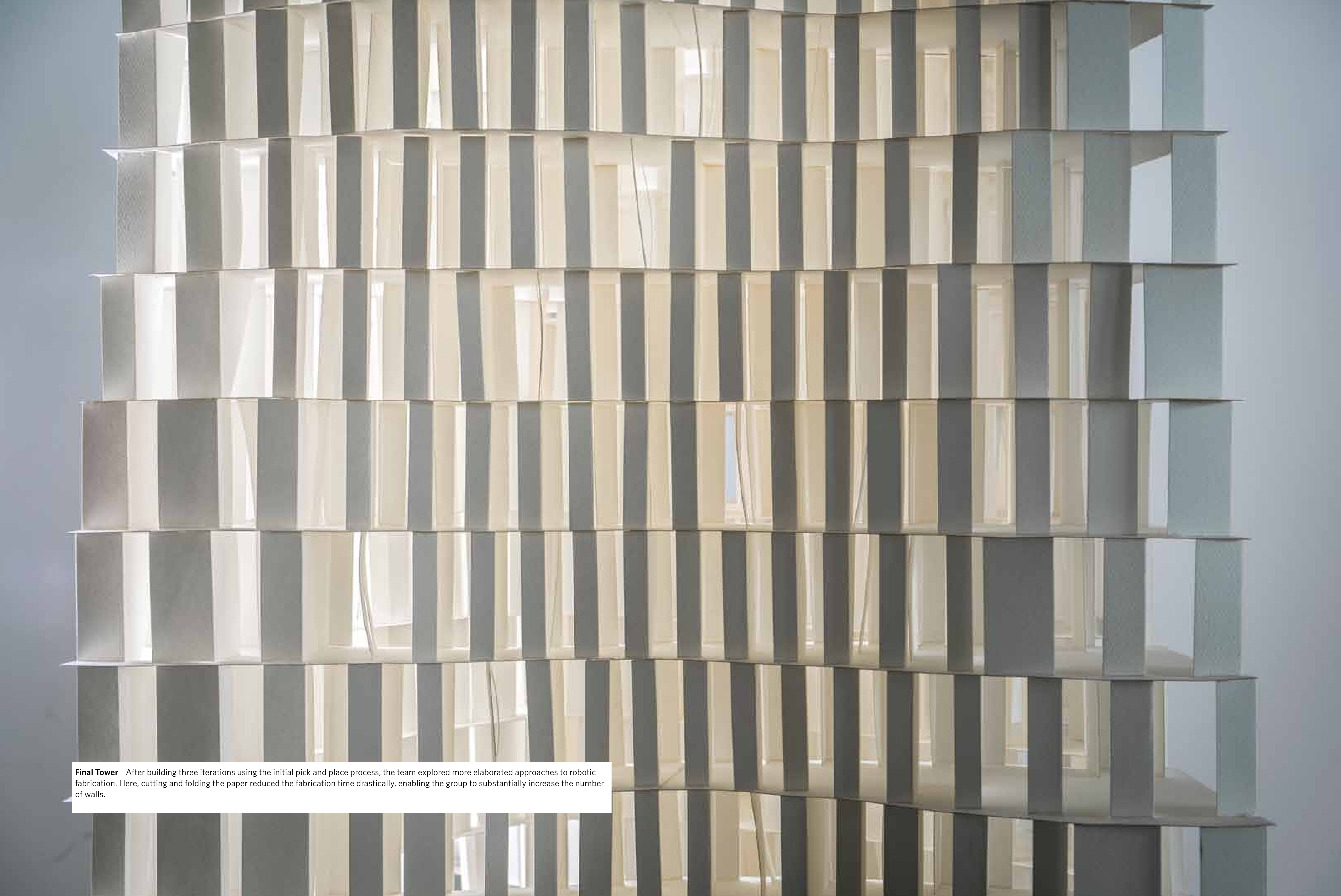
Tower 3

The two images of the model show the same flat type, but on two different floors. Adjusting every wall's geometry to the local force flow makes the appearance of each unit unique



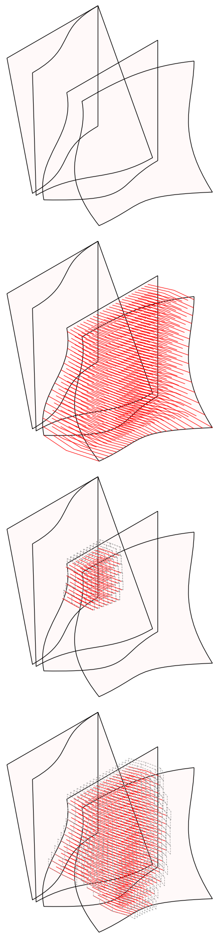
The relation of the tower and its context, and the development of the vertical structural articulation

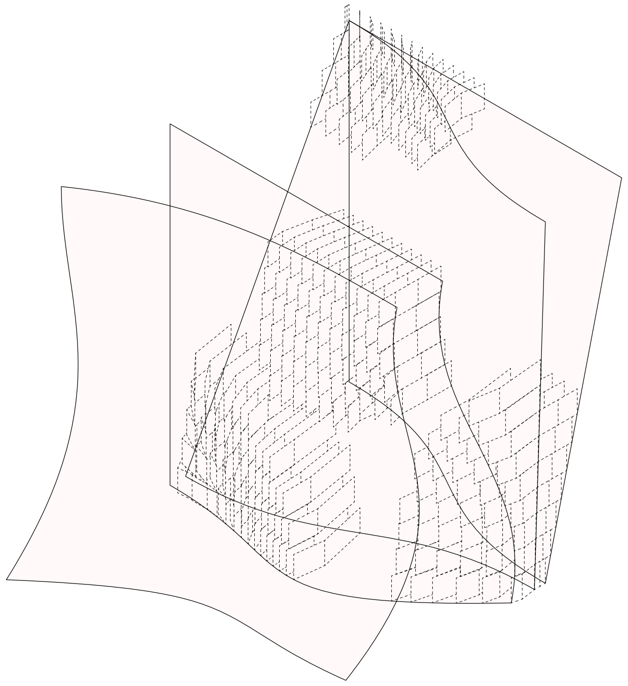
The final model is 2.05 metres high. It consists of 450 wall elements, 66 floor elements and 434 window elements

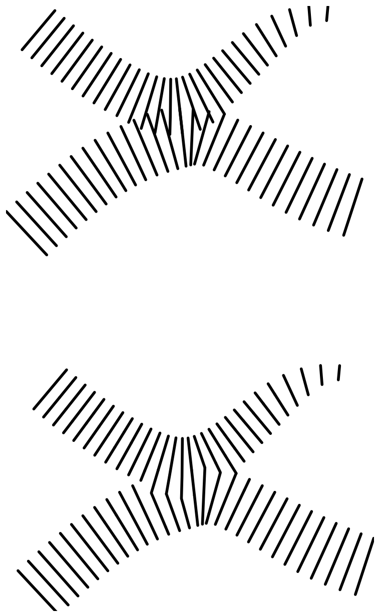


Final Tower After building three iterations using the initial pick and place process, the team explored more elaborated approaches to robotic fabrication. Here, cutting and folding the paper reduced the fabrication time drastically, enabling the group to substantially increase the number of walls.

Final Tower – Computational Design

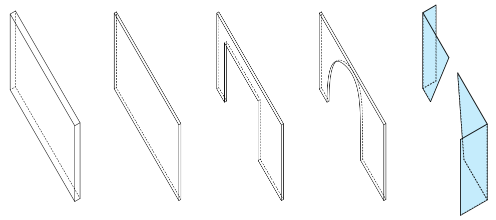




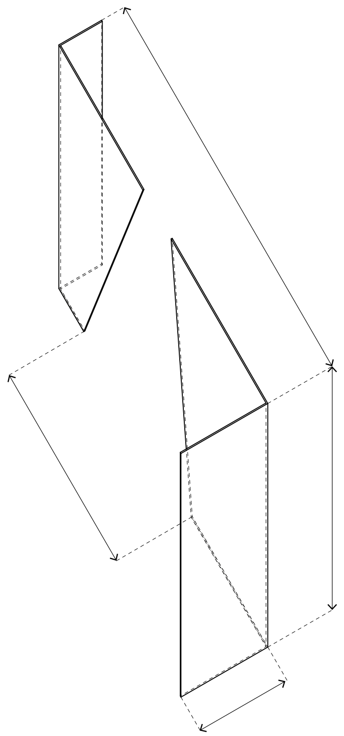


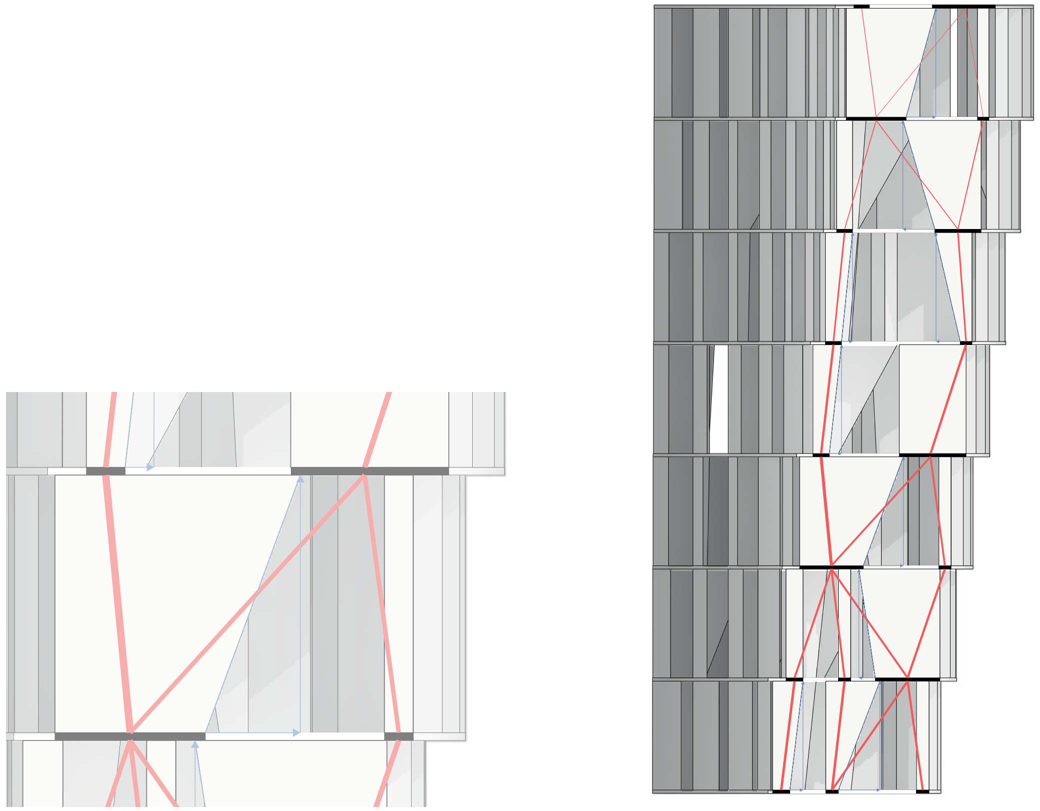
Branching and merging Logic – the computational design engine was extended to solve the meeting points of several shear wall slabs. Walls closer to each other than a certain distance merge into one

Mock-up of the final model in 1:50 scale



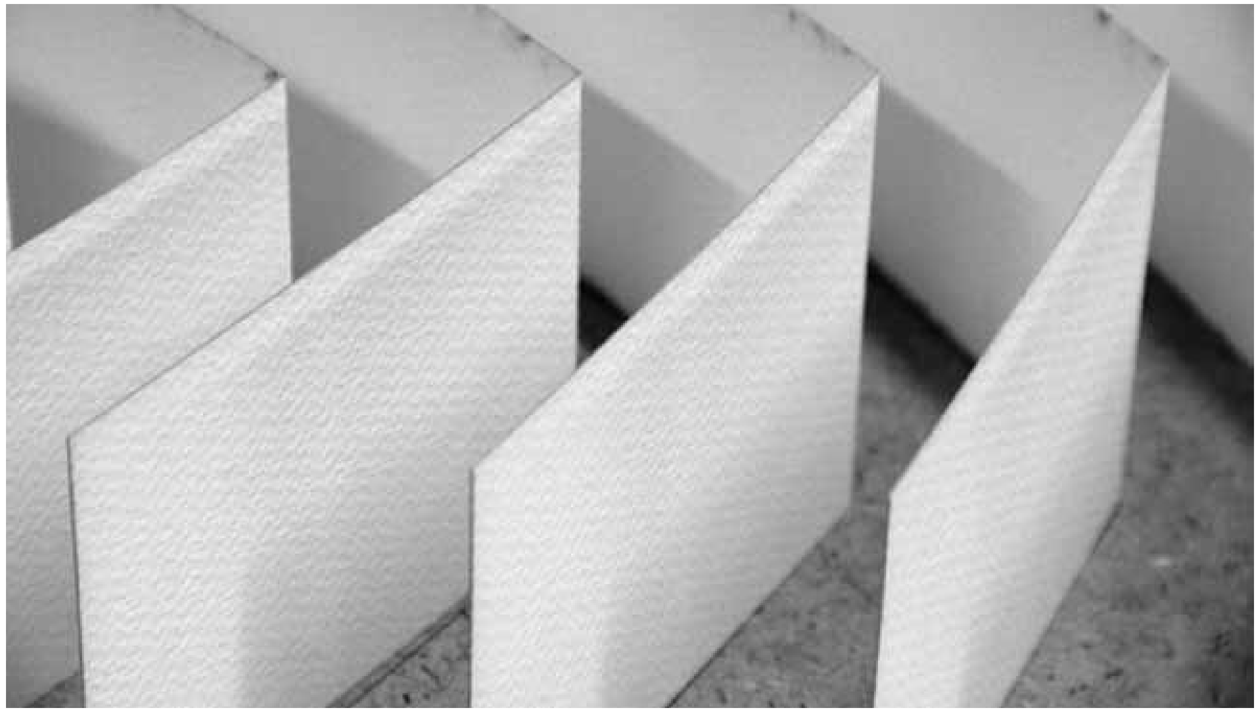
The design is based on the wall parameters: first, for length, height, and type, second, on the load bearing parameters for position, length and force impact, third, on the opening parameters for length and geometry, and finally, on additional values for facade (length and direction of fold) and the robotic fabrication process (folding and cutting angles, placing position)

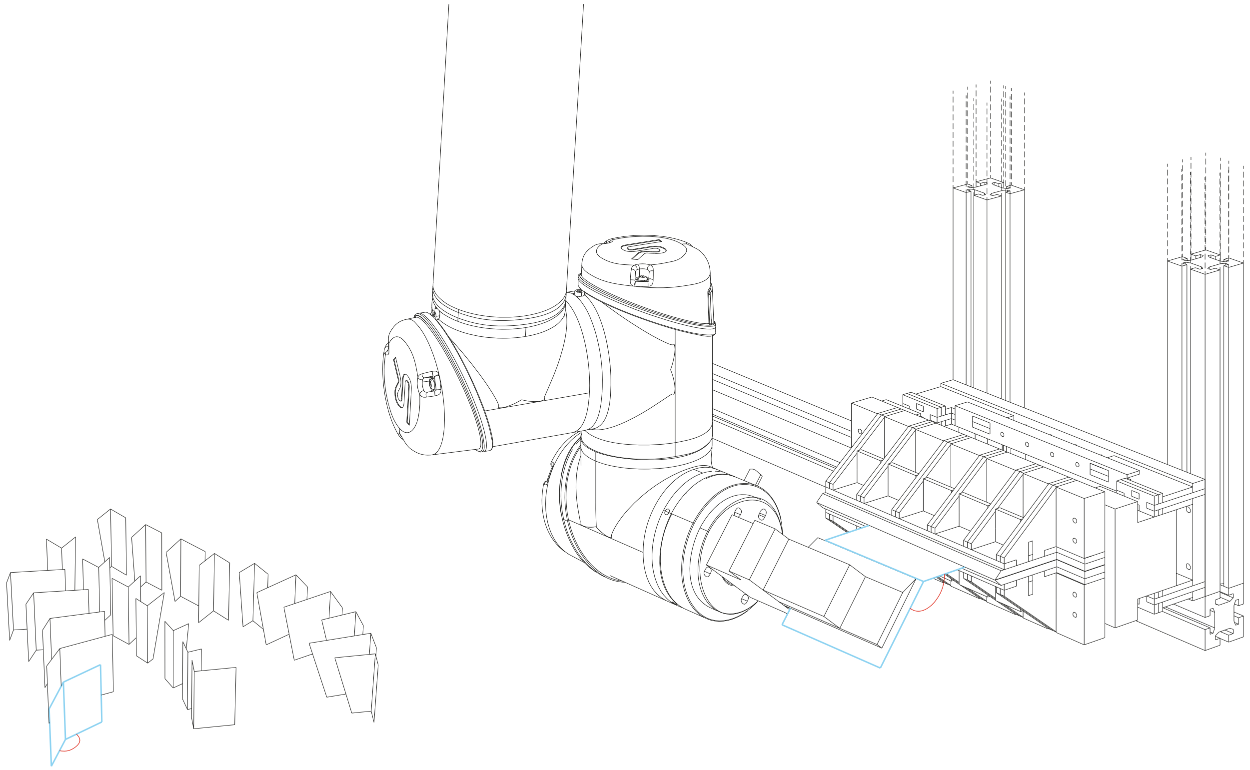


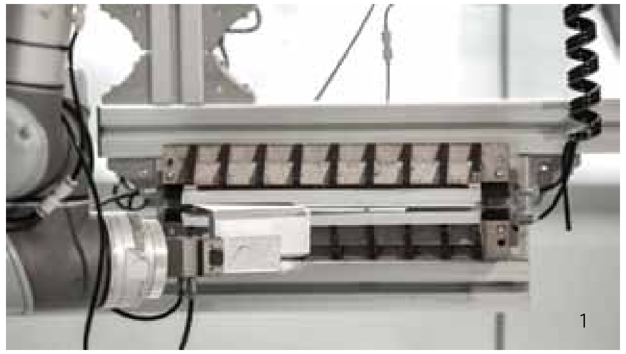


The wall geometry is articulated in such a way to be manufactured by the robotic folding process

Final Tower – Robotic Fabrication



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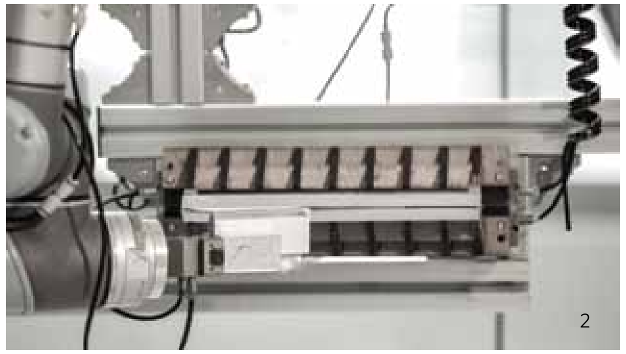
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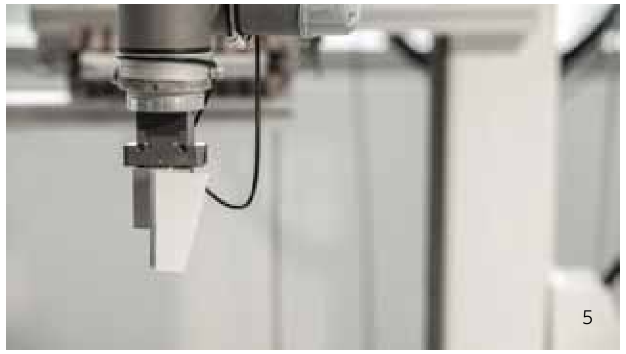

5


6

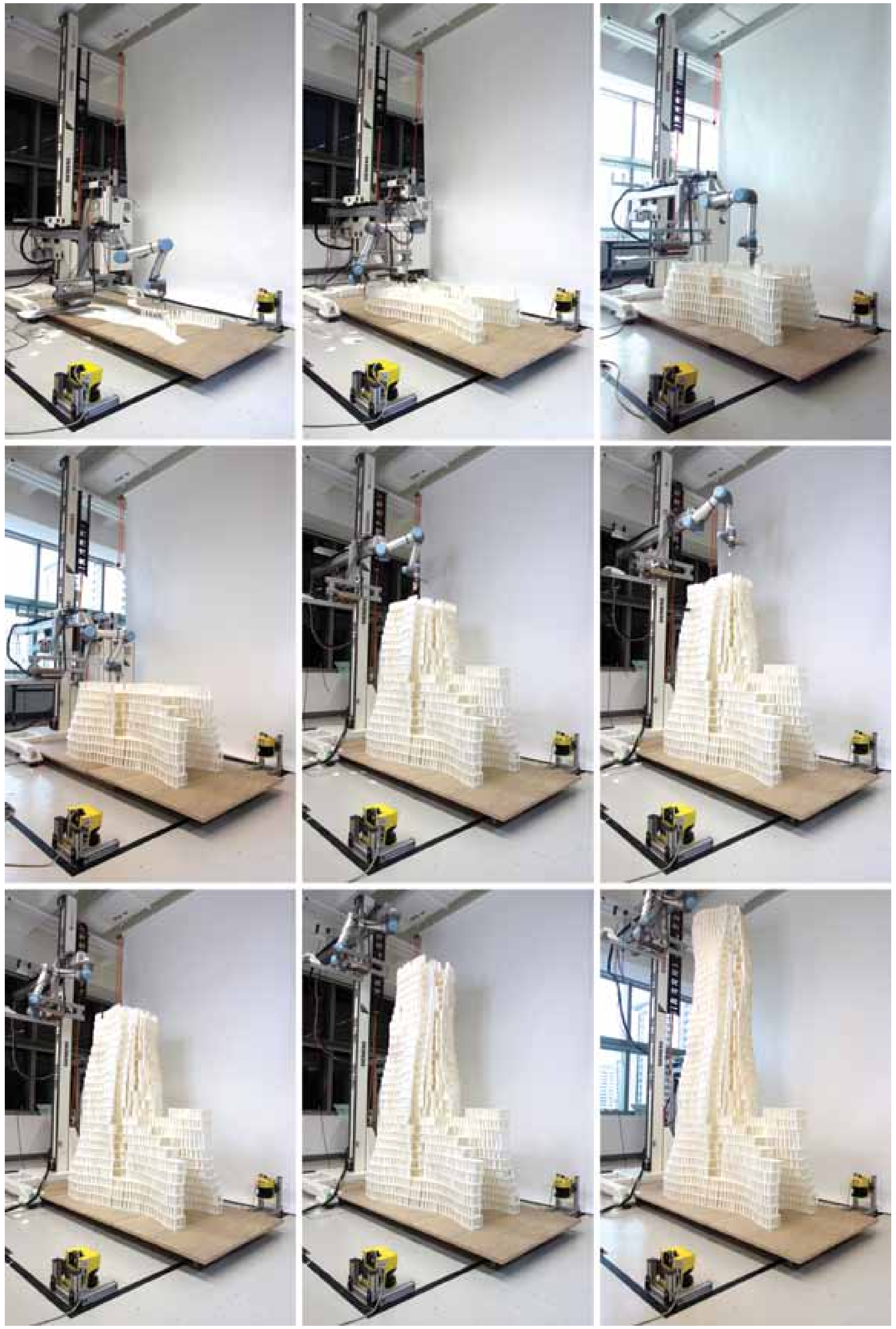
Robotic paper folding – the robotic setup consists of a mechanical gripper able pick thin paper stripes, a gluing station and a custom designed vacuum clamp

1, 2: The robot picks a paper stripe and places it at a specific angle into the vacuum clamp

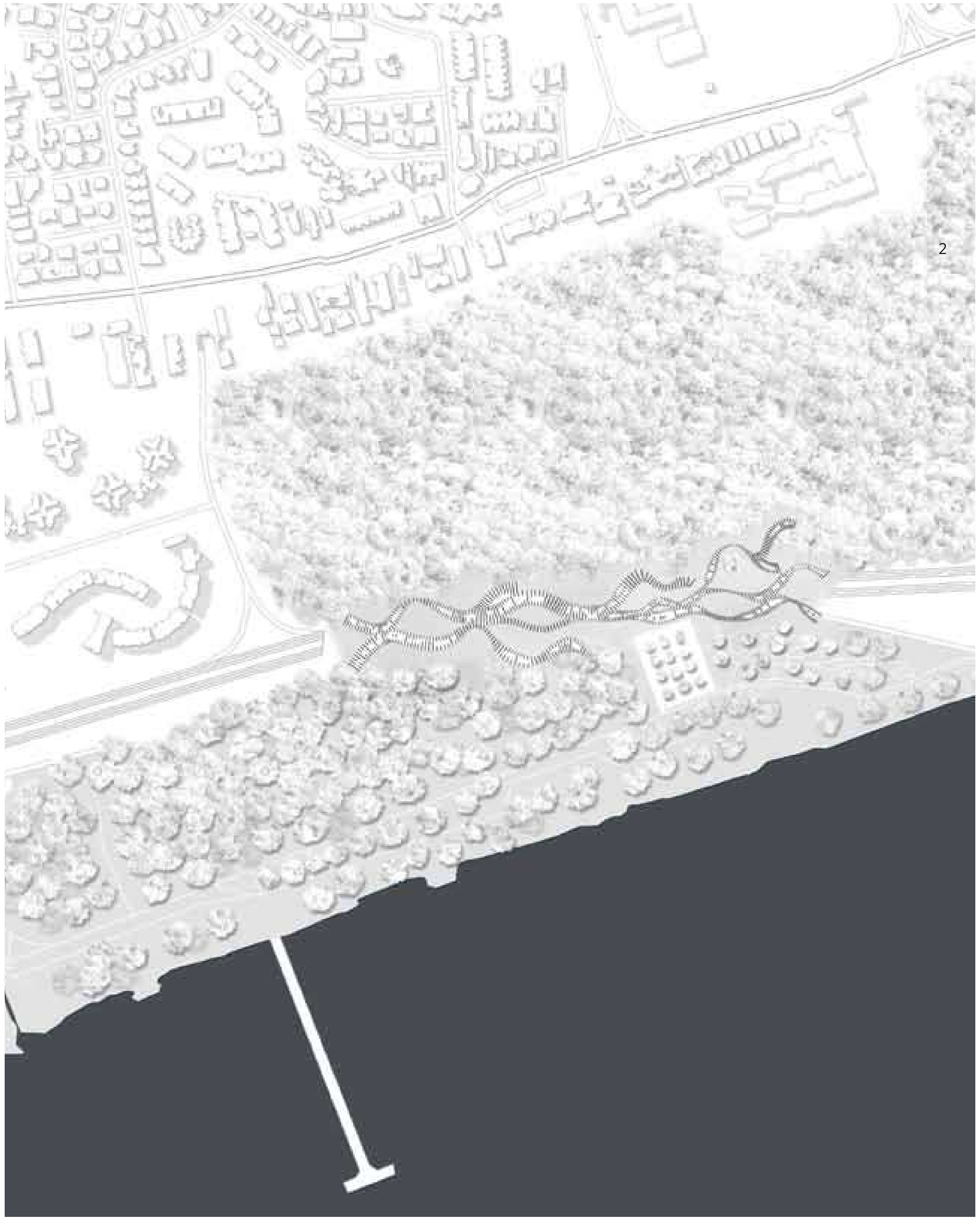
3: The stripe is then cut manually

4, 5, 6: The robot applies glue and then places the wall onto the model

Final Tower – Robotic Fabrication

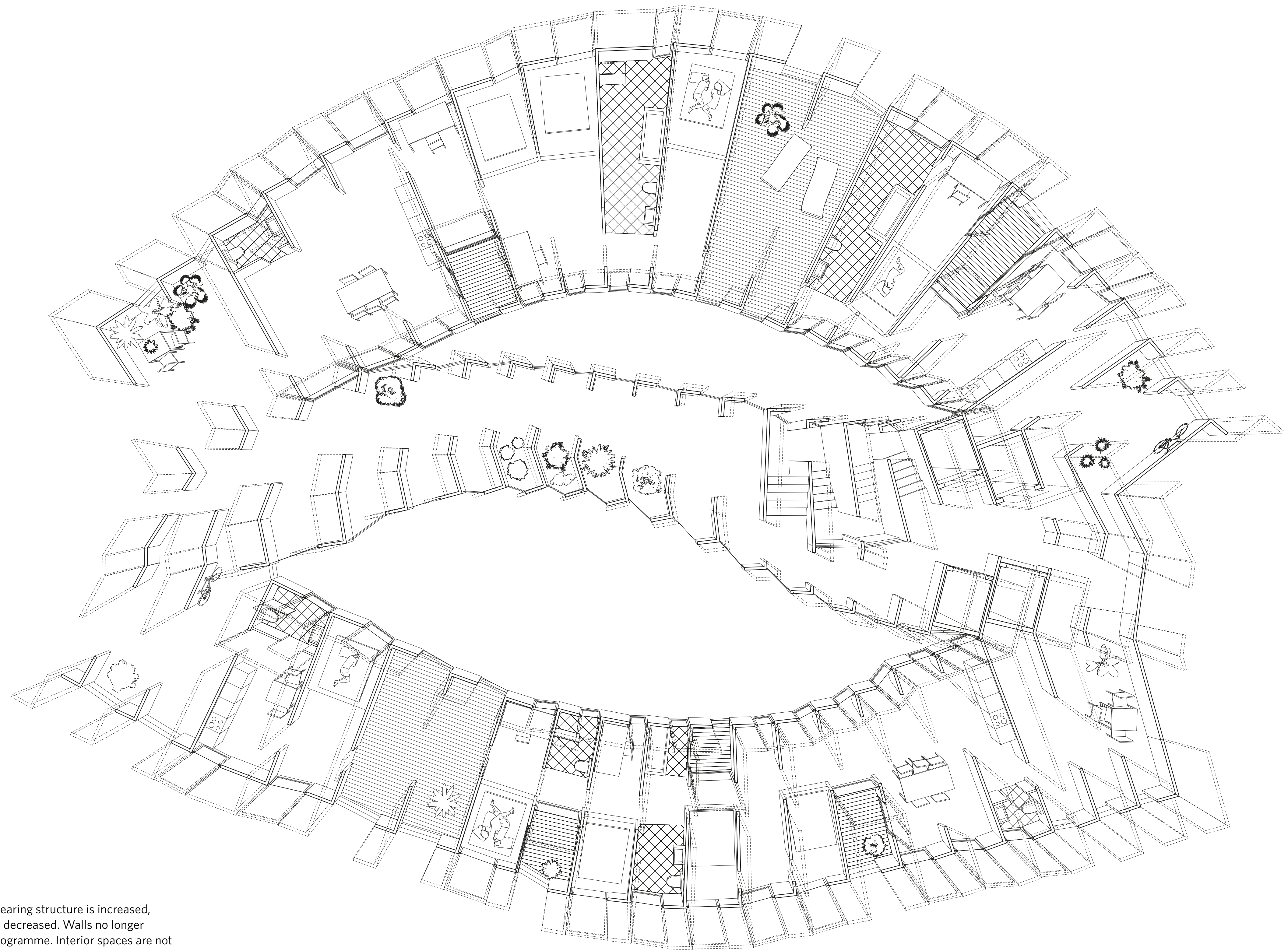


Final Tower – Context



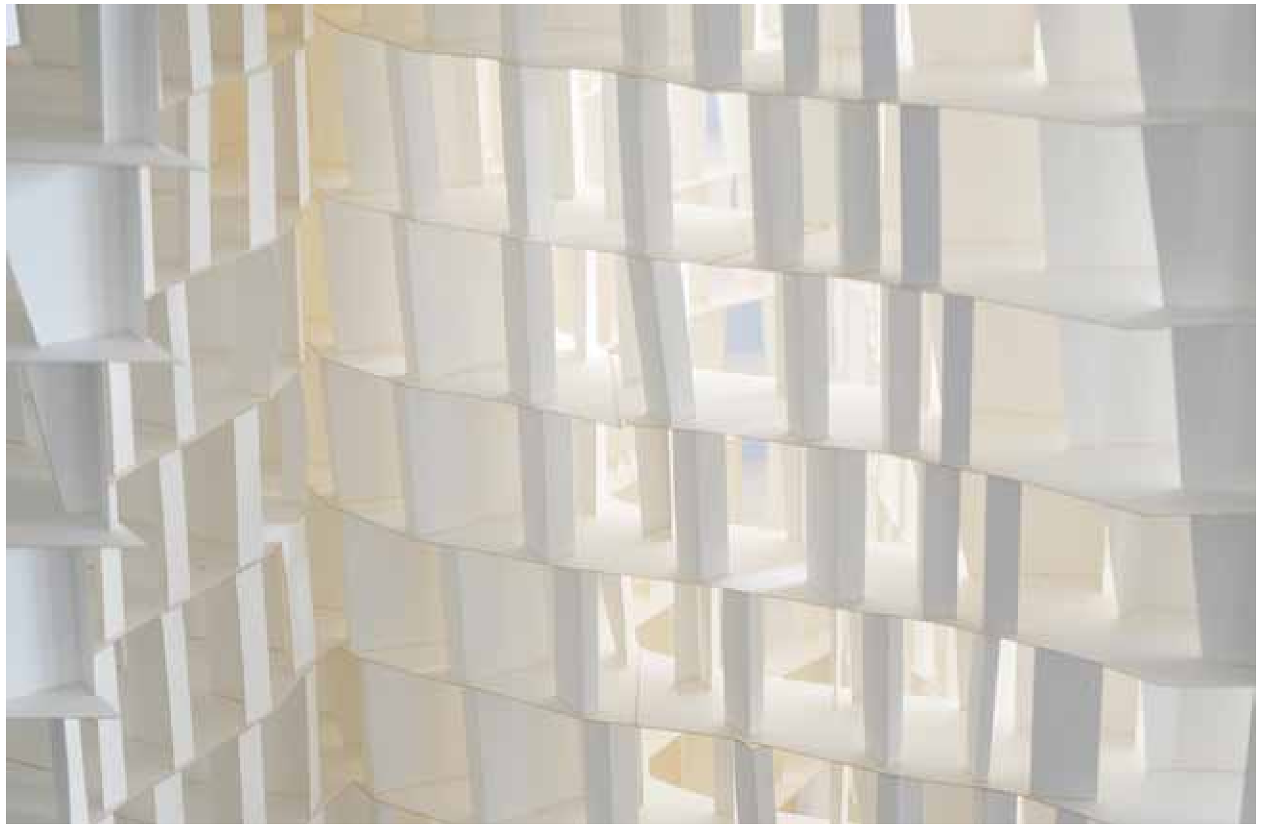
The project is situated in Bedok, East Singapore. The site is along the ECP highway, connecting Changi airport with the city centre. The highway is separating East Coast Park and an adjacent forest. The group proposes a sinuous overall shape constructed above the highway, reconnecting the two parks

Final Tower – Floor Plan



The resolution of the primary load-bearing structure is increased, while the individual wall thickness is decreased. Walls no longer frame a room but an architectural programme. Interior spaces are not defined by enclosure, but by programmed cut-outs in a sequence of densely placed walls

Final Tower – Interiors



Final Tower