The Forumtorget Bench

Digital and Material Prototyping through Computational Design

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DSEARCH WHITE PAPER

white

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Dsearch is a computational design development team within White Arkitekter AB. The Dsearch team is actively engaged in computational design development for specific projects, as well as for generic toolkits generally applied in projects.

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Abstract

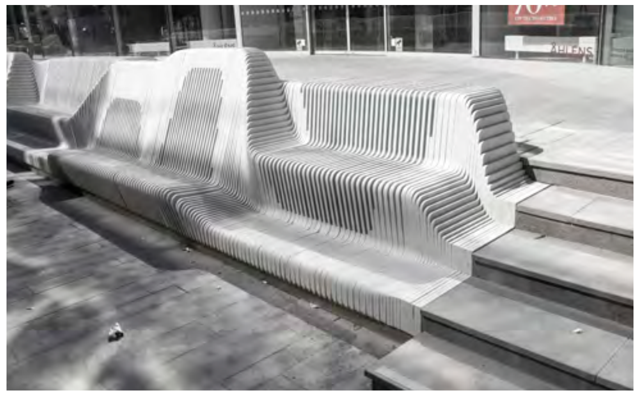
Computational techniques offer new opportunities within architectural design practice, affecting not only issues of form and fabrication, but also the management of architectural design processes. This white paper presents the bespoke process for the computational design development of a public furniture in the form of a 65-meter-long bench specifically designed for Forumtorget, a public square in Uppsala, Sweden.

The paper covers the project design development from concept to completion, as well as the development of computational design system* that facilitated this process. The use of *computational design** methods was essential for the complex design, and beyond formal possibilities and process automation it allowed a postponement of certain design decisions to very late in the project, which in turn facilitated a less linear design process. Reflections on the specific design and development workflows developed are presented, including issues relevant at competition stages, during design development and refinement, and as part of procurement and production. The Endnotes section include additional details in terms of methods, processes and design solutions.

The Forumtorget Bench development was led by Dsearch, a specialist team for computational design within White Arkitekter AB. The bench was a key part of a 2011 winning competition proposal for the transformation of Forumtorget, a square in central Uppsala. The computational design systems* and processes developed were carefully set up to support the collaboration between multiple parties –architects, designers and landscape architects, client representatives, facility managers, producers and the general public. The project development was extended in time due to the refurbishment of an adjacent department store – from 2011 to 2018. This meant that the development was subjected to shifting project conditions, as well as the continuous advancement of the computational design standards developed by Dsearch. The conditions for the design development also included a demand for longevity – 30+ years in a demanding location, which sets this development apart from similar prototypical projects, reflected in the robust design and material selection.

Jonas Runberger
Design and Development Lead of the Forumtorget bench

Terms marked *in this way* * can be found in the glossary.



Overview from the eastern street side towards the square (top), and eaxmples of features, including the "reclining bench", the "deep platform", the "step-up sofa" and the transition from bench to stairs. The ridge-like formation of the backrest (right page).

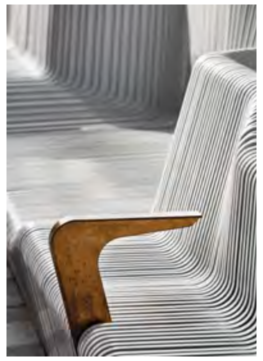
A Landmark Bench

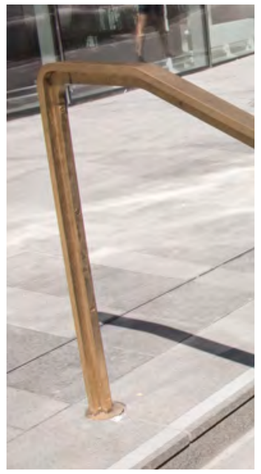
The Forumtorget bench is an urban and architectural multi-functional seating element with a range of seating configurations in order to provide comfort to anyone. A vital element of the transformed square, it is placed as a demarcation between the gradient slope of the square and its extension into a street, and a levelled and ramped passage along an adjacent department store. These shifting ground conditions led to a terrain-like design strategy and the creation of an interstitial space adding new value to the urban context, and a distinct expression to the square in central Uppsala. The development of the bench was led and conducted by the Dsearch team from the competition stage to completion, in close collaboration with the design team for the overall project as well as with external specialists.

Following the Smedsgränd street as extended into Forumtorget, the bench stretches 65 meters, interrupted at two locations by connecting stairs. The bench can be used from both sides, and functions in this sense as a double-sided sofa with a common backrest. The difference in ground introduces a gradual shift between the two sides - in some locations the seats are almost at the same level with a close relation, in others they are separated providing more privacy between the two sides. As part of the overall design for the square, the bench is one of three main elements, together with the public floor that allows different activities and the plateau that provides seating and can act as a stage for events.

The composition with its rhythm and the controlled seating principles provides an overall coherent design. Within this scheme there are many articulations. The changing overall form of the bench combines repeating elements with distinct features. From different perspectives it can be perceived as a meandering ridge or a silhouette shifting in height. It has a rhythm that suits the passage on foot - sometimes calmer, at other times more dramatic. It reaches down and adapts to the stairs at two locations and cantilevers out at both ends of the bench. In its articulation the bench operates as a human-scaled landmark in the urban terrain, designed for human use and interaction. Rather than using a singular template, it acknowledges the differences in human body form, to provide a perfect spot for everyone. This influenced aspects such as seating height, depth, and back rest inclination. Armrests at key locations where the seating height is appropriately high ensures accessibility for all. For a longer stay one can find a low and laid-back position, for a short rest one can choose a higher area.

The vertical transition between the different seating heights in the longitudinal





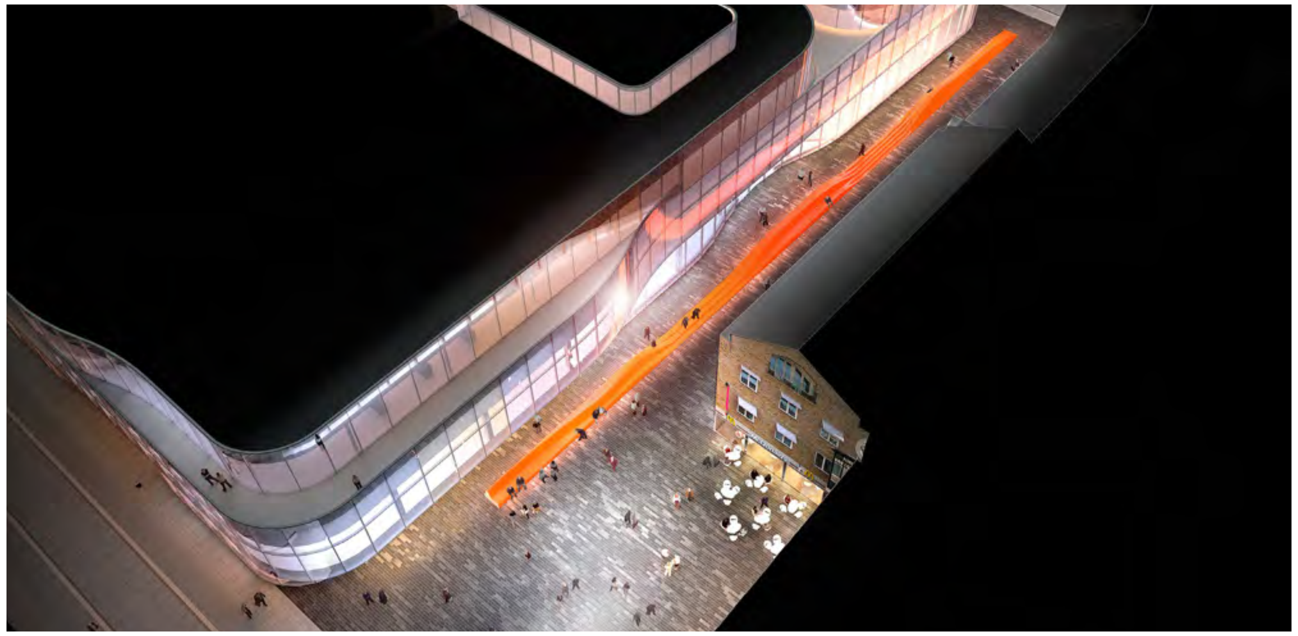
> **The colour scheme in light gray, with inserts in brass slowly darkening over time, makes it softly related to the stone of the solemnly paved square, yet articulated by the drama of its shifting form and the actions of its users.**

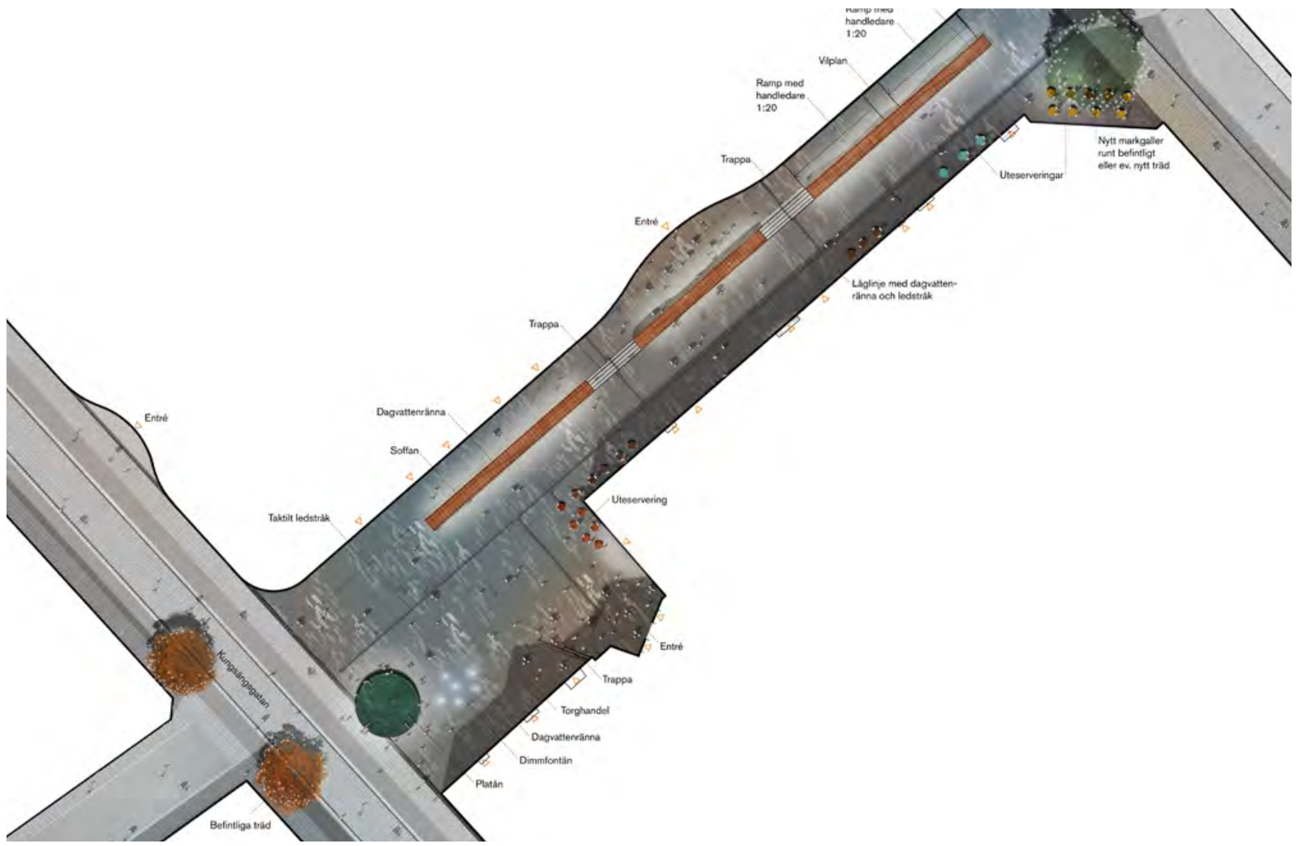
Overview from the square towards the eastern street side, and examples of and the transition from bench to stairs (Left page). Detail of armrest and handrail (above).

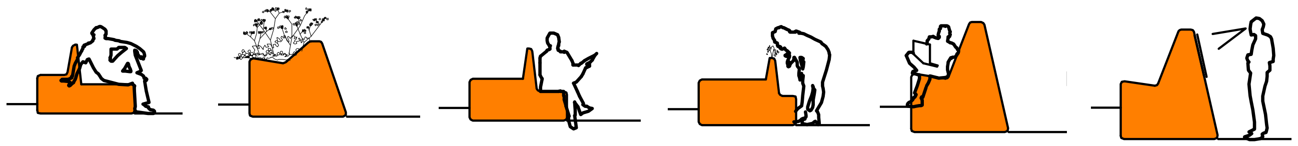
direction along the length of the bench provides a continuity, but also alternate ways to sit or lie down with a head rest. Unique configurations appear at times, such as the ”step-up sofa”, the ”deep platforms” or the ”reclining benches”.

The transformation of the form along the length of the bench is achieved through a lamella principle – the bench is designed and produced through the division of the overall form into sections of 19 mm, materialized through the use of custom cut lamellas in quartz composite and glass. This principle handles all different formal variants and was generated through the development of a computational design system*. The formal principle was further refined through the introduction of gradually shifting fillets of the corners of each section as well as the control of the border between composite and glass - another motif in the overall form. This interplay between opaque elements in quartz composite and translucent elements in glass led to another development, a pullback of all glass lamellas protecting them through the adjacent protruding composite elements, as well as introducing sloping surfaces for water fall off for all horizontal surfaces.

The materials were selected for their permanence. The quartz composite artificial stone takes the stress of the urban environment. It protects the inserted glass that glows at night through the integrated lighting armatures inside the bench. Armrests and handrails are distinctly shaped in brass, a material also used for the protective plates at the base. The in-situ cast concrete foundation, hidden below the bench, is in turn piled to withstand the expected settling of the ground. The colour scheme in light grey, with inserts in brass slowly darkening over time, makes it softly related to the stone of the solemnly paved square, yet articulated by the drama of its shifting form and the actions of its users.







Aerial perspective render, site plan and bench sections from the competition entry (left page).

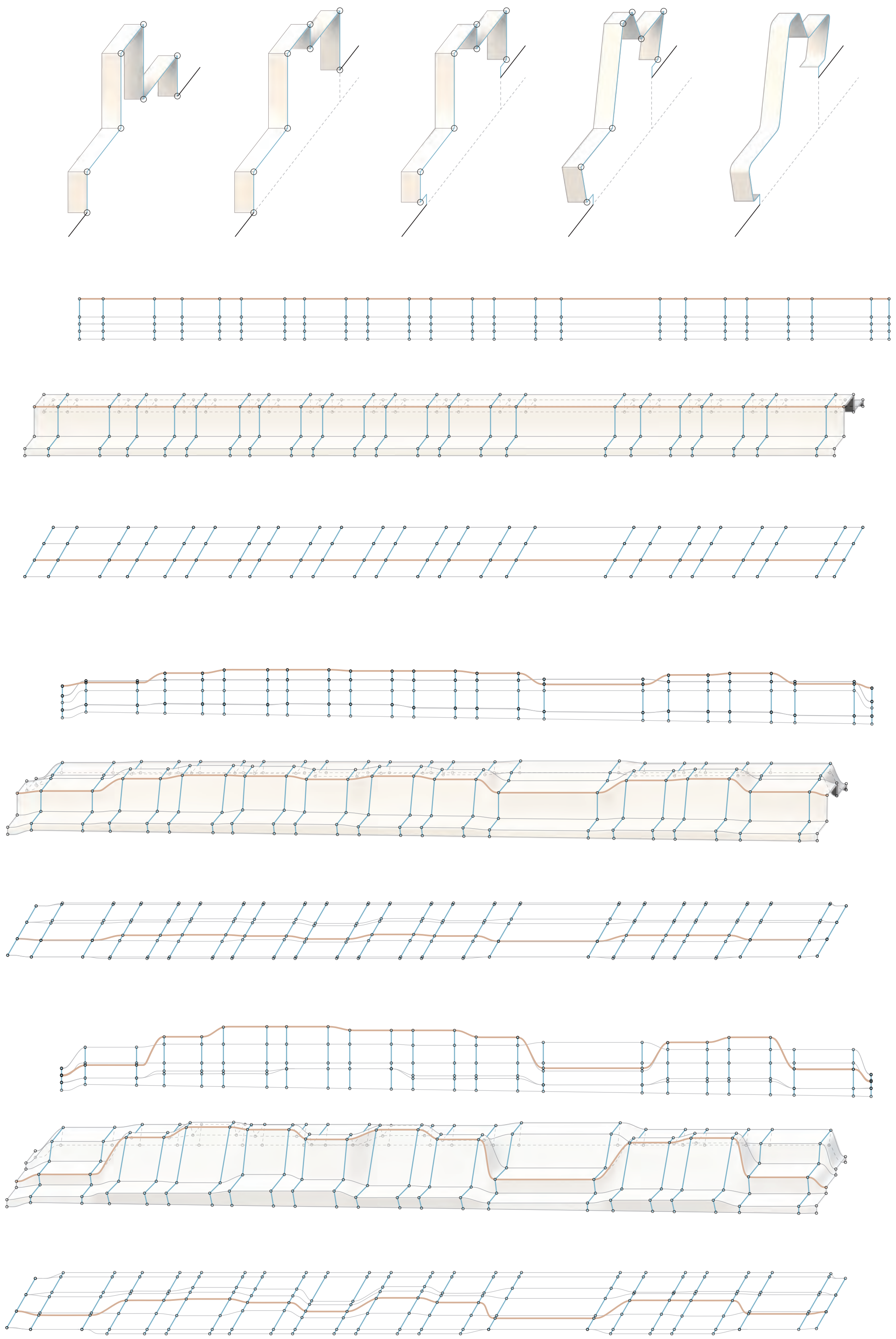
Development Process

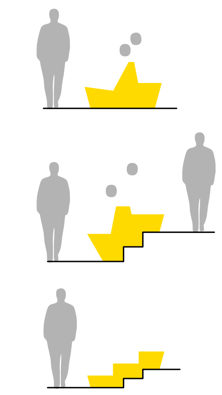
The conceptual development at competition stage relied on the understanding that the bench would be further refined through computational design means after the potential competition win. This planned post-conceptual development was followed through, further refining the form of the bench, and preparing the design for production. The process was guided through a combined leadership of both computational and formal design development, allowing opportunities to make final formal decisions to very late stages in the process.

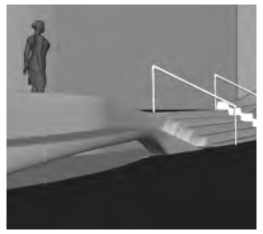
COMPETITION STAGE AND EARLY FORM DEVELOPMENT

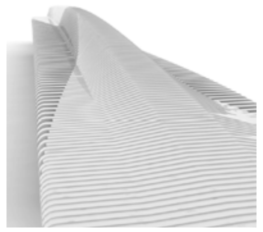
The formal variation of the bench caters for a vast number of different comfort conditions – allowing individuals comfortable seating regardless of physical constitution or preference. This important principle, and the required long life span and resistance to abuse, put high demands on the design decisions. The lamella based geometrical and material build up, material choices such as glass and quartz composites, and the early development of technical / structural details were specific responses to this.

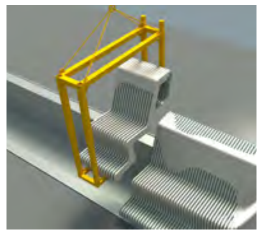
Breaking down a complex geometry into lamellas is a very common digital design trope* within architecture that rationalize production of free form elements. At the early stage this approach was chosen to provide a strong identity to the bench while affording a resolution operating at an intimate as well as global scale, with a rational production in mind. The adaption of an already established design principle further allowed focus to be put on its refinement– primarily looking at the range of alternate seating configurations to provide comfort for a wide range of preferences. With the early ambition to employ computational design as a design strategy – even before the design concept of the bench was defined, a design team with the necessary skill sets could be formed. In turn, this allowed the choice of a strong design concept that would provide many opportunities later in the process. The limited time during the competition stage required numerous short cuts in order to establish a formal principle and a vision fast, but the digital design modelling was conducted in anticipation of the later computational design development[1]. The organisational principles of the bench, three zones divided by two stairs, were set at the competition stage to provide good connections and accessibility across the square and into the adjacent department store. A lamella-based approach was selected to address final production, but the proposed paper-based laminate panels were later abandoned due to the need for more robust solutions. At the competition stage the bench was coloured in orange to make it even more distinct on the site. For several reasons a more sombre grey was chosen at later stages.











The gradual refinement of each section curve from vertices to fillets and the transformation of the overarching form by the individual control through control curves in plan and section (left page). General formal configuration types varying along the site, taking ground level differences into account. (above top). Design models from the competition stage, the form exploration using direct modelling and the first version of the form driven by control curves (above middle). The bespoke lifting tool for future assembly (above bottom).

INITIAL DEVELOPMENT

During the design development after the competition win the formal variants of the bench were further explored to find basic principles such as the relation between a fluid form and a distinct boundary to the site. This was conducted through free form direct modelling* during which the previous strategy of slicing up the form into lamellas was temporarily abandoned, and alternate fabrication strategies such as casting were briefly considered[2]. This development led to the definition of three distinct configuration types aligned with the local variation of ground levels in the three zones of the bench – defined through three key cross sections. With these principles settled, the development moved to a more precise configuration, based on a set of ergonomically good standards and a more refined parametric model.

While an overall understanding of the shifting form early on could be achieved through direct modelling and visual evaluation - on screen and as rendered images - a more precise development required alternate control mechanisms. This also allowed the inclusion of many technical solutions in the computational design system at early stage, extending the possibility of design changes to later stages in the process by defining parametric control. In terms of the formal development, schematic shifts in plan and section provided a certain degree of repetition – a global modularisation of the shifting form giving the bench a recognizable but transforming identity. At a more local scale, minute changes in form such as the rate of transformation between seating configurations, could be controlled very precisely.

Initially the three zones of the bench were designed with their own specific seating configuration. Later more variance was allowed, in which these three configurations were blurred into each other allowing localized identities to emerge while retaining a coherent whole. The initial basic principle of sectioned elements with an open gap between each lamella was furthermore revised into a final solution with a merged combination of opaque and translucent elements following an interlocking approach defined as the overlapping principle.

In anticipation of the final production, the complete bench was modularised into elements for pre-assemble, based on an estimate of 600 mm length to make them manageable. The exact module measures were adapted to the form of the bench, assuming that interfaces between modules would be better concealed in the areas of transformation – this could be rationalized post-tender into more uniform modules given the feedback from the producer. Given the specific design of the modules, a bespoke lifting tool that would allow assembly on site and future maintenance; this was indeed used by the producer for the final assembly.

COMPUTATIONAL DESIGN SYSTEMS

The development of the computational design system allowed for greater control of form at both global (the overall 65 meters of bench) and local (individual seating areas and smaller detail) levels. For this purpose, further direct modelling was avoided, and the model was instead generated through a set of control mechanisms. The design system allowed designers to interact through the definition of key cross sections, and the manipulation of a series of 2D-control curves in plan and section[3].

The design system in this way bypassed the free form surface and instead generated section curves directly – making the step of "slicing up a surface" obsolete, and creating stepped outlines of lamellas to be used as cut lines for fabrication, only occasionally generating solid geometries for visual evaluation through rendering. All in all, the design system was set up to control ca 3000 cross sections, first generated as polylines with sharp corners, later given a fillet with locally defined radii, again controlled through control curves. The use of straight lines and arcs for all geometry was alter beneficial to speed up the production process.

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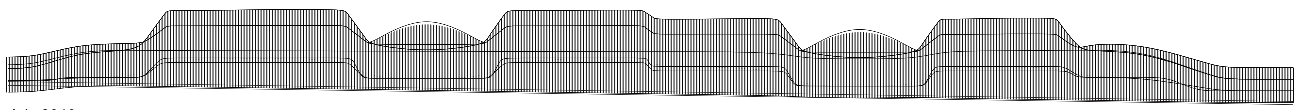

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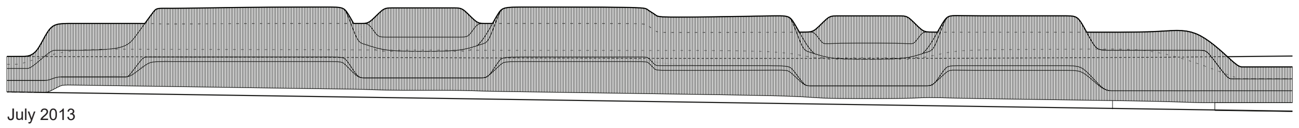

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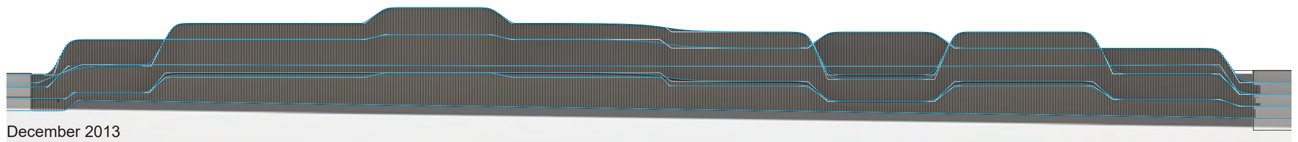

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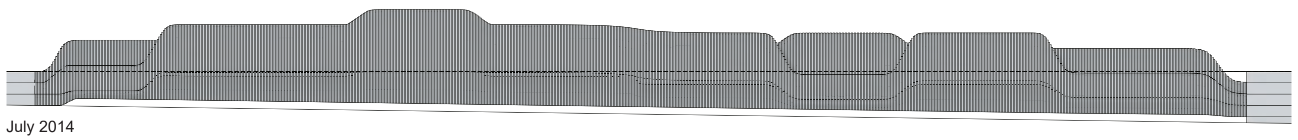

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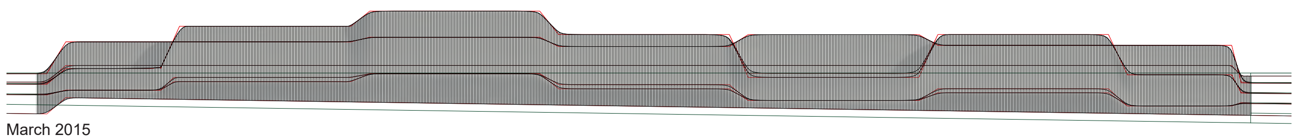

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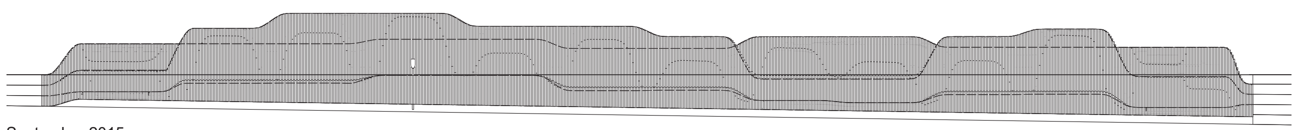

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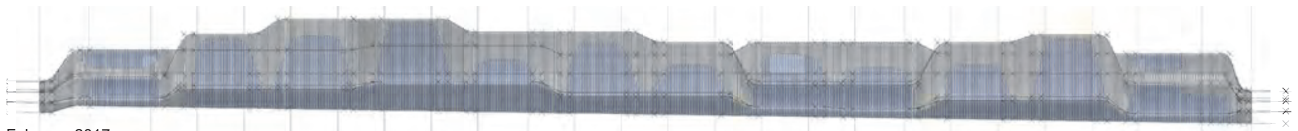

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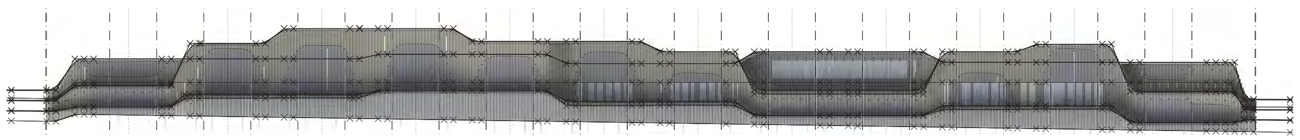

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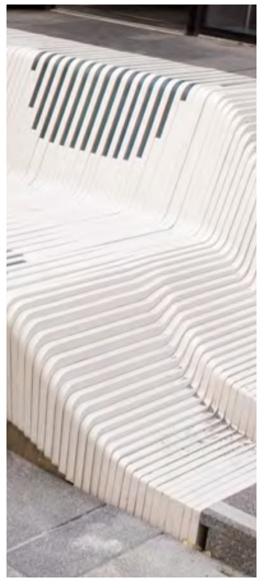
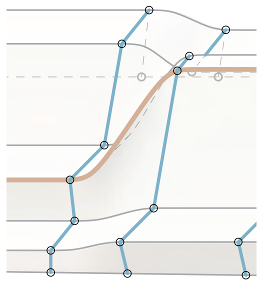




Elevations of the middle section of the bench – between the two staircases – showing the iterations of development from competition stage to final design (left page). Example of fillet transformation (above top). Comparison generated model and final bench, also showing the overlap principle of opaque and transparent lamellas providing a patterning effect (above bottom).

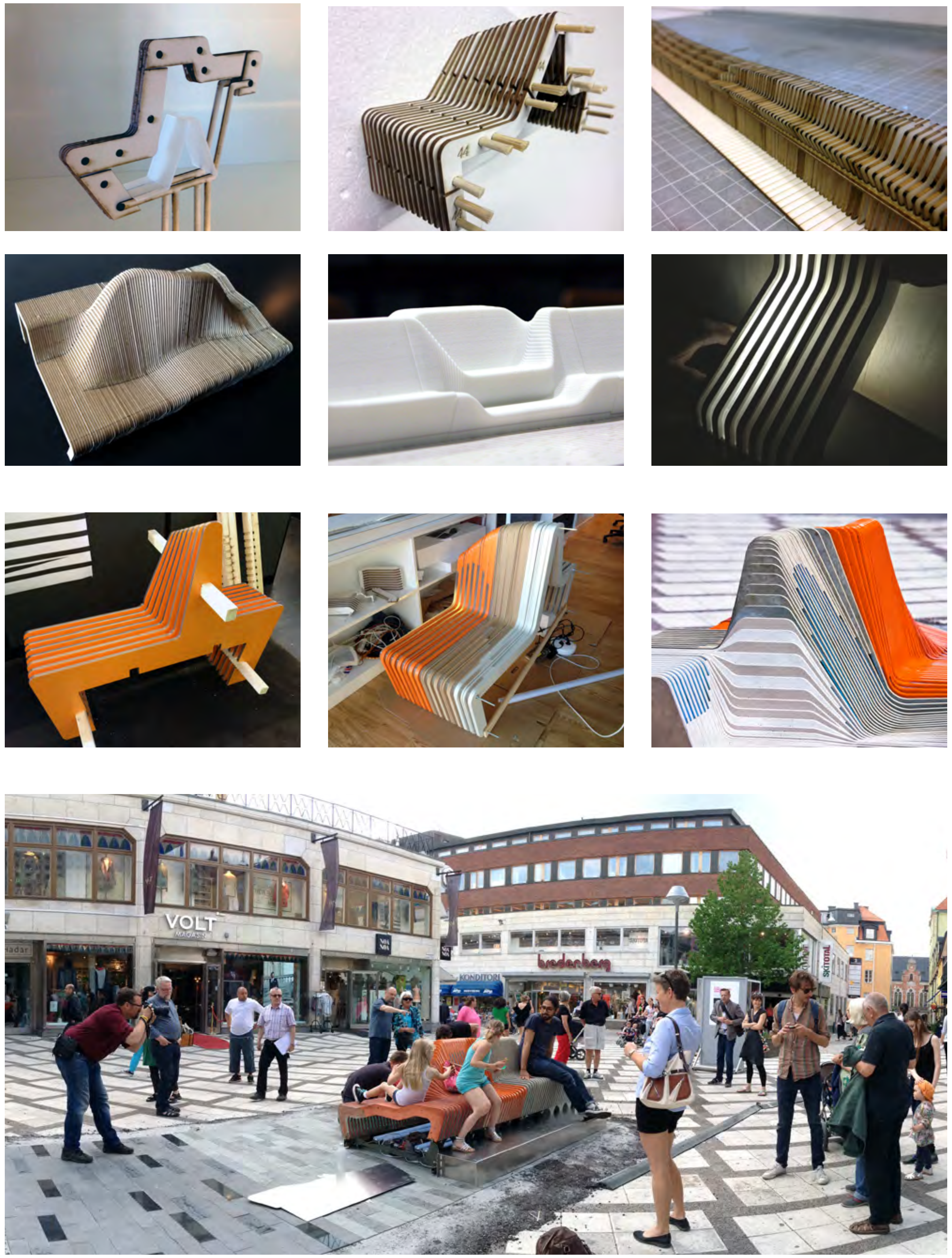
Each section was further divided into two segments in order to achieve the overlapping principle; an opaque part (to be produced in quartz composite) and a transparent part (to be produced in glass). The relation between the segments shifted between each section to achieve the overlaps, where the opaque areas became continuous over the length of the bench, with transparent inserts. The shifting positions of these divisions were automated as part of the system and became an additional design element for further articulation of the form of the bench. This also featured the pullback that protects the glass lamellas and provides sloping surfaces for water falloff. In addition, the design system included the detailing of each element in terms of the interface with the structural base. The exact specifications of these elements could be defined at late stage once the producer was defined. The principle of using 2D elevation and plan curves for the control of the design system was associated with the continuous production of representations of the bench, again in elevation and plan. Given that the global and local composition of the design had to be assessed in parallel, this led to a workflow where the bases for design exploration was conducted through occasional manual sketching on printed 2D drawings, internally in the computational design team as well as in the larger context of collaborating parties.

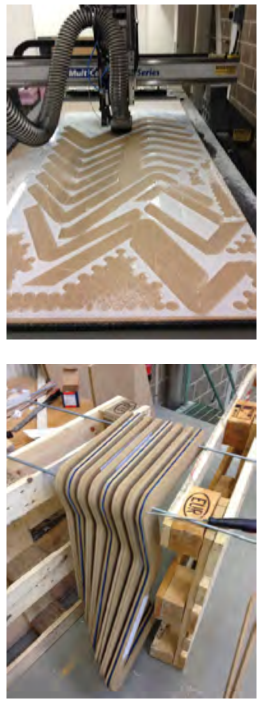
As part of general Dsearch development procedures, the computational design system was developed through definition versioning*, in which different computational functions were developed over time in an iterative way as an integrated part of the development, and all critical steps were documented to ensure quality and process control[4].

DESIGN PROCESS AND REVIEWS

The next stage saw an expansion of the design team, integrating expertise ranging from furniture design and production, to lighting design and landscape architects. The collaboration was facilitated through a series of curated design reviews, where each iteration of development was used as a basis for expert discussions and decisions. This was further supported through the physical modelling and prototyping introduced into the process – see Physical Prototyping - accommodating evaluation by the complete team, and a better understanding of physical performance such as comfort and light distribution.

The outcomes of the computational design development, the scale models and the prototypes were in this way evaluated through a series of internal design reviews[5], each followed by an external client meeting. The design review assembled the full design team, and covered issues such as overall design, seating comfort, materials, structure, detailing and production issues. The interdisciplinary competencies in the design reviews included architecture, landscape architecture, furniture design, parametric design, project management, lighting design and furniture production. The basis for discussions consisted of representations of design in 2D drawings, renderings, models, and prototypes, as well as reports from enquiries into materials and cost estimates. The findings and decisions from each review were presented to the client, and important issues were brought to the following review.





Examples of physical tests produced throughout the process, including physical models employing laser-cutting and 3d printing (left page top), prototype 1, 2 and 3 (left page mid), and the placement of prototype 3 on the actual Forumtorget square (left page bottom). The in-house production of prototype 2 (above).

MATERIAL DEVELOPMENT

At this stage of the design development, physical scale models were used to evaluate the design - both internally within the design team and with the client. The lamella-based solution made it optimal for smaller models to be produced by a laser cutter available within the office, but the overall form was also explored in 3d-printed models[6]. In order to develop principles for fabrication and to evaluate comfort and function, four full-scale prototypes were also produced at key steps of the process[7].

The material model and prototyping process led to many design decisions regarding detailed form, the overlapping principle and combination of opaque and translucent elements, and dimensioning in relation to seating comfort. The findings together with environmental considerations also led to the final decision regarding material choice; coloured quartz composite boards and frosted glass, with a substructure of stainless steel.

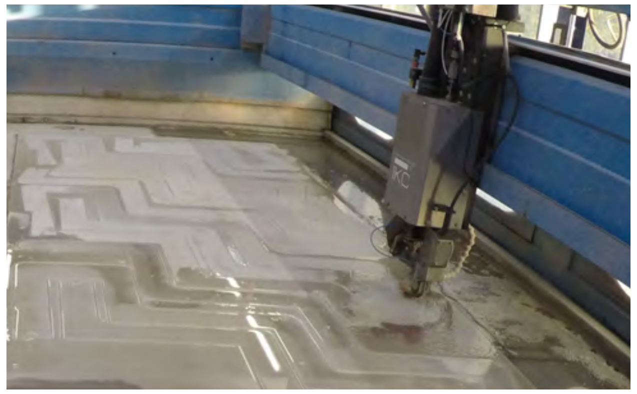
TENDERING AND PRODUCTION

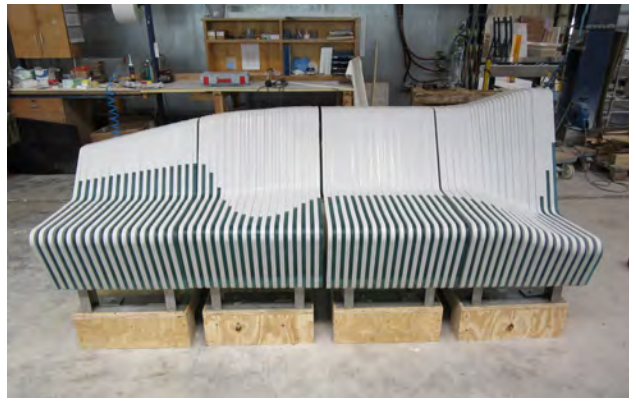
Given that the Forumtorget project as a whole was subjected to Swedish regulations on public tender, the bench was managed as separately from the general Forumtorget project in order to be tendered as a product, a model normally used to purchase public furniture of more standard character. This process was initiated by an open Request for Information (RFI) providing the team with the opportunity to get feedback from interest producers based on samples from the forthcoming tender documentation. This was followed by an open call to qualify for the tender, after which selected parties were invited to bid. In the final tendering process the assessment was advised by the White design team. The German firm Rosskopf + Partners partnering with Swiss Design-to-Production was selected and completed the production and assembly of the bench.

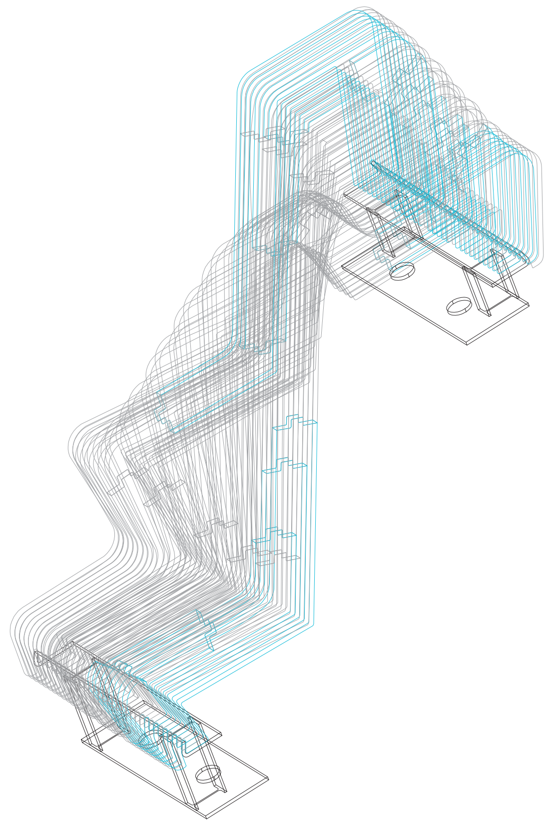
During this stage, the computational design system was revised for partial automation of the tender documents. A drawing management system was set up in Rhinoceros, using the Work Session functionality. A set of 19 tender documents were generated, including overviews of the project, fabrication planning documents as well as detail and assembly drawings.

Several final detailing decisions had been left unresolved awaiting direct communication with the producer. Once the tender was over, these decisions could rapidly be made, and changes could be implemented through the computational design system. This primarily covered issues such as tolerances, modularisation, and assembly procedures.[8] In addition, further development of the design system was conducted for certain features that depended on production feedback.[9]

After system changes regarding lamella thickness and module sizes were implemented, the producer delivered a final prototype of one module, in order to ensure that the production and assembly principles were adequate, as well as making final checks on design. The prototype module ended up being 5 mm too wide, which led the producer to adjust the assembly and gluing process. A few other minor issues were resolved, such as a weakness in the armrest solution. A new version was designed in collaboration with the producer, now integrating the armrest into the lamellas (by removing part of the relevant lamella), rather than fitting it on the lower steel structure independent of the lamellas.



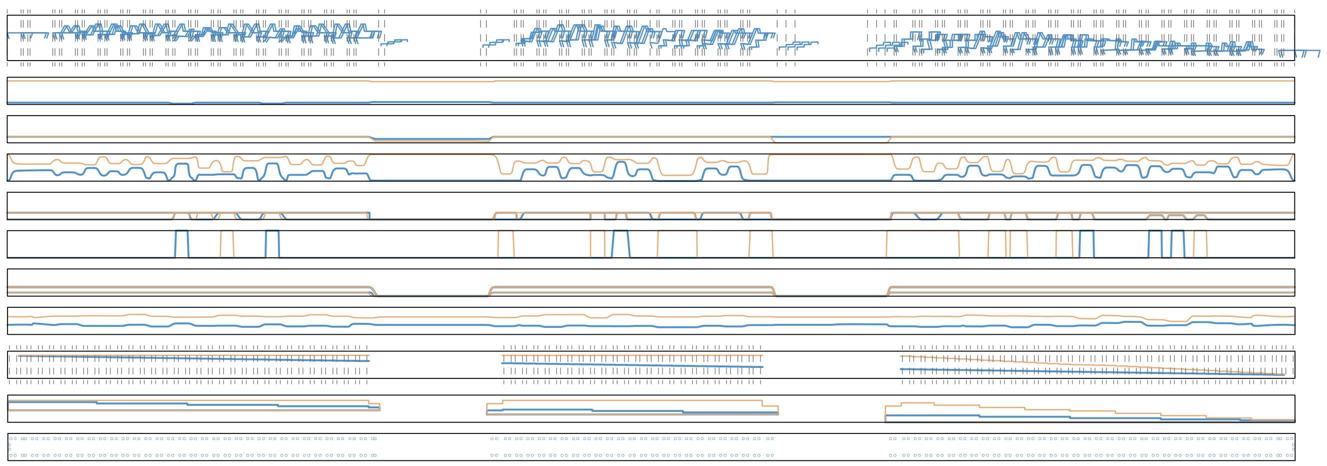


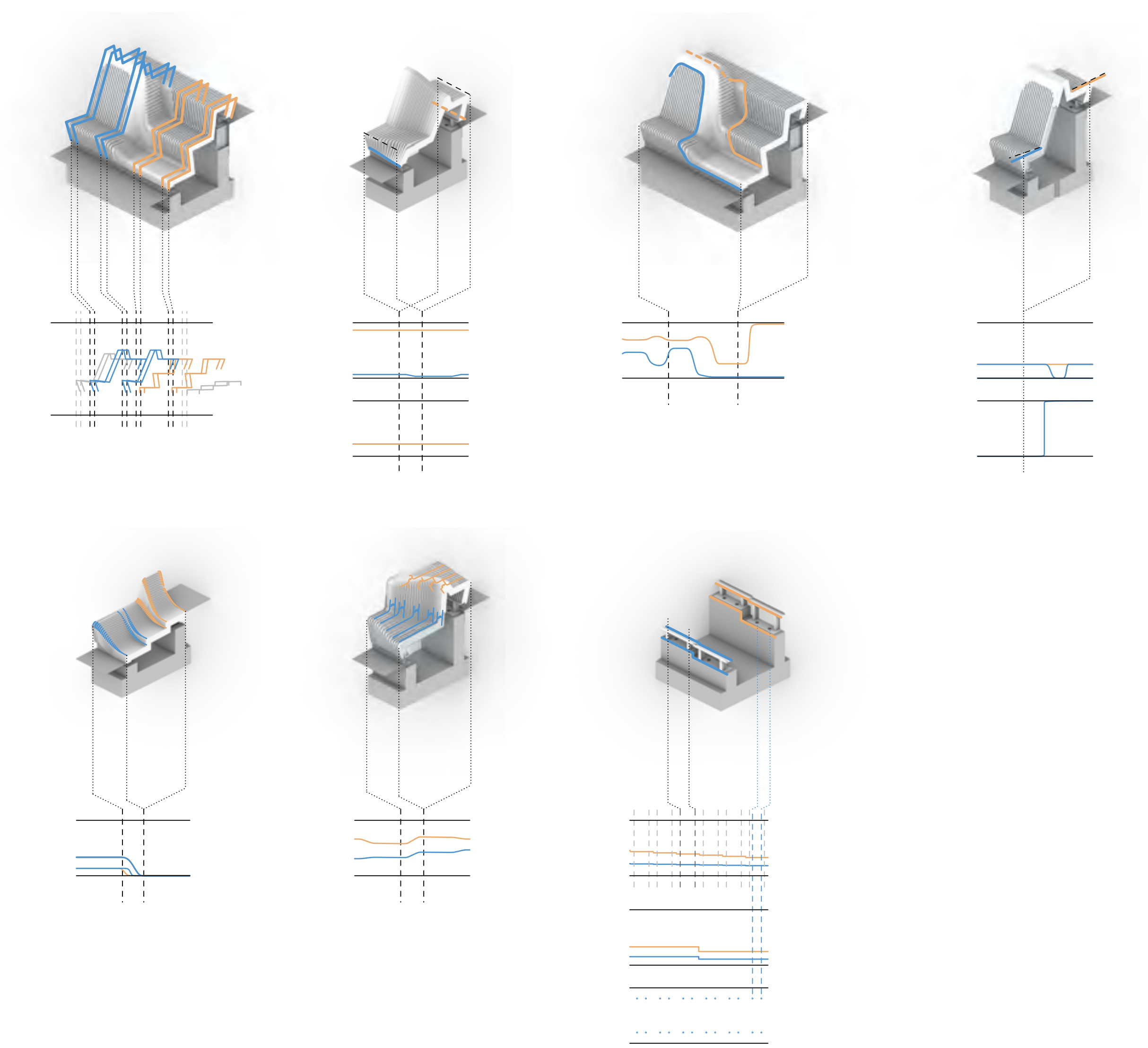


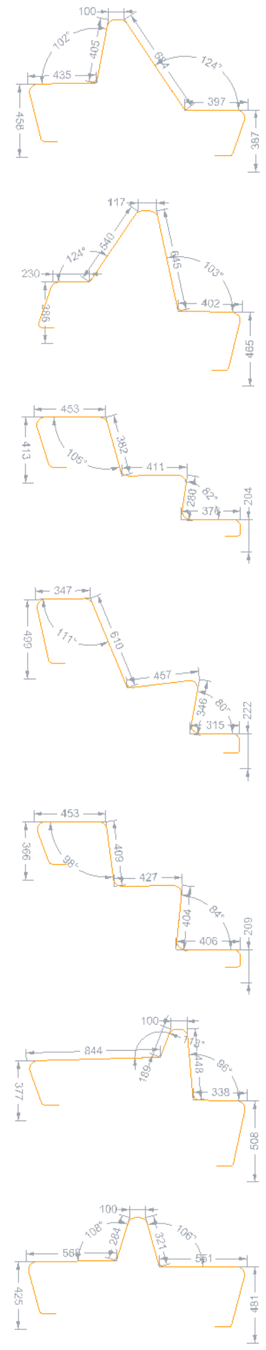
Due to the necessity of starting the production early, it was decided that delivery of production instructions would be done in phases, allowing more work on parts that needed additional development. Instructions were sent to Design-to-Production for final proofing in the form of the lines and arcs of each lamella, positioned correctly in a 3d model. Any errors identified was corrected by the Dsearch team, after which the responsibility for quality control was given over to the producer and partner. For the final pre-production step, Design-to-Production nested* all geometries based on the stock side of composite and glass panels and submitted production documentation directly to the producer.

All quartz composite and glass components were produced directly from the nested production instructions through water jet cutters, manually tagged and sorted with the module they belonged to. Production was following the order of assembly on site, starting with zone A. All cut elements were manually sanded to improve the surface quality and assembled directly on the stainless-steel foundation, mounted on a jig that simulated the local ground condition. Several modules were put in series together to make sure they would align in an appropriate way, and then packed for transport module-by-module. When delivered on site, each module was mounted directly in its location on the concrete foundation, with an assembly team from the producer using the custom lifting tool. The complete mounting time for the overall bench was ca two weeks.

Pre-production prototype, production, assembly, and on-site montage (left page). Close-up of auto-generated axonometric from final production documents (above).







All control curves defining the design, including cross sections, bottom edge, glass/composite overlap, pullback of lamellas, fillets, division of lamellas, structure, concrete foundation and position of fitting bolts (left page top), with seven selected examples of their effect (left page bottom). The variation of seating dimensions represented in seven key sections (above).

Reflection

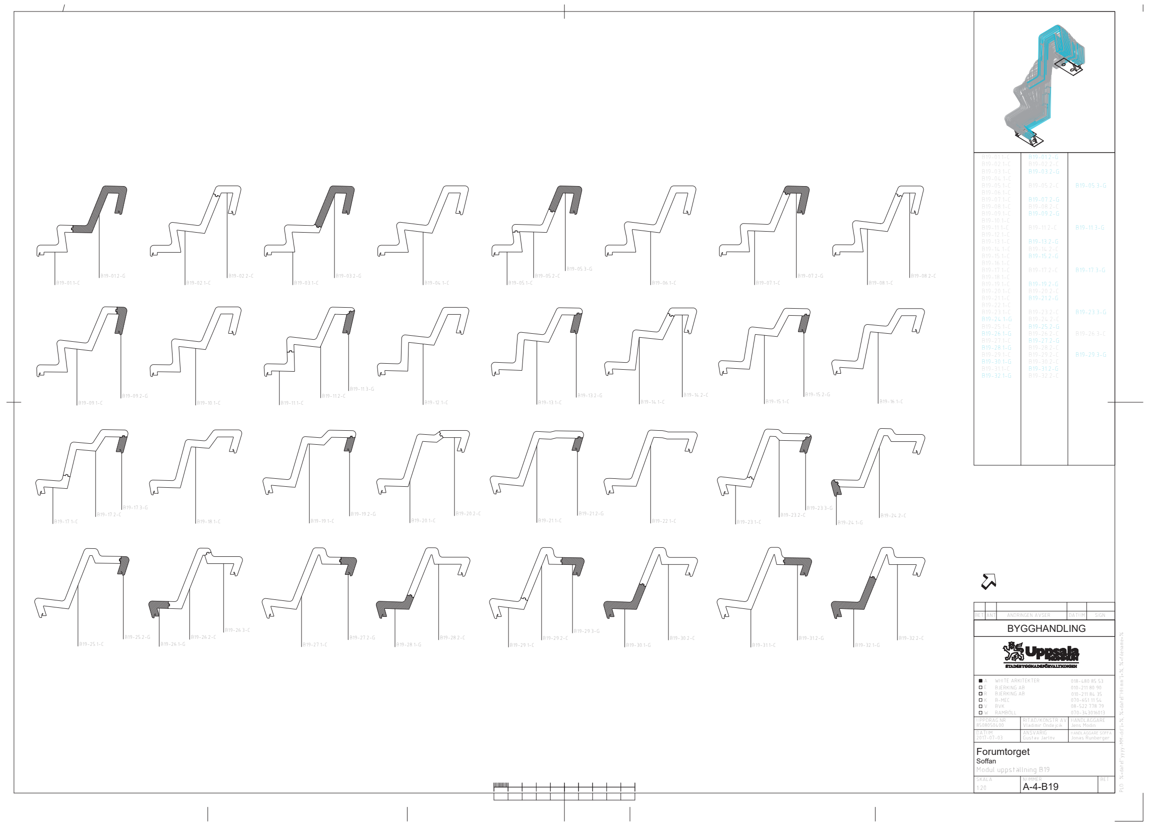
The set-up of the computational design system to support a project from competition stage to production stage requires strategic understanding of the future potentials of the methodology. As many factors are unknown at early stage, careful consideration is needed when deciding how much time can be spent for development at each stage. Once the project specific conditions are fairly well defined, development can go into more advanced levels.

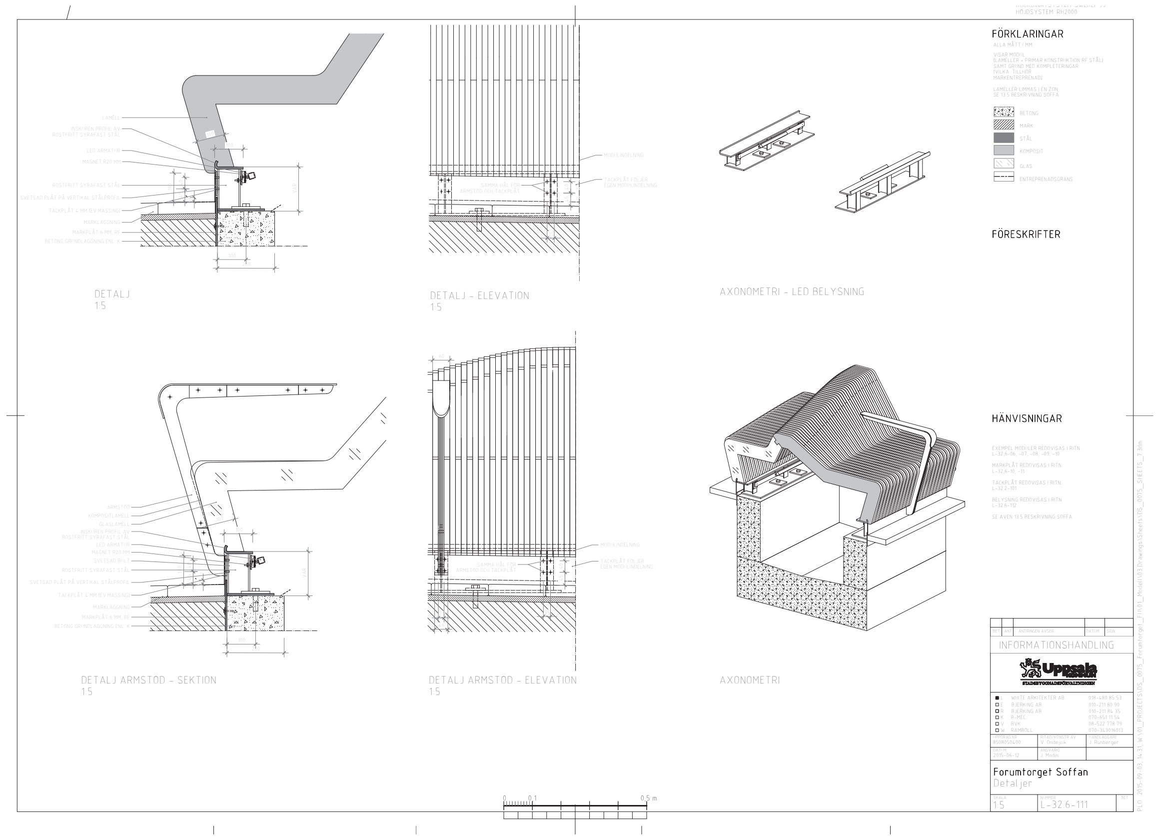
In the computational design development for the Forumtorget bench, a number of critical issues were addressed at different stages. In the early concept phase, the geometrical build-up was defined in principle, allowing for later stage refinement. Basic computational techniques at this stage were used to provide representational models for competition presentation, including potential principles for construction and fabrication.

Following this the range of possibilities were explored in an open-ended way, allowing for an agreed upon span of variants. Schematic principles for comfortable seating considerations were defined, and distinct features for the three different zones of the bench were set up.

During the next stage the computational design system was developed iteratively to allow full control of formal variation, detailing, fabrication documentation and representation. Most major conditions were known at this time, including the overarching formal strategy as well as principles for production. Details, joints and structure were developed as parameterised principles well before the final form was set. This allowed a reversal of the process in terms of keeping final decisions on form to a very late stage, while providing general solutions for fabrication and structure early on. In the last stage the design system allowed for potential technical updates depending on producer feedback, while maintaining the possibility to make design changes to the form. The focused design reviews based on representations and reports produced through the versioning approach catered for the consideration of many issues at early and intermediate stage. A number of issues were identified and deemed to be unique for this type of project (in terms of challenges in design, fabrication and procurement). This included the documents for tendering and procurement and the need to detail them at technical level, while still keeping them open for continued formal development. The procurement process following Swedish legislation for public projects through initial advertisement for interest, followed by a market survey and invitation to selected producers to leave offers, was a key to completing the project in the best possible way.

With a project that depended on development through careful considerations of production potential and limits, the design stage strongly benefited from the development of computational design systems, the production of physical models and prototypes, and co-planning for production and assembly as a joint effort with the producer. All in all, the Forumtorget bench was successful due to collaborative efforts, in many ways enabled through the iterative development of the computational design systems.





Endnotes

These notes add further details on methods, processes, and design solutions, referenced in the general text.

1. The competition development was carried out as direct digital modelling* in Rhinoceros* 3D. Key 2D cross-sections were lofted in order to rapidly create conceptual forms, while computational design techniques in Grasshopper* were used to slice up resulting volumes and generate the schematic sections for the final presentation. The Rhinoceros model was finally exported to 3ds Max* for the final renders in the form of schematic axonometric perspectives, presenting the general overall form as well as the lamella principle.

2. The direct modelling in the first stages of refinement after the competition win was enhanced through the T-Splines* plug-in, allowing for a greater control of overall form – in effect turning the design development into a moulding of digital clay.

3. The design system was set up to translate 2D geometries “drawn” in Rhino in two ways. Key cross sections could be placed at specific positions along the length of the bench, ensuring that seats and back rests would have appropriate height in relation to the shifting ground. The continuous shifting form between these key cross sections could be defined by 2D control curves in plan and elevation at control point level. The scripted design system transformed the geometrical information into data processed through computation, in order to directly produce a 3D geometry consisting of the actual cross section curves representing individual lamellas. A cross section control curve consisting of a polyline with eight vertices and seven lines was set up as a basis for this generation.

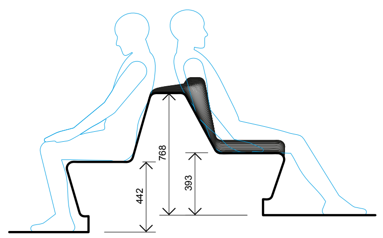
Examples of production documentation for one module (left page)

4. Excerpts from the definition log* shows the following key steps of development:

- Version 05: Setting up the generation of curves, with position controlled directly from Grasshopper.
- Version 08: Setting up the control curves in plan and section to control the generation of cross sections.
- Version 17: Setting up first version of laser cutting production documents.
- Version 20: Revising definition to more efficient layout.
- Version 23: Setting up production documentation for physical prototype 2, with manual modelling of overlap.
- Version 38: Replacing key graphical elements in definition with Python Script.
- Version 41: Initiating Prototype 3 development.
- Version 48: Adding automatic “overlapping feature” for lamella system.
- Version 54: Adding detailing elements interfacing with structure.
- Version 56: Final production documents for Prototype 3.
- Version 59: Adding features for drawing production of sections, plans and axonometric.
- Version 65: Adding automatic import of Rhino geometries such as control curves.
- Versions 66-72: overall design development of all zones.
- Version 74: Developing parametric scale figure.
- Version 76: Developing features to export models for 3D printing.
- Version 80: Introducing automated log-file generator.
- Version 82-83: Complete design revisions of all zones.
- Version 87: New model set up for final design and tender doc, update of definition log to 2.1.
- Version 88: Revision of definition to new graphic standards for visual scripting.
- Version 89: Modularisation of bench, first alternative.
- Version 91-93: Design revision all zones.
- Version 94: Foundation revised.
- Version 96: Pullback revised.
- Version 100: Design revision all zones.
- Version 101: Primary structure parameterised.
- Version 119: Flux connection integrated.
- Version 127: Design revision all zones.
- Version 128: Pullback flip for special situations developed.
- Version 132: Delivery Zone A for production - general modules.
- Version 142: Delivery Zone B for production - general modules.
- Version 157: Armrests revised and parameterised.
- Version 158: Delivery Zone C for production - general modules.
- Version 159: Final deliveries of all production documentation.

5. The following key aspects were covered during the design reviews:

- Design Review 1: New material alternatives considered (quartz composite and glass), internal lighting by LED, alternative lamella assembly considered.
- Design Review 2: 1:2 scale model for light studies evaluated, prototype 2 planned, production costs roughly estimated and related to materials used.
- Design Review 3: Evaluation of prototype 2, ‘overlapping principle’ between solid lamellas was evaluated and confirmed, decision was made to close gaps with glass, and material variants with specific cost estimates were considered.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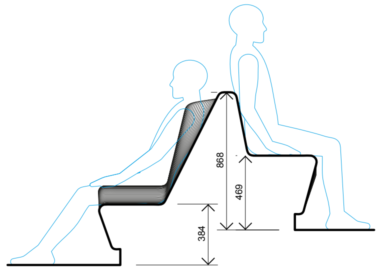
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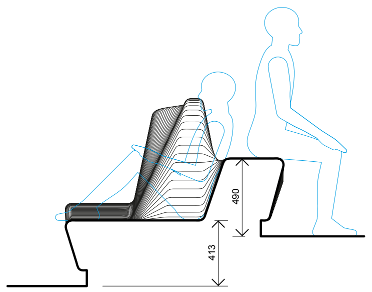
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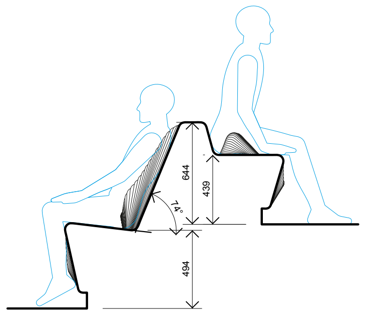
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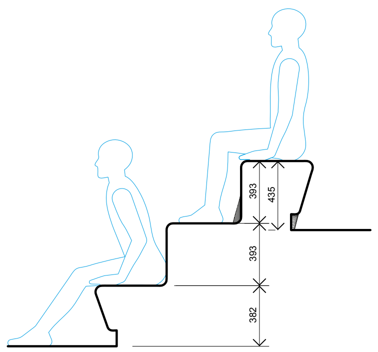
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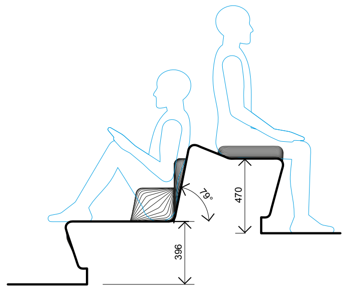
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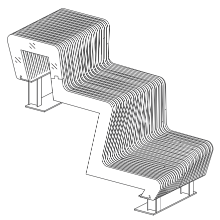
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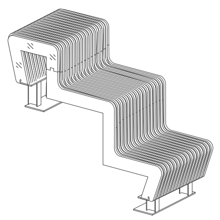
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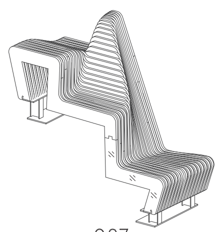
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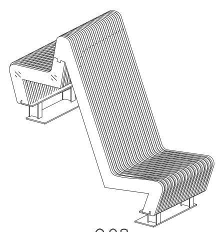
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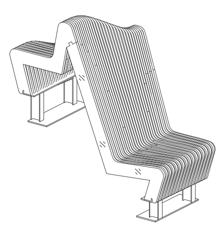
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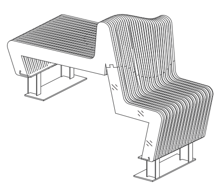
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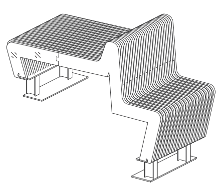
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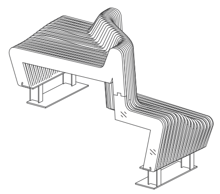
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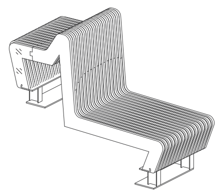
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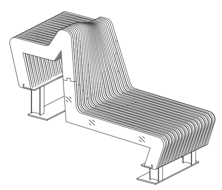
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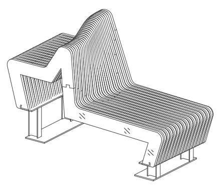
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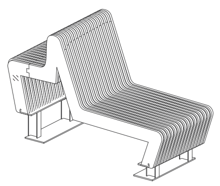
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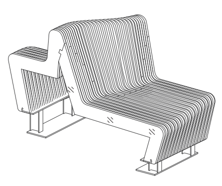
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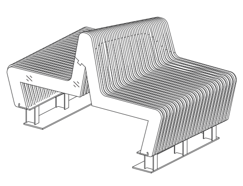
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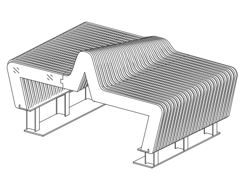
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- Design Review 4: Detail solutions considered, production and delivery of prototype 3 planned.
- Design Review 5: Evaluation of prototype 3, production issues and surface treatment were considered, material choice was evaluated, and tolerances in structure and assembly considered.

6. The following scale models were produced:

- Laser-cut scale model of complete bench at scale 1:50.
- Multiple laser-cut scale models at 1:10 to explore the formal principle of overlap and details of joints.
- Partial laser-cut model at scale 1:2 to study light transmission.
- Multiple laser-cut scale models at 1:10 to evaluate form of prototype 3.
- 3d-printed scale model at 1:20 of complete bench.

7. The following prototypes were produced:

- Prototype 1 was based on principle sections with little variation and using high density laminate boards. This prototype was prepared by a producer and was brought on site temporarily to improving the understanding the scale and the effect of the double-sided bench principle in context.
- Prototype 2 was developed as one 600 mm long unit of the actual design by the Dsearch team, using a 3-axis CNC-router for the production of lamellas in medium density fibreboard (MDF) and clear acrylic plastic. It explored the principle of overlapping and alternate solutions for the use of transparent material, as well as coloration.
- Prototype 3 was developed as a compressed version of several formal principles of the complete bench, as four units of the actual design (4 x 600 mm). This prototype explored actual materials, fabrication technologies, and solutions for joints and underlying structure, and was produced by an external party. Three different materials for solid lamellas were tested - glass fibre reinforced concrete (GFRC), wood fibre reinforced concrete and quartz composite - in combination with glass. It was placed on site at Forumtorget for four weeks, allowing the public to use it. At a later stage it was also used to determine the best location for light fixtures and evaluated in terms of vandalism and abuse.
- Prototype 4 was manufactured by the selected producer post tender, and was used to assess assembly, final dimensioning, and structural integrity.

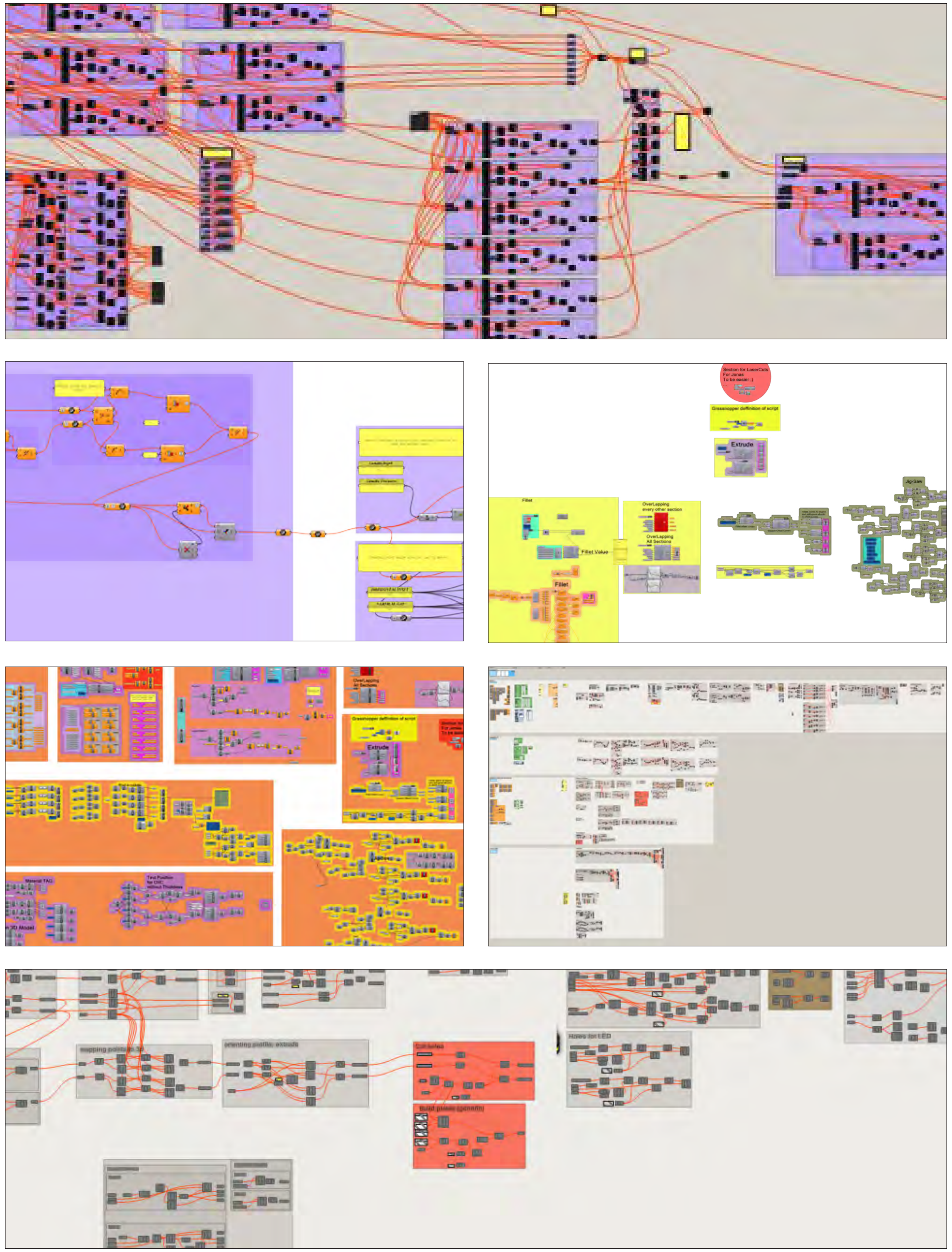
8. The following changes and considerations were done through the computational design system after tender:

- The lamella thickness was changed from the original 20 mm to 19 mm to better suit standard glass panel thickness (the quartz composite would have a custom thickness regardless).
- Tolerances were of particular importance, both in regard to the stack of lamellas along the length of the bench (Y-direction), and the height levels in relation to the in situ cast concrete foundation (Z-direction). The Y-tolerances were a potential issue, given the build-up of thickness due to the glue. The final decision was to model the complete bench with a 19.5 mm section thickness and providing another 1.5 mm gap between each module. The Z-tolerances depended on the accuracy of the cast foundation and were handled by adding thin steel plates under the steel structure at the assembly on site.
- The modularisation of the bench was changed from an irregular module size (relating to the form of the bench, to a standardized module with a width of 624 mm (with a few exceptions). This was based on the producer's confidence in that gaps between modules would be minimized and not visually disturbing.
- A change of material for the supporting structure from stainless to galvanized steel was considered from a budget perspective, but later abandoned given that the producer received matching offers in stainless steel.
- The final decision to mount lamellas with glue only was taken, making the need of supporting rods inside the lamella structure obsolete. This required a new strategy for future repairs, where damaged sections of lamellas would be cut open with a diamond wire.
- The final decision on the colour of the quartz composite was made, shifting from the original orange to light grey, based on expected UV colour degradation of stronger colours, and the effect from the coloured light.
- It was revealed that the machine used for final production - a somewhat dated water jet cutter, had difficulties in processing spline curves - which would have slowed down the production process extensively. As the geometrical principle for the lamella form was only based on lines and arcs, this was not a problem.
- The setting of the final form configuration.

9. The following features were added to the design system after tender:

- Full parametric control over gradual shifts of edge fillets.
- Full parametric control over the shifting borders between composite and glass and setting final configuration.
- Design of both end-sections of the bench. After conversation with the producer, it was decided that the ends would simply be glued on to the adjacent modules, using rods inserted into the lamellas for guidance.
- The lamella depth was increased at points where the bench transformed rapidly, making sure of a minimum of 70 mm overlap between lamellas.

Examples of representations used throughout the design process - cross sections with scale figure to assess bench proportions and comfort, and axonometric views of selected modules (left page). Snapshots from automated dimensioning tool (above).



The evolution of standards for visual scripting within the Dsearch practice during the development for the Forumtorget bench.

Glossary

Terms in the article marked in this way * are described in this glossary.

Computational Design
Refers to the joint process of design and programming, often through the use of dedicated modelling software with scripting capacity.

Computational Design System
The complete set-up of models and scripting environments that enable innovation in a project.

Definition Log
An automated log that allows Dsearch development to be continuously document of each version for quality control.

Digital Design Tropes
Digital design tropes are reoccurring design principles that have emerged during the recent history of digital design, often linked to specific parametric techniques.

Direct Digital Modelling
Refers to the direct manipulation of geometry in modelling software, with no aspect of scripting or computational input

Grasshopper
Grasshopper is a visual scripting environment for Rhinoceros*, and allows the association of geometrical elements in visual scripts* for a fully parametric system.

Rhinoceros 3D (Rhino)
Rhinoceros is a surface modelling tool, which can be extended by numerous add-ons. Together with the Grasshopper* plug-in it constitutes the main design platform within the Dsearch team.

T-Splines
The T-Splines plug in for Rhinoceros* allowed free form modelling of complex topological forms – and extends the possibilities for free form modelling. The plug-in is no longer available.

Versioning
In the Forumtorget project, the development of computational design systems* follows a versioning logic, where each version is applied and tested, to inform the next iteration.

Visual Scripts
A back-end environment for computational modelling – in this case the Grasshopper* scripts. Allows programming through the linking of graphical elements.

3ds Max
A 3d-modeler and visualization tool.

Full nesting of quartz composite components.

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