Project Specific Innovation

Computational Design Development in Architectural Commissions

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DSEARCH WHITE PAPER

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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.

This is a self-published document from White Arkitekter. The format white paper is used for informational documents presenting offers, projects, or methodology in depth.

Abstract

Computational Design is a heterogeneous field of digital development enhancing architectural design, which has emerged and expanded during the past 20 years or so. There are many different definitions, but in general the computational design developer combines expertise in scripting and programming with design competence, and the ability to develop and apply digital code to resolve issues or enhance workflows in architectural design processes. One can argue that it entails a designerly way to write code, or a more systematic way to design. For certain, computational design is a field that continues to advance, with applications in all stages and scales of the architectural design project providing the architect with the ability redesign and improve the design process.

This advance has been pushed for a long time within experimental practice and academia, but the application within architectural practice is increasing. To add new capabilities and new ways of practice can be challenging, however. This white paper addresses some of these challenges and presents a set of strategies in response to them. It also provides examples of how computational design has been used at White Arkitekter to enhance architectural commissions of all scales. The computational design development in these selected projects has been conducted by Dsearch, a team of computational design specialist engaged in project specific innovation as well as generic method development since 2010.

Jonas Runberger
Head of Dsearch 2010 - 2023

The EcoCanopy concept explored strategies for more energy efficient transformation projects through semi-climatized courtyards, and computational design was used to develop design cases where advanced timber structures provided optimal and aesthetically articulated spaces (left page). In the Sediment art project, computational design was used to translate the images of the artist Johannes Heldén to perforated steel panels using bespoke grids (cover page).

More detailed information can be found referenced in the Endnotes, and terms marked *in this way* * can be found in the Glossary.

The Humanistiska Teatern façade is in itself a public artwork, where computational design was used to translate the artist's vision – and actual drawings – to the complex form of the building and the rasterized perforated façade panels (left page).

Introduction

This document presents findings from 13 years of computational design development in architectural commissions, in response to all the conditions of architectural practice – societal needs, client expectations, architectural ambitions, economical resources, and available competence. In short, it is a recount of the experiences of computational development in a context where ambition is high, but resources are meagre.

*Computational Design** involves the development and application of design and analysis methods and workflows through scripting and coding, rather than the direct use of off-the-shelf software. It can play several roles in the formulation and formation of design concepts, and how they are further refined during the design process. It also entails a new interactive mode of communication in the design process, providing a means to be specific, also with very abstract ideas.

When computational design development is conducted within a project, it can amplify the design process and increase the agency of the proposal in response to briefs, contexts, and other conditions. The outcome of this development can be seen as a *computational design system**, which contains one or several *scripts** linked to *design models**, and a set of workflows that fulfils the requirements of the project. Once in place, the design system can provide a concrete basis for further refinement and articulation – informing the project through a mediation between qualitative design development and quantitative analyses and enabling automation* of repetitive tasks.

APPLICATIONS

The design process is commonly described as a non-linear activity where proposals are reviewed and developed in an iterative fashion. Somewhat unintuitively, computational design is especially powerful when it comes to the *automation** of exceptions and the creation of variation. They bring a new level of precision when it comes to architectural *design modelling**, allowing for control of complex geometric shapes as well as massive amounts of geometry and associated data. An *informed design** approach allows performance parameters to inform the design process of a proposal through an intricate intertwining of shape and analysis. Structural logics can be employed as design concepts to be articulated, as constraints to navigate within, or as simulated forces that direct architectural components into place. In the latter *form-finding** techniques, *physics engines** simulate forces that can be used to find more optimal global forms for specific structures, or to adapt a generic geometry to specific local conditions. The systematic characteristic of computational design systems also makes them suitable for the creation of textures and patterns. While a static geometric pattern easily can be repeated ad infinitum, it can just as easily transform, for instance, unique site conditions into texture.

Computational design in these senses expands the notion of design iterations in two distinct ways. Serial iteration happens for instance when a shape can be informed by qualitative design assessments or quantitative analyses through

The 65-meter public bench for Forumtorget was conceived, developed and finally produced through the development and application of computational design systems (left page).

incremental changes in shape that is evaluated at each step. Parallel iteration entails producing a batch of alternatives from the same design system.

CHALLENGES

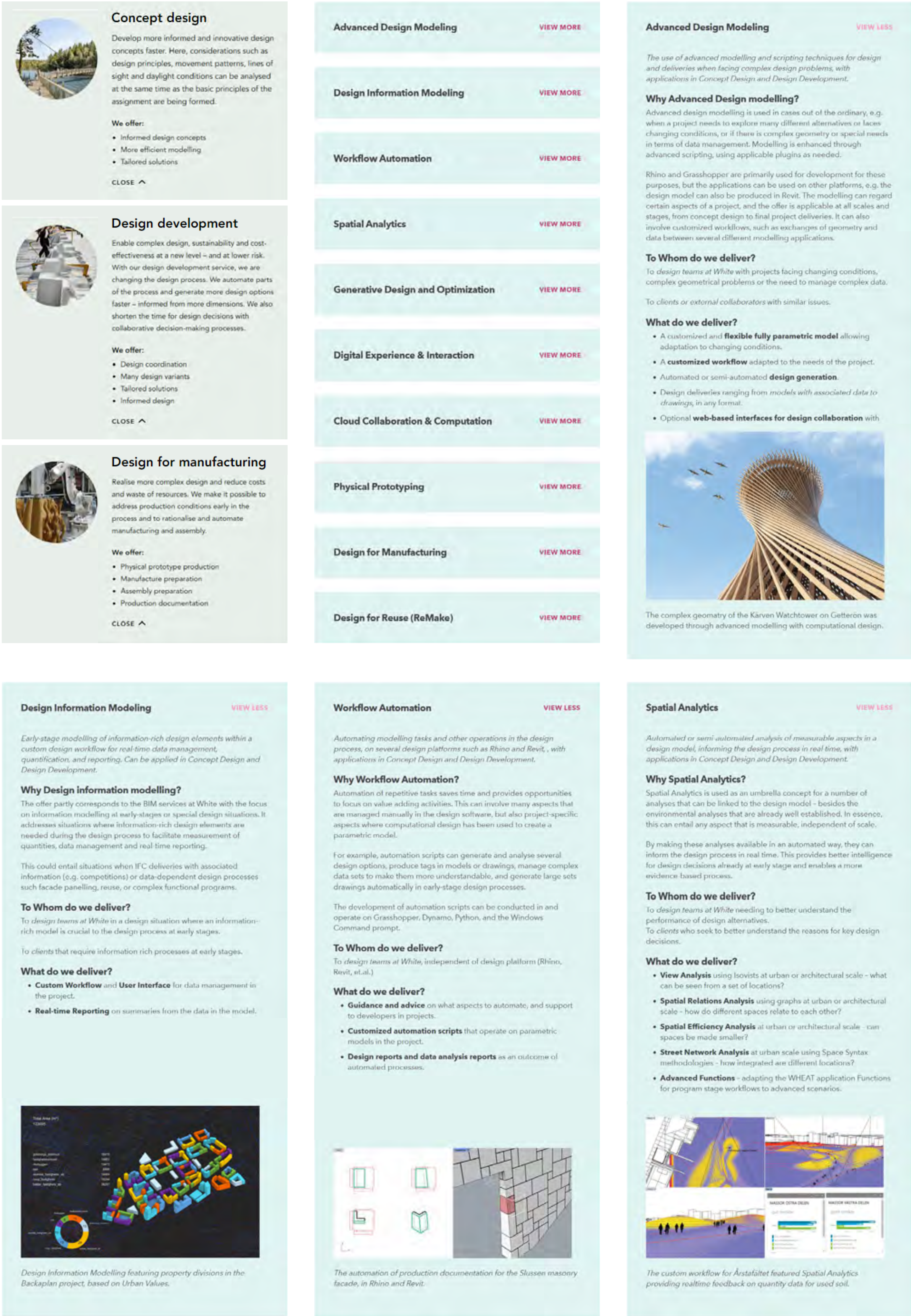
The integration of computational design development in projects means that the design process is changed from the convention, something which is challenging, especially during the short timeline and constrained resources of an architectural project.

The first challenge regards the expected benefits and scope of this development. In the practice of Dsearch, this has been resolved through the definition of ten offers that relate to common aspects, phases, or issues of an architectural project. The offers guide project leaders and teams in terms of setting the scope for the project and identifying key aspects that can benefit from development. The following chapter presents the offers, and they are also used to organise the project engagements presented.

The second challenge is that the computational design developer often is a new role within the design team. The typical computational design developer is often an architect with advanced scripting and programming skills, and the experience of integrating these skills in the design process. The developer's role within a design team and a design project can therefore be diffuse and shifting, from traditional project responsibilities and mandates to the development and management of new applicable methods. The *Project Development Matrix** is a tool to identify the responsibilities and mandates of a developer or development team within the larger context of the project. It is further presented in the Commission Developer Roles chapter.

A reallocation of resources within the project is required to ensure that there are means for development, but the third challenge is to manage the development process in relation to the general process within an architectural commission. This requires a process that on the one hand is very sensitive to the immediate needs of the project, but on the other can be extended in time to make the process more efficient downstream. With shifting project conditions, this has led to the establishment of four alternative computational design development workflow scenarios in relation to commissions – presented in the Commission Development Workflows chapter.

A general challenge to the computational design developer is that many commission requires new methodological solutions. The responses to the first three challenges presented in this white paper were defined as facilitating frameworks to clarify challenges, define roles and allocate resources for the integration of computational design in architectural commissions. The actual development is further supported through the use of *script** repositories - where reusable parts of computational design scripts can be shared, and graphic standards - principles for how scripts are organised and annotated for improved legibility.[1] Besides delivering a specific architectural proposal, a computational design system can form a bespoke workflow for the design team. These systems range from the general and tool-like, to specific explorations of concepts, problems, and aesthetics. Development efforts are here directed towards the interface between designer and system. Such a system must facilitate design thinking by striking a balance between augmenting the capacity of the designer and minimizing complexity. In essence, this is the design of design workflows.



The three themes and overview of the ten offers defined to clarify the benefits of computational design development in architectural commissions, with details of the first four (left page).

Computational Design Offers in Commissions

Computational Design development can be applied in a wide range of project situations. To make the potential benefits legible for clients and collaborators, this section presents three areas of computational design application, and ten specific offers, that can be included in projects from the start or initiated later in the project process.

The development of the offers has been closely associated with method development and over the 13 years of experience in applications in commissions. The offers have aided the communication with other design teams and clients to make the potential of computational design more understandable, and to identify opportunities within new and ongoing commissions, where computational design development can provide valuable enhancements of the process or design outcome. The ten offers formed in this way based on the experiences of the Dsearch team, where all team members have contributed to a range of architectural projects. They have been defined and revised over time and have continuously been updated with new methods based on technological advancement within the field.

The offers can be divided into three overarching themes. Concept Design includes contributions at early stage, where many key aspects are still unknown. Design Development indicates processes where the design, and the *computational design systems** used, is being refined and revised. Design for Manufacturing can be conducted at both early and late stages, making production limitations a parameter at early stage, or preparing a design for final production.

The ten offers are all applied in different stages of the architectural design process. They are often integrated into conventional services and stages of architectural projects, but at times they can be used as distinct commissions in themselves. They are overlapping, and in many situations a set of offers would be applicable.

Advanced Design Modelling is the most generic service, with a broad range of applications. It lies at the core many other services and entails the development of *associative design models** through scripting and coding. It enables modelling of complex geometries, the integration of a range of analysis methods, and the consideration of

Generative Design and Optimization

VIEW LESS

Digital framework for generation, multi-objective optimization and selection of high-performing design options in a design process with multiple conflicting design goals. Can be applied in Concept Design and Design Development.

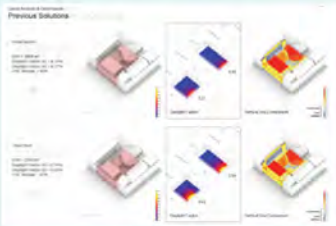
Why Generative Design?

If a project is facing a design problem where several factors are influencing each other, and there is no obvious simple solution, a generative design process can allow the team to find a number of possible design alternatives where these factors are balanced.

The factors can belong to different domains, such as:

- Regulations and laws
- Urban and architectural indicators
- Spatial requirements
- Sustainability metrics
- Cost constrains
- Structural requirements

- **Generative Design Exploration** of a relevant number of variants in relation to the complexity of the design problem.
- **High-performing Options** in a matrix of short-listed variants and their corresponding performance evaluation results.
- **Design Guidelines and recommendations** resulting from comprehensive analysis to the design space.
- **Digital models** of all relevant design options.



Generative design and multi-objective optimization was used to identify the best massing solutions against three different environmental criteria in the Njord project.

Digital Experience & Interaction

VIEW LESS

Virtual Reality (VR) is an immersive way to visualize designs, while Augmented Reality (AR) is a technology that merges digital models with the physical world. Can be applied in Concept Design and Design Development.

Why digital experience and interaction?

VR helps the design team and clients to experience a project design, understand qualities, and find possible flaws. **AR** allows digital models to be viewed in a physical context - on site, or as an overlay to a physical model - which provides further understanding of the design.

Combined with **computational design**, these technologies can allow the viewer to manipulate the model in different ways through a **parametric project viewer**.

To Whom do we deliver?

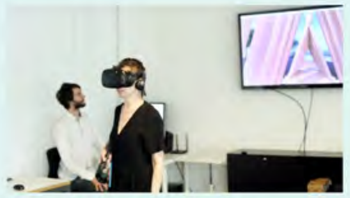
To *design teams at white*, to be used as a part of review process internally and externally and as an external offer.

To *clients* as a packaged delivery to showcase projects at public presentations and exhibitions.

To *manufacturers*, where AR can be a timesaving and quality assurance for assemblies of complex structures.

What do we deliver?

- **Digital models** for AR/VR publication.
- Support in **hardware setup** for AR/VR.
- **Adaptation of parametric models** developed through computational design into fully parametric immersive and/or augmented experiences.



The VR-setup for the Järvsö Pavilion allowed spatial qualities in relation to the human body to be examined.

Cloud Collaboration & Computation

VIEW LESS

Cloud-based computation allows time-consuming calculations to be conducted at higher speed, without interfering with other activities of the designer. It also enables internal and/or external interactive collaboration, with applications in Concept Design and Design Development.

Why Cloud Collaboration & Computation?

The computational tools currently in use can be moved to the cloud for increased efficiency and collaborative potential. This can be used at all stages, for different applications (design and/or analysis) and for several design platforms (Rhino and Revit).

Applications such as Rhino Compute and Speckle enable data exchange between platforms, versioning approaches in the design process, and the external storage of data. In turn this makes it possible to work platform independent, and new applications are continuously integrated into the overall ecosystem of tools.

To Whom do we deliver?

To *design teams at White*, to optimize processes and further enable collaboration.

To *clients*, as part of our general offer.

What do we deliver?

- **Cloud-based Parametric Project Viewers**.
- Frameworks for project-based **data exchange**.
- Cloud Processing for Grasshopper Scripts in Rhino Compute.
- Speckle **Repositories and Connectors** allowing further applications to be connected.

The cloud-based parametric online project viewer allows anyone to explore alternatives of the Järvsö Pavilion with feedback on the use of the associated material library.

Physical Prototyping

VIEW LESS

The production of physical models and prototypes through digital production tools such as 3d printing, laser/plasma cutting and/or CNC milling. Can be applied in Concept Design and Design Development.

Why physical prototypes?

Physical models and prototypes are increasingly used to assess designs and test alternate materials or production methods. They allow new production processes to be tested before final production and construction, and the physical prototype can be assessed in terms of buildability, sustainability, and performance.

Computational design can be used to automate and streamline the production process also at prototype stages. It can also facilitate fast and precise physical scale model production.

Models and prototypes can be produced inhouse at White, but for more advanced production the use of sub-contractors is advantageous, based on production documentation prepared with the aid of computational design.

What do we deliver?

- **Advice and support** for digital prototyping.
- **3d model files and/or g-code** for 3d printers.
- **Templates or final production documentation** for laser cutters.
- **Tool paths and/or g-code** for cnc milling.
- Final **physical models and prototypes**.

The physical prototype for the Forumtorget Bench tested the production technology, the sub-structure and three different materials for the 65 meter bench and was also deployed on site for user feedback.

Design for Manufacturing

VIEW LESS

The inclusion of production parameters at early-stage design, or production adaptation of a design for digital fabrication at late stage. Can be applied in Concept Design and Design Development.

Why Design to Manufacturing?

Computational design allows fabrication and production parameters to be considered already at early design stages, enabling them to inform the design. This enables more efficient, cost effective and quality-controlled production, as well as the production of complex designs in a rational way.

Production criteria can in this way be included in early stage analysis as a factor together with performative criteria such as sustainability measurements or material optimization. Design to manufacturing can address several alternate production methods for comparison, which also provides flexibility at later stages taking shifting materials costs into account.

What do we deliver?

- **Design strategies** using computational design to fulfil production expectations.
- **Custom workflows** following an automated file-to-factory principle, adapted to specific production requirements.
- **Production documentation** for any computer numerically controlled (CNC) production technology.

The production and assembly documentation for the Forumtorget Bench was produced directly from the computational design system developed, and a custom assembly jig was designed by the team.

Design for Reuse (ReMake)

VIEW LESS

A digital framework that supports design for reuse by connecting material libraries with design models, allowing the designer full control of amounts of materials used and their climate impact. Can be applied in Concept Design and Design Development.

Why ReMake?

Design with reused materials and elements changes the design approach, and it is important to have direct access to the available material library when making design decisions.

This is still an emerging field of practice, and each project can have its own conditions. Given this, the ReMake framework is adaptive to project specific conditions in order to provide relevant information at each step of the design process.

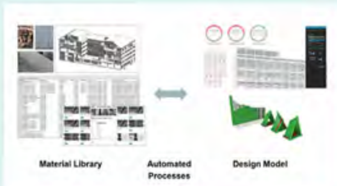
To Whom is the offer directed?

To *design teams within White* engaged in reuse design processes.

To *clients and external collaborators*, as an integrated part of overarching offers.

What do we deliver?

- **Customized workflow** adapted to project specific conditions.
- **Realtime feedback and reports** on quantities of reused materials and their environmental impact during the design process.
- **Information rich design models** at early stage and building elements with relevant associated data.
- **Improved quality control** of reuse design processes from early stage.



The ReMake framework addresses broad range of material libraries and associates them to the design model for automatic feedback.

Read more about ReMake on Whitenet here.

The details of the last six computational design offers (left page).

COMPUTATIONAL DESIGN OFFERS

downstream aspects such as fabrication and buildability already at early stages. It is applicable in any scale or approach, from landscape and urban design, to buildings, interiors, and products.

Design Information Modelling allows information-rich elements carrying relevant data already at early stages of the project, corresponding to the later stages where BIM is fully used. What data to be used can be customised to the needs of the commission, and when combined with Spatial Analytics it can provide an additional layer relevant feedback.

*Workflow Automation** allows repetitive tasks to be automated providing opportunity to focus on value adding activities. This can regard many steps normally conducted manually in any project, but when combined with an *associative design model** it can increase efficiency at an even higher rate.

Spatial Analytics is an overarching denominator for analysis methods based on spatial criteria, applicable at all scales and stages. It is usually linked to the *associative design model** and provides any quantifiable and computable data as real time feedback during the project development.

Generative Design and Optimization is the next level of *automation**, where parts of processes can be fully automated. It is especially relevant when facing a design problem where several factors influence, and even contradict each other. A generative process can also be used to produce many variants, where the designer and stakeholders can decide what factors to be prioritised.

Digital Experience and Interaction includes the broad range of immersive ways to visualise design alternatives, from stand-alone Virtual Reality environments to the merger of digital and physical worlds through Augmented Reality. When combined with Advanced Design Modelling, *the associative design model** can be manipulated by the audience in real time, providing the opportunity to experience alternative solutions.

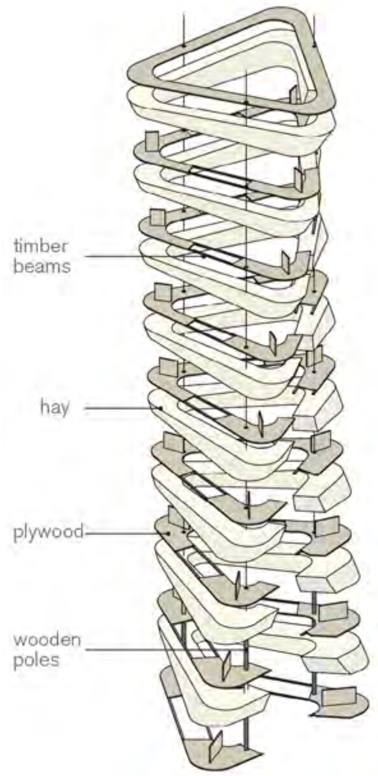
Cloud Collaboration and Computation is a way to make computational processes faster and more efficient but can also be used to improve collaboration through the exchange of data, or to allow different stakeholders to assess and contribute to the process through web-based interfaces.

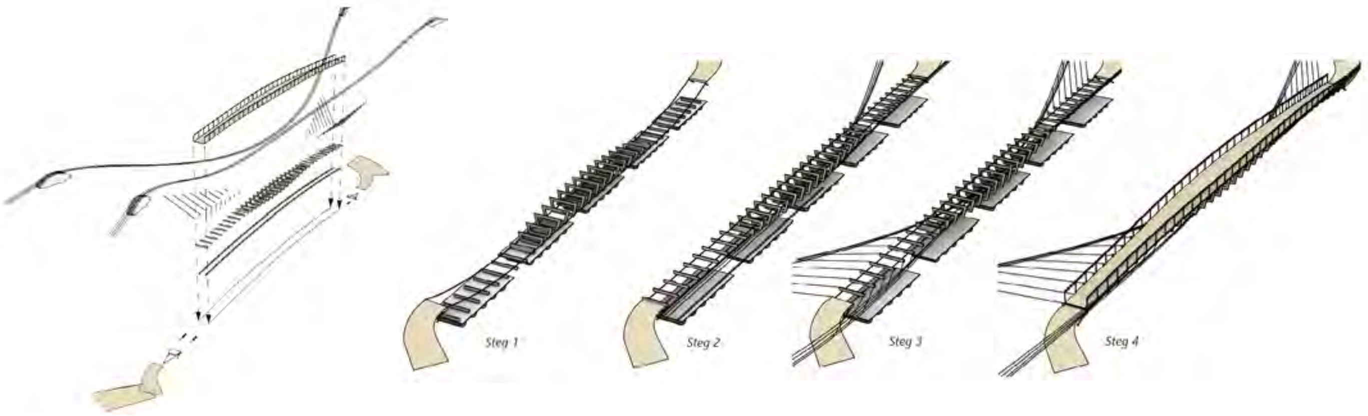
Physical Prototyping allows design alternatives to be assessed in scale models or full-scale prototypes. Computational design here allows a faster production time and more precise models and can simulate final production conditions.

Design for Manufacturing fully considers final production and construction issues already at concept stage and can follow a project all the way to detail design and delivery. Production criteria can in this way be considered as a factor from early stages, allowing alternate processes or more material efficient design solutions to be considered.

Design for Reuse allows specific material libraries to be used as assets during concept and detail design, with direct feedback on sustainability and cost informing decision making in real time. It relies on advanced design modelling and design information modelling in order to provide information rich models where the identity, status and performance of each element is documented.

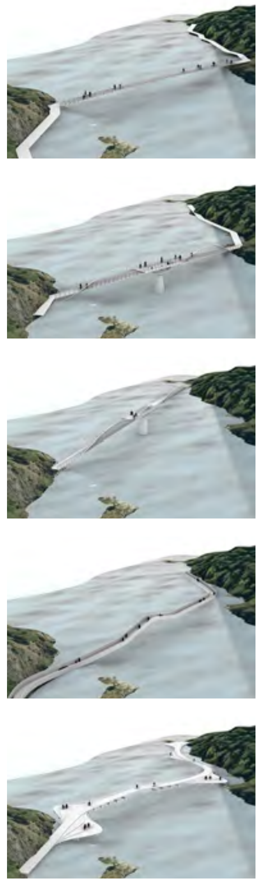
In the end the completed project tells the story. The following chapters presents 40 project situations, organised through a selection of the defined offers to further clarify how computational design can be beneficial to design teams, clients, and the successful completion of architectural commissions.





Advanced Design Modelling

The Advanced Design Modelling offer is a prerequisite for many other services if there is a need for a fully associative design model. This can depend on the geometrical complexity of the project, its performative aspects, or needs to automate the process in different ways.



Sheaf Shack with visualisation and construction logic (left page top) and physical model (top). Tyresta Pedestrian Bridge with visualisation, assembly overview and construction logic (left page bottom) and five alternative topologies generated through the computational design system (top).

At concept stage, computational design can enable rapid *design exploration** through many iterations. It also possible to include contextual or performative data to inform the process, such as topography, daylight, or structural performance. Once a *computational design system** has been set up, it can be further developed to be useful also at later stages. This can entail the consideration of new parameters emerging during the process, as well as maintaining the possibility of design changes at late stages.

SHEAF SHACK

This is a conceptual proposal for a bird watching and feeding tower and competition entry to Toronto Winter Station, for winter activation of the beaches of Toronto. The proposal combines materials used in vernacular thatched roofs with the traditional Scandinavian bird-feeding sheaf, through a simple yet robust structure in straw, hay, and plywood.

The computational design system employed a twisted construction principle to create a varied profile against the natural surroundings and to ensure good bird-watching locations in the tower. The system defines the volume, as well as the sequential layering of sheaves for rational construction and erection. The fast development was targeting the competition delivery, where the generated model was used for vector-based schematic drawings as well as perspectival renderings. A *3d-printed model** was also produced, exploring the possibility of representing the packed sheaves in a conceptual way.

The computational development supported fast iterative refinement of the form and the production of all representations in the proposal, which was nominated for the Design S Concept award 2018.

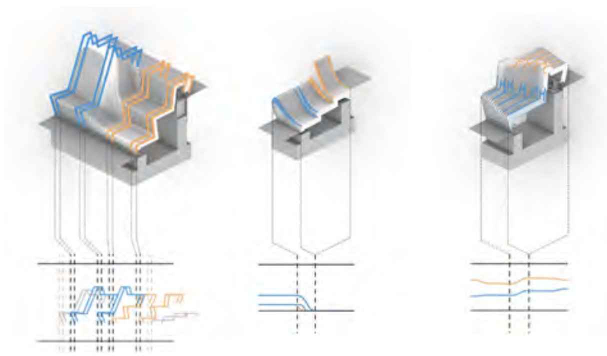
TYRESTA PEDESTRIAN BRIDGE

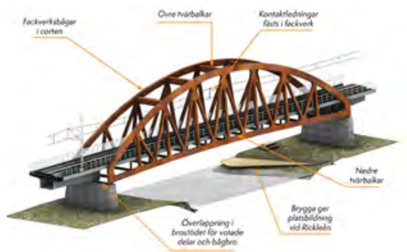
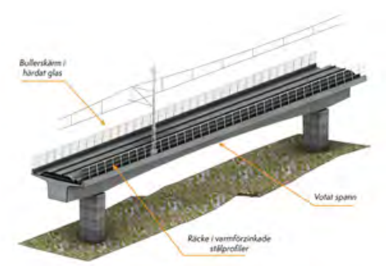
This suspension bridge proposal was a part of the 3rd prize competition entry for new entrances to the Tyresta National Park and considered the surrounding terrain as an asset in order to minimise structures and construction work in this ecologically sensitive area.

The first design system developed was used to generate ten different bridge typologies at early stage of the design process, including structural principles at a basic level and allowing parametric variation of each typology. Once the post-tensioned suspension bridge was selected, the final design system was developed, allowing refinement through *form-finding** for optimized curvature of suspension cables and deck, in alignment with the structural engineering partners.

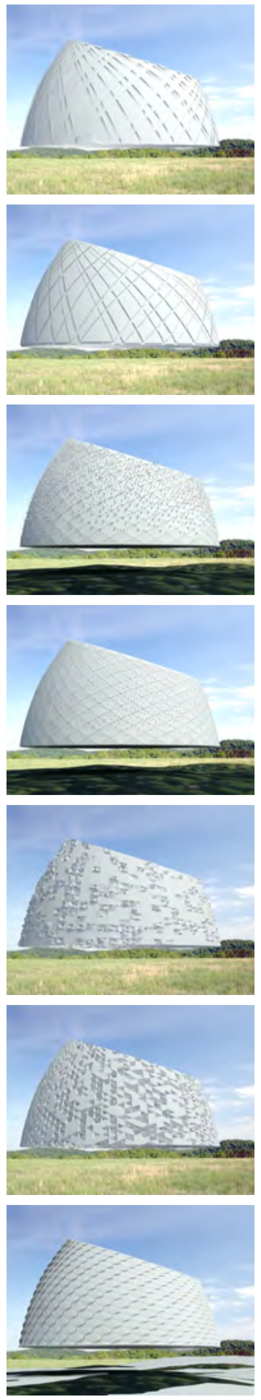
The computational development in this way allowed a rapid and collaborative design process with full control of expected performance and material use.



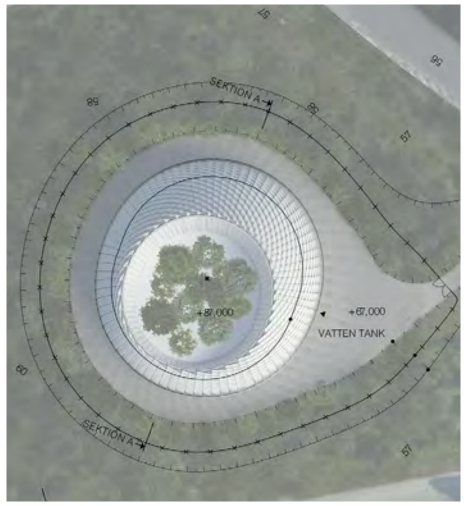



ADVANCED DESIGN MODELLING



Örebro Water Tower with visualisations, panel system (left page top left) and seven generated panel alternatives (above). Forumtorget with photograph from the square and samples of *control mechanisms** (left page top right). Robertsfors Landscape Bridge with visualisation and axonometric details of steel arch section, general section, and landing (left page bottom).



ÖREBRO WATER TOWER

This competition proposal for a new landmark water tower in Örebro was founded in the alternate water reservoir to be used, in suggesting an artificial hill format, including a protected grove of trees at the top and bird habitats integrated in the façade.

The computational design system used a series of arcs as a footprint in the generation of the volume for the abstracted artificial hill and aligned this with primary and secondary structure as well as cladding. The fast development of the design system in the rapid pace of a competition allowed not only the design of a building form, but also informed the proposal with a detailed understanding of associated quantitative data, including dimensioning, materials used and size of bird habitats.

The computational development enabled a fast collaborative design process and allowed technical details to be resolved for the complex façade system.

FORUMTORGET

This winning competition proposal for the Forumtorget Square in Uppsala included a unique 65-meter double-sided public bench as a main feature formed as a series of changing sections. Over the length of the bench, the pace and intensity of section transformation provides unique local environments for sitting and social interaction - carefully curated to provide a strong landscape element in the urban context.

The computational design system went through a long series of iterations, from the conceptual studies for the competition, to the full integration of relevant data on seating heights, production parameters and detailing used for tender and construction documents. Spatial articulation is accomplished by a large series of flat lamellas, gradually *interpolating** between the various seating *configurations**. Several *control mechanisms** were set up to allow the design team to compose and calibrate the global form and local variation, and enabled design changes in the very last stages of the process.

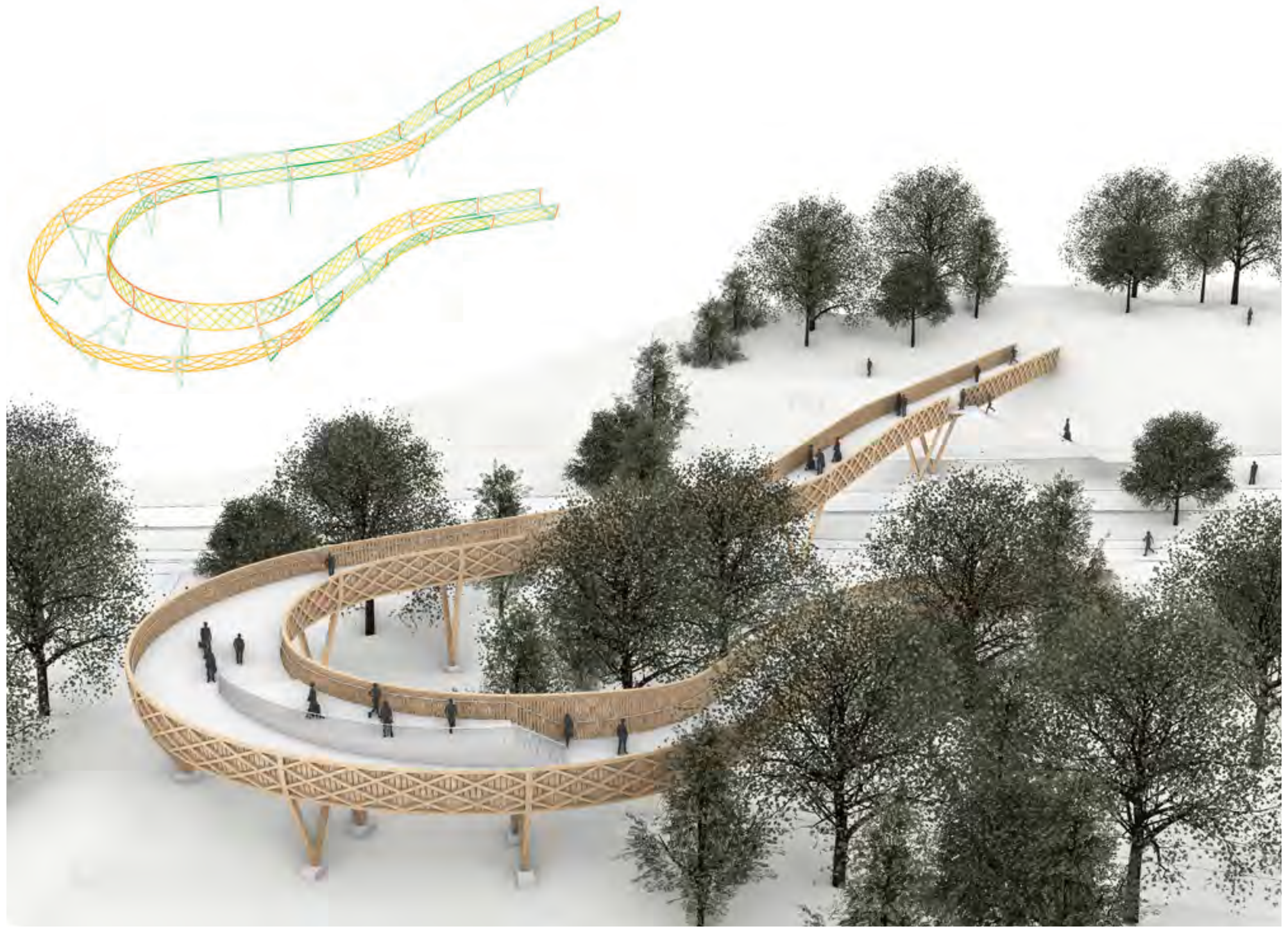
The computational development was key to the design concept, development, and final production of the Forumtorget bench, and contributed to the awarded AMP Architecture MasterPrize in 2019.

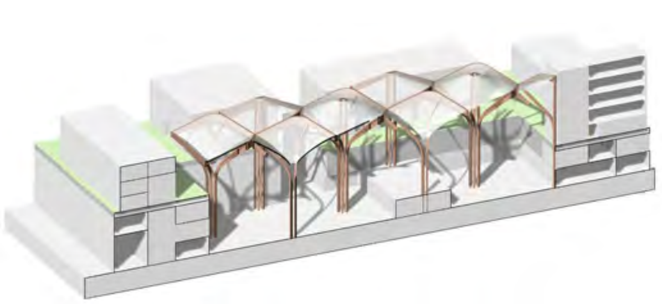
ROBERTSFORS LANDSCAPE BRIDGE

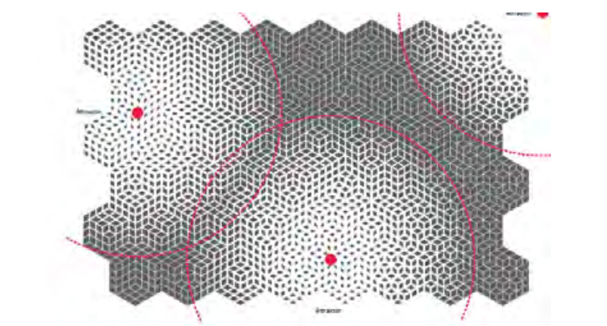
This proposal was a invited competition entry for a 800 meter railroad bridge across land in Robertsfors, as part of the development of the new Norrbotnia Line. A majority of the stretch is a slightly vaulted concrete bridge, with an articulation through a steel arch bridge crossing the historically significant river Rickleån.

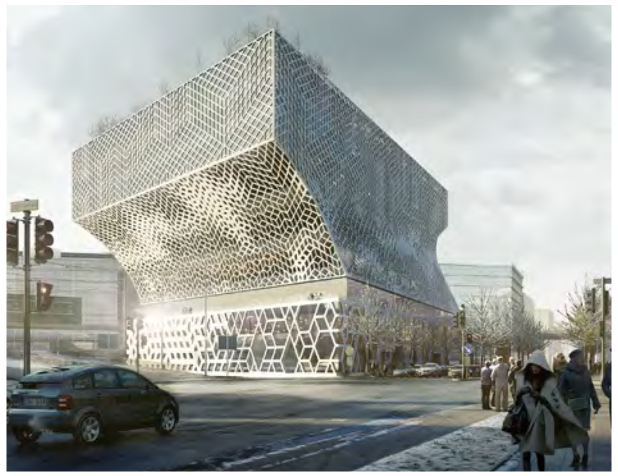
The computational design system developed allowed the terrain to be considered in detail in the generation of 14 alternate versions of the full bridge, to identify the most efficient solution regarding environmental effect, material use, and cost. The steel arch section was further developed and detailed, and the final model was used for detail drawing extraction and renderings across the landscape.

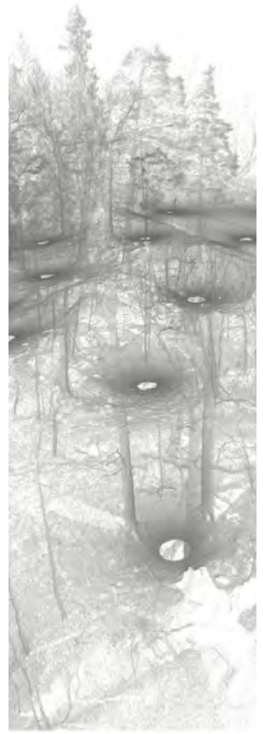
The computational development enabled the *design exploration** and most optimal responses to the formed concept, and the alignment between landscape and bridge design elements.

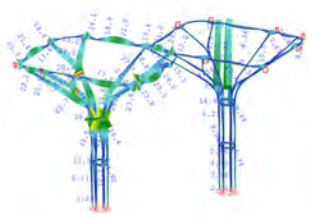


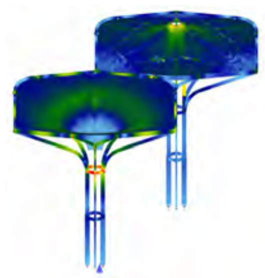












Magelungen Park Bridge with visualisation and timber layer curvature analysis (left page top) and representation of site *3d-scanning** (above top). EcoCanopy concept with visualisation and sectioned axonometric (left page bottom left), and force and snow load analysis (above bottom). Park 1 with visualisation and design system representation (left page bottom right), and model sample of façade system variation (right).

MAGELUNGEN PARK BRIDGE

The design and development of the Magelungen Park Bridge was part of the commission for a landscape design program as part of a larger residential development by lake Magelungen in southern Stockholm. The form depends on site criteria, including the need to manage the height difference between the landings, while bridging the free space above a road and a railway. The 5% maximum inclination determined by the standards for accessibility resulted in an extension of the bridge layout, curving it through a nature area. The proposal is using a curving glulam structure, where structural depth is created in the railings to manage the free height under the bridge.

The computational design system was informed by site conditions, structural principles, and fabrication conditions for curving glulam. 3d-scanning was employed to map the site in great detail, in order to carefully avoid a number of protected oak trees when laying out the bridge.[2] Fabrication data was included in the early-stage development to minimise curving glulam elements, resulting in an expected 40% decrease in lamination cost.

The computational development was crucial to the complex situation and form of the bridge and facilitated the collaboration with external parties.

ECOCANOPY

The Eco Canopy concept was an innovation project where environmental strategies and design join forces to improve energy consumption and provide all-year cultivation of plants for residential transformation projects. Manifested as a semi-climatised space between existing or new buildings, it uses residual heat from buildings, rainwater collection, natural ventilation, and heat exchangers to harvest energy and resources. Computational design was used to create several design proposals for the architectural implementation of the concept, using advanced glulam structures and double layer ETFE membranes.

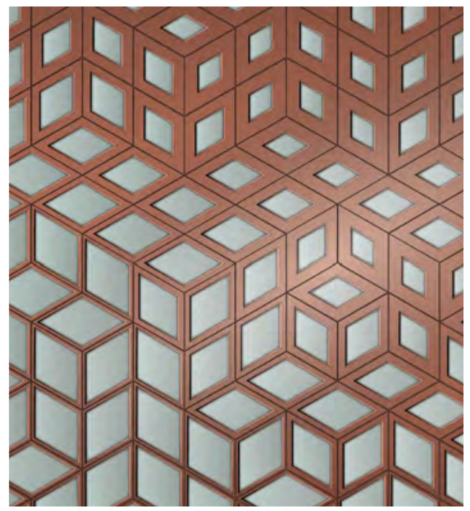
The computational design system was developed for the structural system and was linked to simulation tools for structural FEM[3] and snow load analysis conducted by structural engineer team members. It geometrically defined the bespoke modular structural system allowing full parametric control of dimensioning, allowing iterative design studies that resulted in three distinct proposals that could be evaluated against each other.

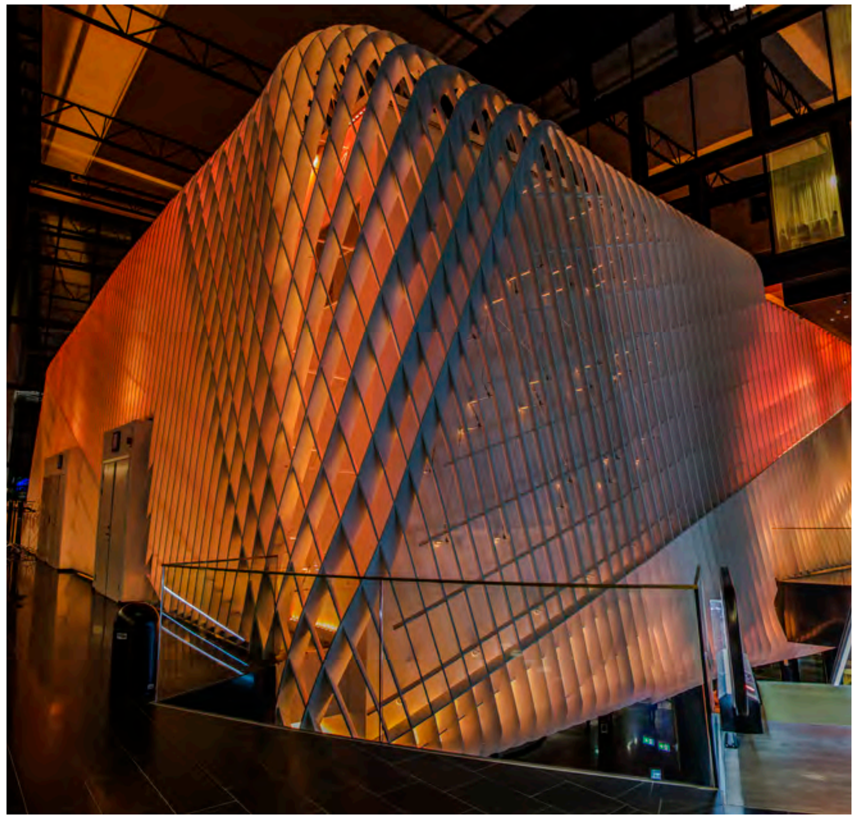
The computational development enabled the planning of the structural system, and we critical in the simulation of its performance.

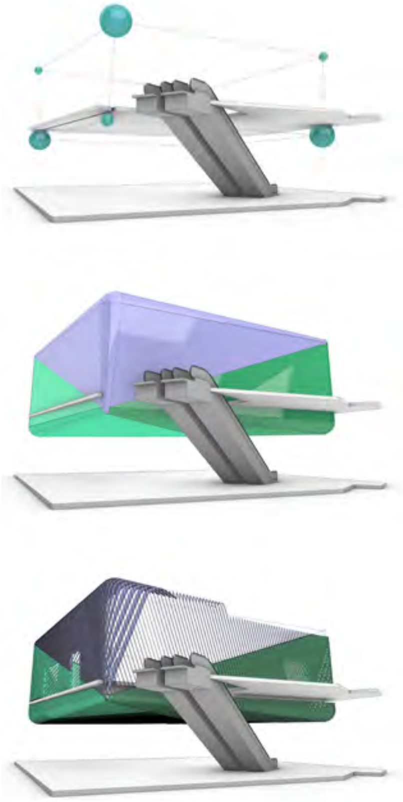
PARK 1

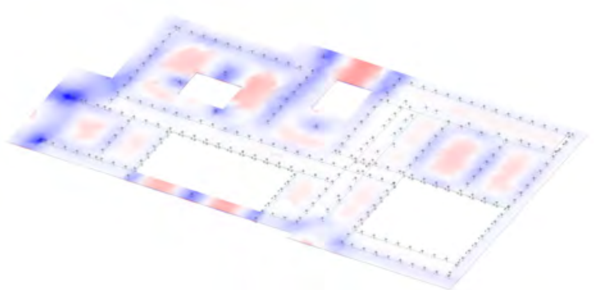
A commission for a joint traffic and emergency management centre and a new fire station for effective communication among civil services, as well as 1,200 new workplaces and a public park for increased urban biodiversity, located on Kungsholmen, Stockholm. The project underwent several iterations of its overall form and concept before the final anvil-like proposal, partially formed from considerations of the security zones of the nearby highway.

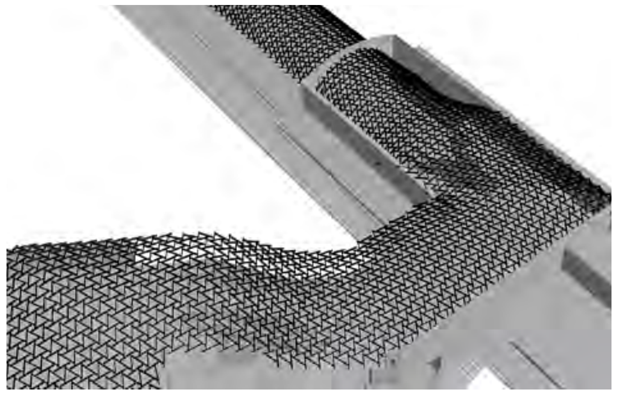
Computational design systems were used to develop the overall massing as well as the façade texture. The façade system uses two interlaced principles - a shift of pattern topologies, and a











ADVANCED DESIGN MODELLING

Quality Hotel Globe with photograph from upper level, representations of geometrical generation (left page top) and lamella system overview (above right). Skövde Crematorium with visualisation and structural analysis (left page bottom left). Barkaby Subway Station with visualisation at platform level, ceiling system overview (left page bottom right) and physical scale model (above).

gradient variation of mullion thickness, controlled by attraction points manipulated by the design team for iterative development. The texture was to be used to control daylight as well as visual accessibility to the security classified programs of the centre.

The design systems were developed in collaboration with the external structural engineering partner which enabled the design team to explore more alternatives in an informed way.

QUALITY HOTEL GLOBE

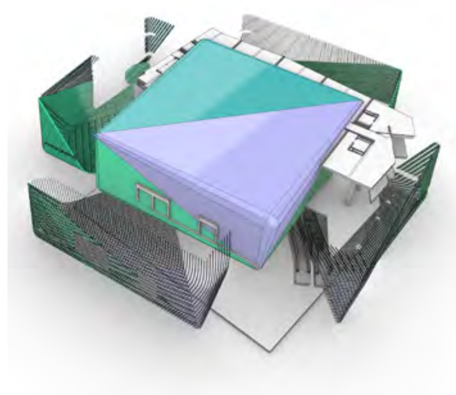
Development of a bespoke interior wall cladding system for the new entrance and adjacent lobby as part of a commission to transform an existing hotel and restaurant, covering a 400 m² / 400 seat conference / banquette space. The main objective was to provide spatial, visual, and acoustic qualities in the semi-public space of the hotel atrium, while partially disguising the conference space protruding into the same space. The design features a series of lamella panels that are oriented depending on their local position and intersect in transition zones.

The computational design system was used to develop the overall volume of the cladding, as well as the 8 lamella systems required to ensure the cover of the volume from all directions. Several alternatives were explored in a versioning process, based on the projection of linear patterns from several directions, identifying the intersection between systems to be critical.

The design systems were in this way critical for the development, production, and construction management of the final envelope.

SKÖVDE CREMATORIUM

The winning competition entry for a new crematorium for the parish of Skövde, where the design was addressing the need for consolation. This was facilitated with solemn brick structures and an elevated saw-tooth timber roof over the ceremonial spaces.



Computational design was fully integrated in the design process from competition phase and allowed structural analyses of the roof at concept stage, predictions that could be confirmed at lates stages.

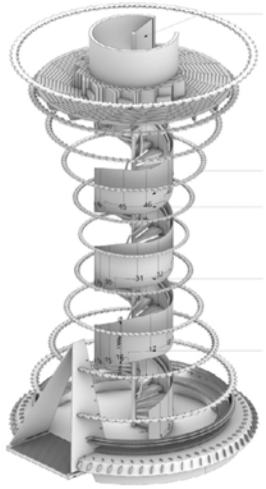
The developed design system contributed to the successful completion of the competition phase and was the basis for the design development at the next stage.

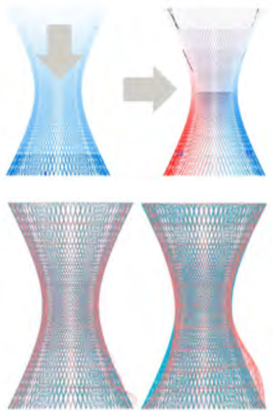
BARKABY SUBWAY STATION

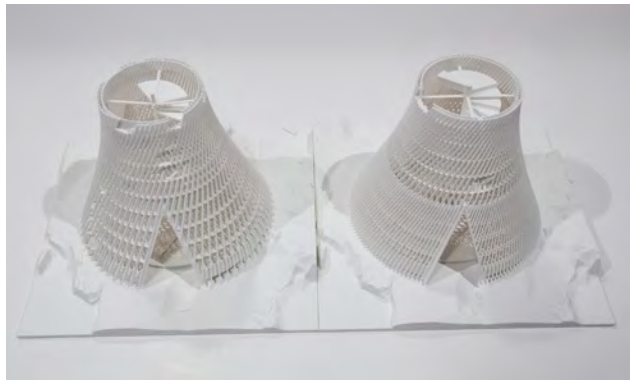
This was part of the commission for the subway stations for Akalla – Barkaby, where an alternate ceiling was considered at very early stage. The proposal consists of a reciprocal timber structure of smaller elements, deployed all through the station from the exits down to the platform, following a series of twists and turns.

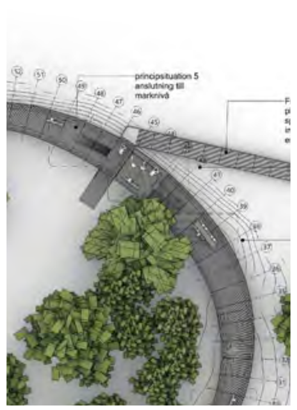
The computational design system was propagating a general geometry through *form-finding** processes to adapt it to the form of the station complex. It allowed full parametric control over the dimensioning of the elements and was also used as basis for a physical model.

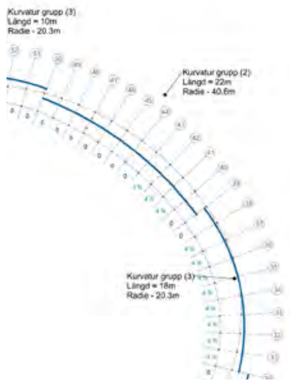
The developed design system allowed for an idea to be explored fully at concept stage and would have been a strong starting point if the concept had been further pursued.

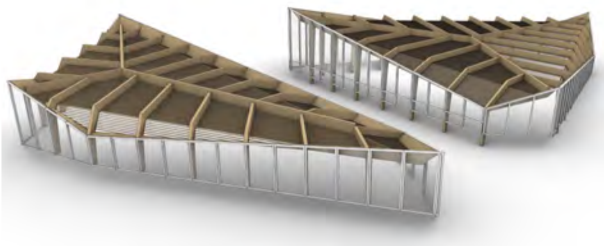


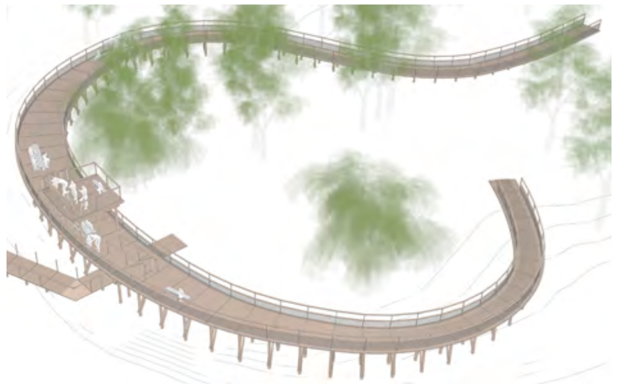


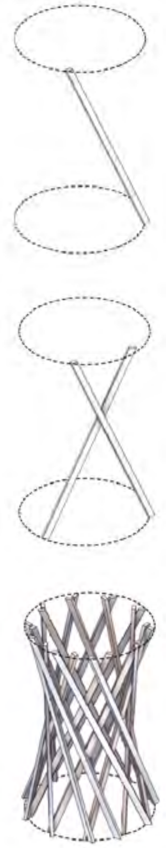












Kärven Watchtower with axonometric view of steel parts, stress and deflection analysis of timber elements, competition visualisation, *3d-printed models** of two design alternatives (left page top) and geometrical system principles (above). Grängarn Dyarna with visualisation, plan, system overview (left page top right) and construction logic for decking (right). Slussen Pavilions with interior visualisation and structural system overview (left page bottom left).

KÄRVEN WATCHTOWER

A winning competition entry for a new bird watching tower for Getterön, Varberg. The hyperboloid overall form provides a strong symbol and identity for the local nature resort, and while constructed from standard straight wooden beams, the spectacular form suggests a more complex build-up. 140 standard timber beams in two layers opposing directions fitted in a series of steel rings provide the main structure for the tower and its stair and platform.

The computational design system gave full parametric control over the geometrical *configuration** allowing *design exploration** informed by computational analysis of vertical loads and buckling. It was the basis for the collaboration with external structural engineers and was also used to produce a series of *3d-printed** physical models.

The computational development was key to the conceptualisation, and iterative refinement of the tower, and the process has been documented in scientific conference contributions.

GRÖNGARN-DYARNA

The project is a commission for upgrading the national park Dyarna in Enköping through a series of design interventions, where the main one replacing the old bird watching tower with a more accessible and aesthetic solution.

The developed computational design system managed the geometry and streamlined the workflow at different stages and allowed an agile design exploration as well as an *automated** data extraction used for tender documentation.

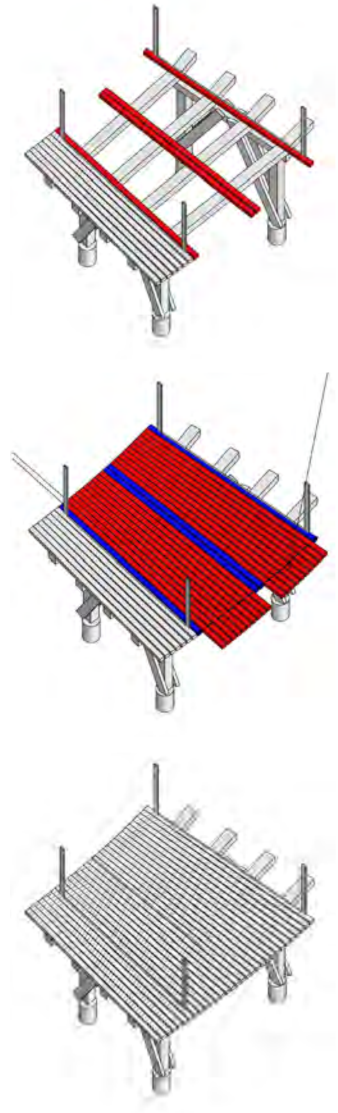
The developed design system enabled the definition of a rational solution to the complex ramp and was used to provide appropriate tender documentation where principle sections are combined with spreadsheets of material dimensions, rather than complex models.

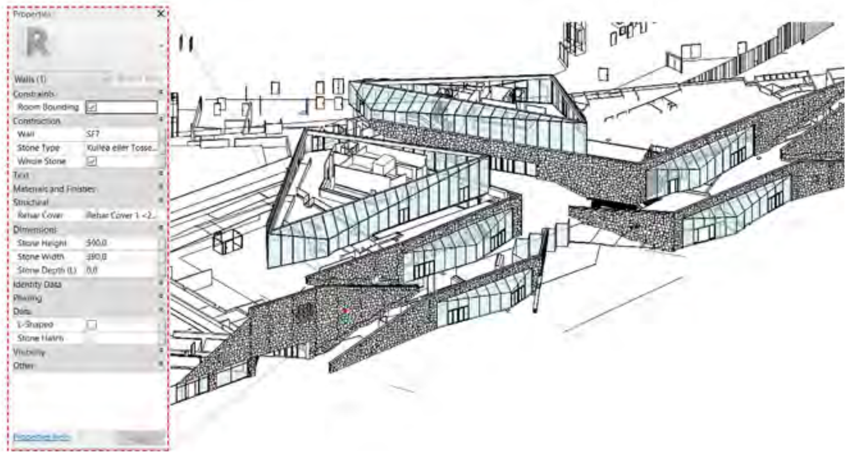
SLUSSEN PAVILIONS

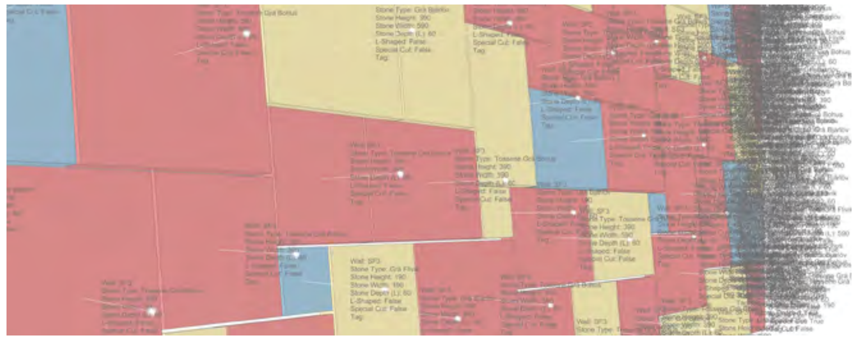
This was a late-stage development to refine the structural principles of a series of smaller buildings, as part of the transformation of Slussen in central Stockholm. The objective was to rationalise these triangular-based smaller buildings in terms of structural logic and timber element alignments.

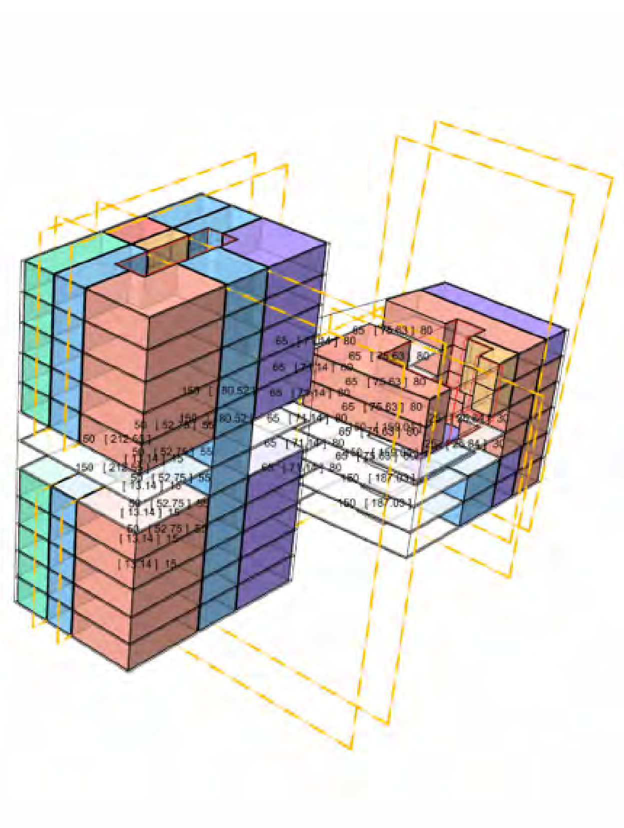
The computational design system was based on existing geometry, but introduced a new organisation of all elements, and parametric control for the exploration af alternative solutions.

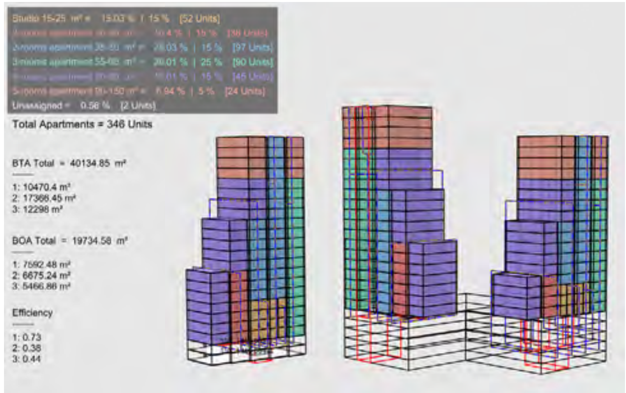
The design system was finally used to export relevant data to the detail design models of the complex Slussen project.

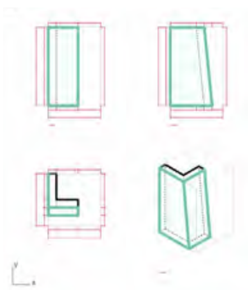


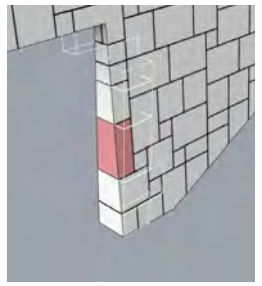












Slussen Facades with screenshot from Revit interface, element annotation in model, full-scale mock-up (left page top), visualisation and element division overview (above). Zakusala with visualisation and design system interface (left page bottom).

Workflow Automation

Computational design allows for the development of bespoke automated **workflows, where geometry and data can be processed according to a prescribed yet flexible process. This can be employed to remove repetitive manual tasks, to increase the speed of iterative design exploration or to manage complex data in a rapid way.**

*Automation** is integrated into most *computational design system** to some extents, this is in the nature of the scripted workflows, but there are some cased where more advanced automation processes can really make a difference. This can be helpful in particular if design changes need to be implemented in very short time, if large number of objects needs to be altered in a similar way, or to produce production documentation directly from the design system.

SLUSSEN FACADES

The Slussen project included a series of stone facades with very specific designs featuring a seemingly random stone pattern. The large number of stones and the complexity of the pattern provided a challenge, especially given the many factors that affected the design continuously during the process.

The computational design system was developed tackle these challenges by providing a mass-inspection tool to check the compliance of approximately 16,000 stones to the construction limitations, collect the descriptive and geometrical data, apply it to the corresponding stones and finally move the geometries carrying the *meta-data** to the detail design model in Revit. Using this system allowed for a fast-track updating to the BIM model needed to keep up with the continuous updates resulting from the complex design situation of this large-scale and multiple stakeholders project. The design system also facilitated auto-generated tender drawings for the hundreds of unique stones that do not follow specific stones' templates.

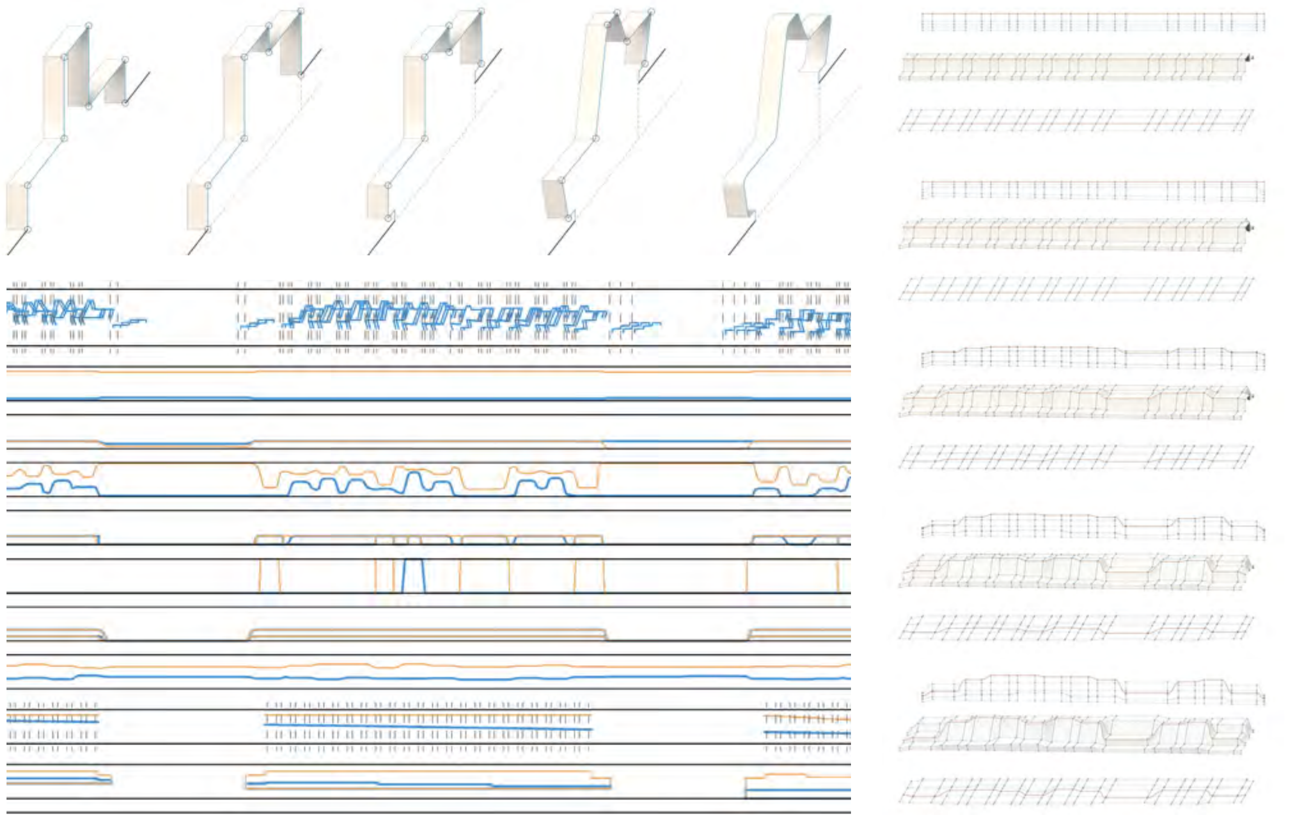
The design system was aligned with the process of the overall Slussen project and ensured a fast yet reliable workflow including architects, landscape architects and structural engineers.

ZAKUZALA

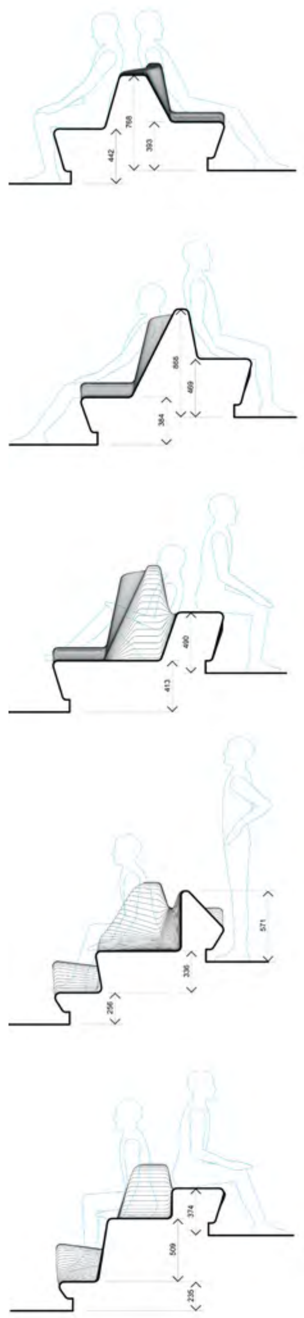
Proposal for an invited competition for an adaptation of existing office building proposal into residential buildings on the Zakusala island in central Riga, Latvia. The proposal enhances social sustainability by balancing the private home and the neighbourhood, through community building features.

The computational design system was developed to facilitate the mapping of the project program onto the envelope using flexible guides to create the potential spaces, identify the potential use for each space, report the total figures and metrics and evaluate the performance according to the compliance to the project program. In a later step, the system also helped with the panelization of the facade to allow design exploration of different options in a fast and efficient way.

The design system was developed aligned with the competition team and was as a toolkit to speed up and inform the collaborative process.



WORKFLOW AUTOMATION



FORUMTORGET

During the iterative development of the Forumtorget bench, the global form was controlled through a set of *control mechanisms**, in principle contour lines in plan and section. The full digital model was created from these lines through the automated generation of each of the 3000 section curves each automatically divided into one glass and one quarts composite lamella. This allowed a manual sketching procedure for sensitive composition to be directly reproduced in the model, where representations such as dimensioned cross sections or volumetric renderings could be extracted automatically.

The model creation also featured a set of verifying processes that checked the model to ensure that errors could be avoided. Besides this design approach, the computational design system was also used for the automated production of the production documents, where the cutlines for each of the 6726 elements were generated, and the assembly documents to guide the contractor were created.

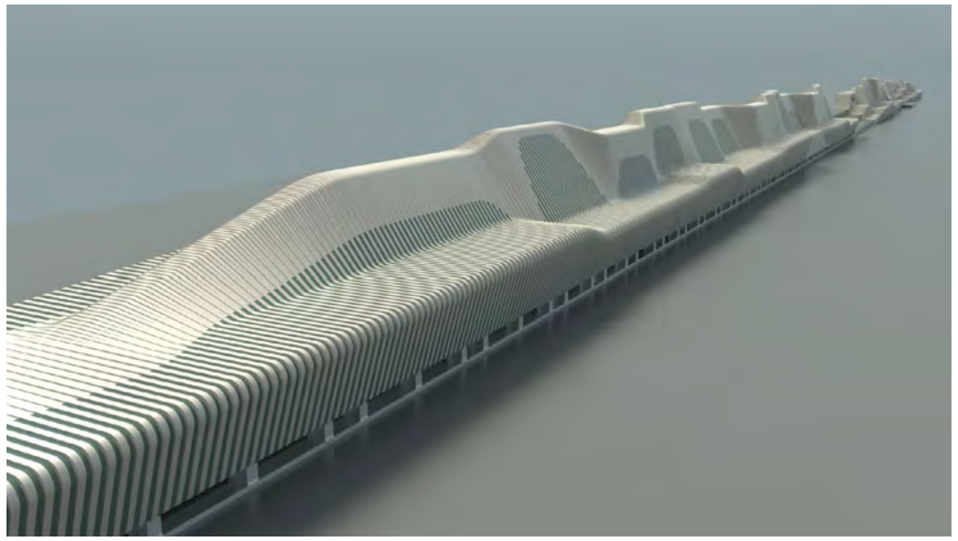
The design system automation in this way assisted in the management of all aspects of the project, and enabled the implementation of design changes up until the point when the production documents were created.

BERGEN BYSTRAND

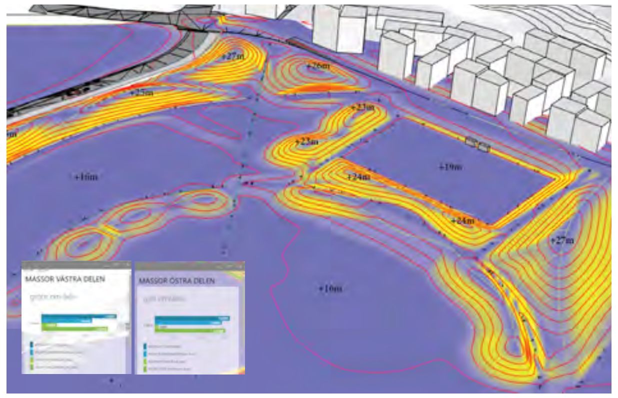
Bergen By Strand was a large-scale landscape competition win for the development of Bergen's new city beach and city park at Store Lungegårdsvannet. The almost one-kilometre-long park will be the city's new landmark, where residents can experience the different characteristics of water and nature in all seasons.

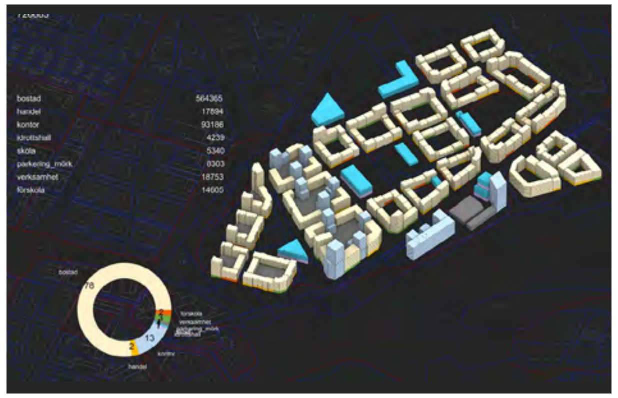
A computational design system was developed to streamline the process of building a detailed 3d model out of 2D drawings using a few sets of geometrical and graphical logics. The workflow starts by the creation of a modelling dictionary functioning as a mediator between the landscape architect and the 3D model. 2D curves are retrieved, categorised according to the dictionary, and the 3D geometry is created depending on dictionary type (extrusion, hard surface, soft surface et.al.), and trees are added. During design development the design system automatically updates the 3D model, which also can provide a data rich IFC export when needed. The design system also allows for instant analytics such as slopes and local and global mass calculations.

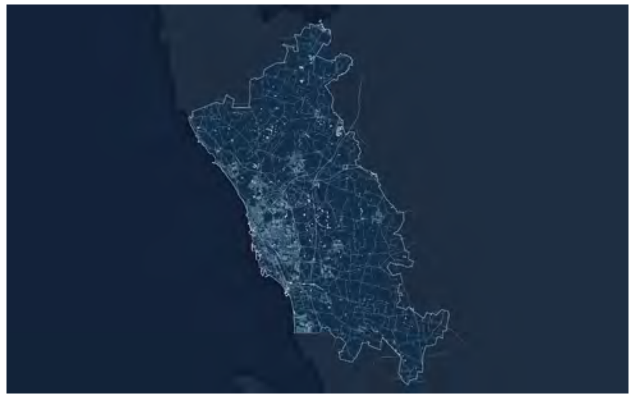
The development team developed the workflow iteratively aligned with the team of landscape architects, which allowed a sped-up modelling process and increased control over the topography.

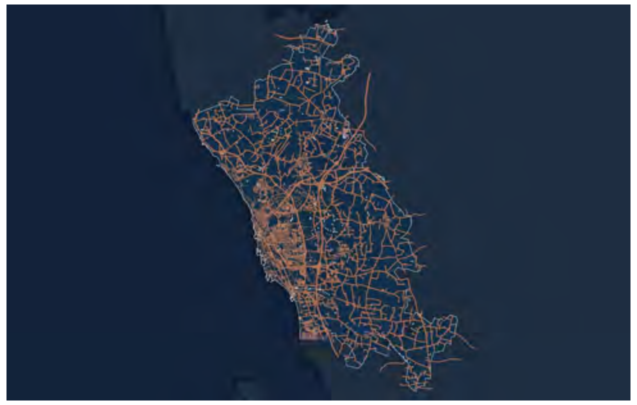


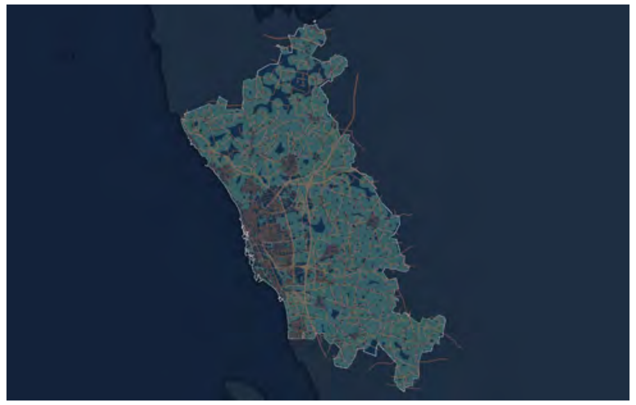
Forumtorget with sectional geometry buildup, *control mechanism** curves and step-by-step transformation of global bench articulation (left page top), samples of the automatically produced cross sections with scale figures and rendered view of generated design model (above and right). Bergen Bystrand with rendered visualisation and samples from the design model (left page bottom).

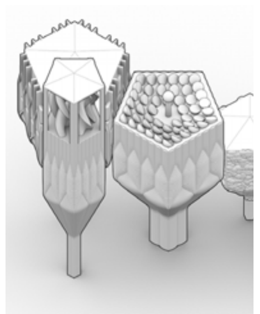












Årstafältet Soil Masses with visualisation of the proposed ridge landscape and the computational design system interface providing direct feedback (left page top left). Urban Values Backaplan with two versions of the computational design system interface (left page top right). H22 Interstitial Towers Site Location with Helsingborg maps with filtered data (left page bottom), a sample site as a result, and a visualisation of the Interstitial Towers (above).

Spatial Analytics

Computational design allows the bespoke association of data and geometry, allowing real-time calculation and quantifiable feedback.

Spatial analytics includes a range of analysis approaches that can be defined as part of the development process. Most frequently it refers directly to aspects that can be measured from the created geometries and processed directly within the computational design system without need to link this to analysis software.

ÅRSTAFÄLTET SOIL MASSES

During the landscape commission for Årstafältet, Stockholm, the masses of soil from adjacent residential construction projects were considered as assets for the transformation of the public park. The proposal featured a series of ridges that introduced alternative microclimates for biodiversity as provided noise protection from nearby traffic.

The computational design systems provided an interactive design tool for the landscape architects, with real-time feedback on the current use of soil masses, as well as slope rates for accessibility and assessment of view lines.

The design system enabled an efficient design process where real-time collaborative sessions could be conducted with stakeholders, and if the approach would have been fully implemented dramatically increased level of sustainability would have been achieved.

URBAN VALUES BACKAPLAN

The Urban Values design system has been developed iteratively over several projects and allows real-time feedback on key metric during early-stage urban design development. In the Backaplan project it facilitated the management of 700 000 square meters divided between eight programmatic types and seven developing property owners.

The computational design system allows *direct modelling** or automated generation of geometries, and a *user interface** providing the user to input key parameters, get direct visual feedback on property and program division in the model, and to extract reports.

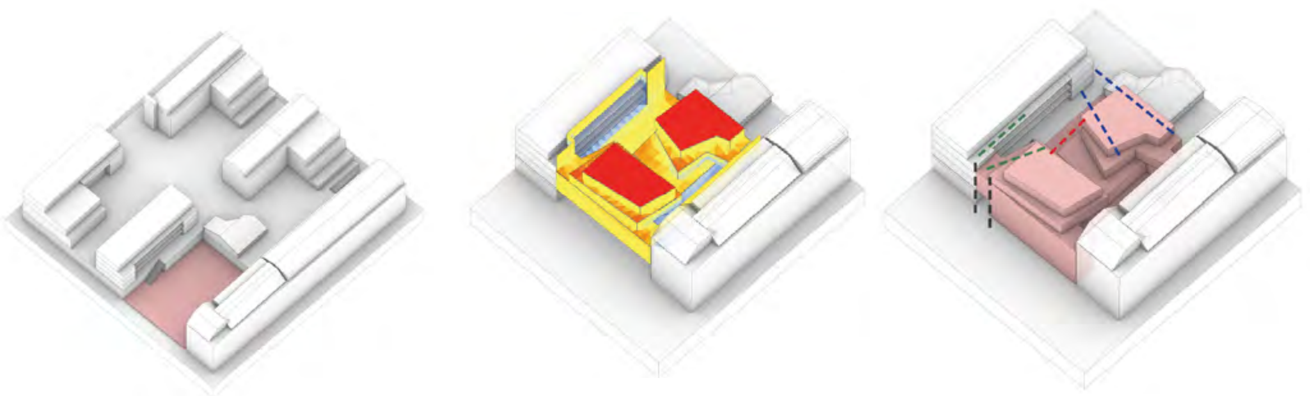
The Urban Values design system was developed iteratively between projects with further refinement for reach iteration, allowing more informed decision making.

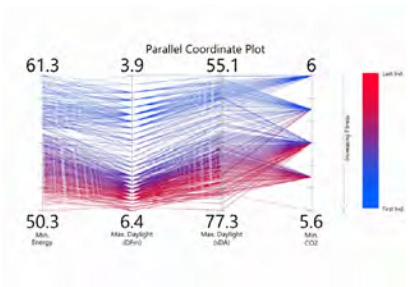
H22 INTERSTITIAL TOWERS SITE LOCATION

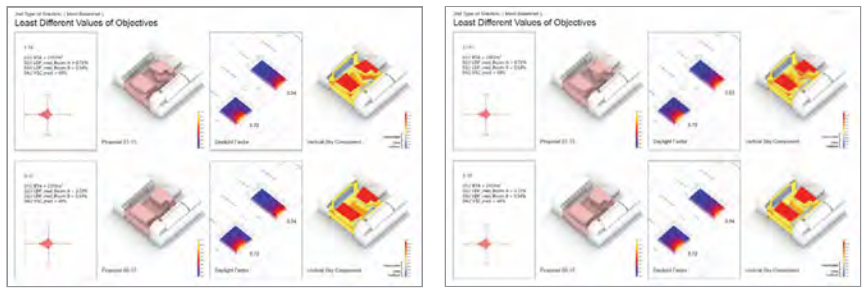
Interstitial Towers is a speculative design project for alternate typologies providing increased biodiversity and local energy production in suburban contests.[4] It has also been used to develop and apply a range of design and analysis methods, including site identification through the automated processing of geodata. As part of the H22 event in Helsingborg, the methodology was applied to identify 150 potential sites for the towers.

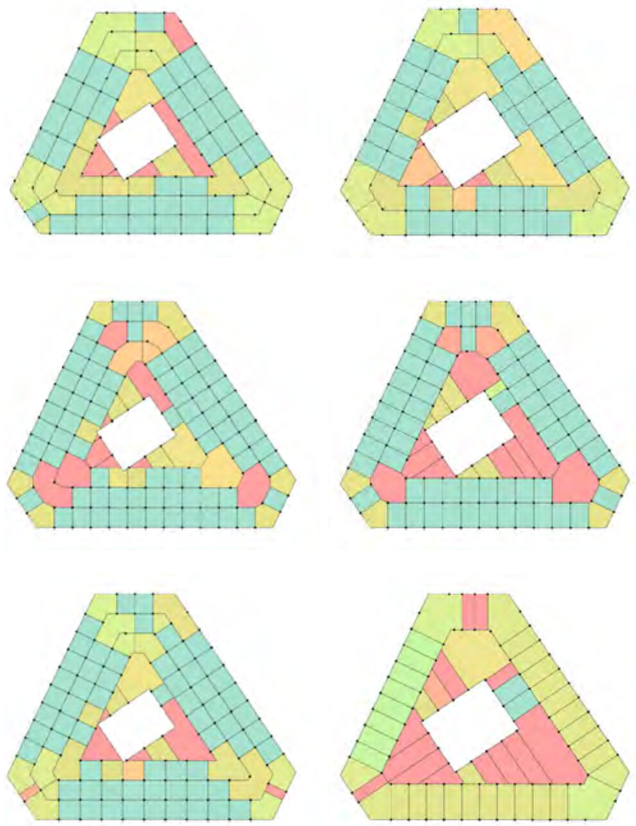
The design system filters geodata in GIS-software[5] considering aspects such as street type, property borders, building adjacency and freshwater proximity for site assessment. Geometrical data is then transferred to design models for automated deployment of digital tower models.

The design system uses real-time connectivity between geodata models and design models, and in this way enables parallel studies at regional and architectural scales providing more informed design decisions at both scales.









Njord, with the defined infill plot, a general daylight analysis, a diagrammatic view of the outcome of the generative process, as well as the parallel coordinate plot and a selection of instances from the process (left page top). Makasiiniranta with visualisation and six instances of the generated structural system (left page bottom).

Generative Design & Optimisation

Generative design can be used to enhance productivity and resolve complex design challenges at all scales and stages, where conflicting design goals can be assessed through multi-objective optimisation.

In this way, they can be applied for specifically challenging tasks, where they allow a designer to get a better understanding of the situation, and to balance sometimes contradicting goals in an informed way. The framework developed at White builds on existing plugins for multi-objective optimisation, where selected *solvers** take control over relevant parameters, and the *automated production** of a very large number of solutions.[6] Each solution is assessed either through simple mathematical analysis (e.g. measuring an area) or more complex simulation (e.g. a simulation in simulation software). The solutions are refined as they are evolving through the process and are represented in a Parallel Coordinate Plot and can be assessed against each other through a combination of automated filtering (removing solutions beyond the scope), and visual assessment by the designer.[7] In this way, the framework provides a set of tools that allows the designer to assess and weigh different solutions against each other.

NJORD

In the external commission for Njord, the design architect faced challenges when trying to fulfil daylight requirements as well as the required new areas for an infill plot in Uppsala.

In the generative process the computational design system sought to maximise new building area, daylight for existing buildings, daylight for remaining courtyard and the vertical sky component[8] for the new building. The delivery included a set of optimized high-performing solutions from which recommendations for massing and building materials were concluded in a summary report.

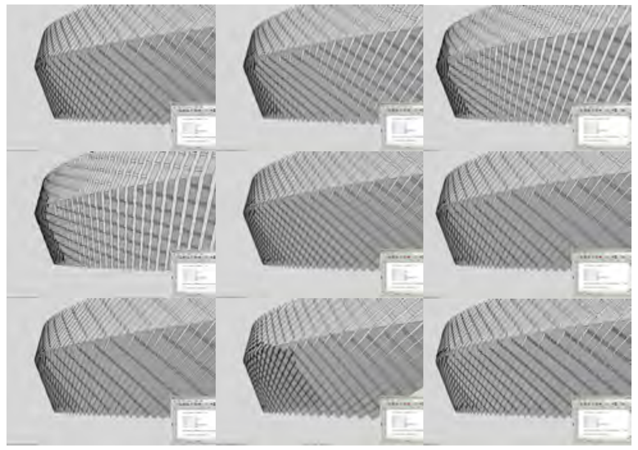
The design system was developed in direct response to the provided design concept and delivered an informed design strategy for further development.

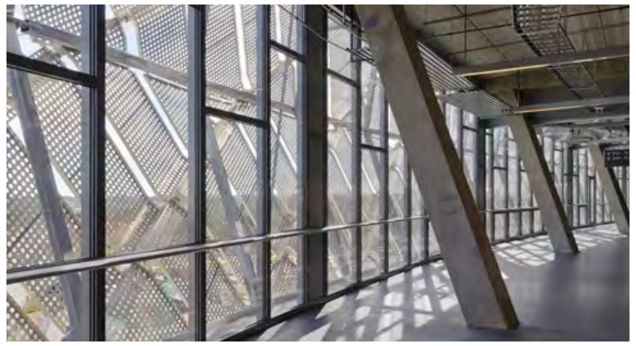
MAKASIINIRANTA

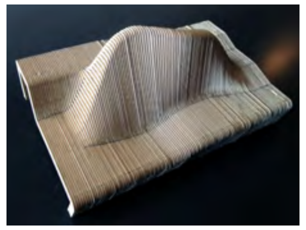
The winning competition proposal for Makasiiniranta, the development of a quayside area in Helsinki, features as set of triangular blocks with truncated corners, and interior atrium or courtyard spaces. The unusual base geometry had no obvious structural system approach and required *design exploration** to identify the most efficient to organise the buildings.

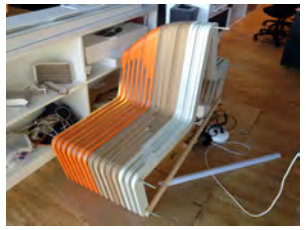
The computational design system was set up to parametrically control the form and size of the atrium, and the general *configuration** of two structural orders (aligning to triangular block footprint and atrium rectangular form respectively), where a formula for the calculation of spatial efficiency was defined.[9] In the generative process, this spatial efficiency was measured against the total floor area, and a series of principle solutions were created to be used as a guide in the continued design development.

The design system provided alternative structural frameworks as a basis for the further refinement of program division, allowing an adaptive approach throughout the design process.









Tele2 Arena with nine instances generated through the computational design system, the completed mock-up, and interior view photo of completed façade system (left page top). Forumtorget bench with *3d-printed model** at 1:20, laser cut model at 1:10, light study model at 1:2, and full-scale prototypes (left page bottom).

Physical Prototyping

Physical prototyping through scale models and full-scale mock-ups can identify and resolve key issues in terms of design qualities, production processes and assembly steps, to improve design and make construction more efficient.

Computational design can allow physical prototyping to be conducted iteratively during the design process, with more precise models and mock-ups. It also allows final production methods to be simulated, following direct file to factory workflows.

TELE2 ARENA

The façade membrane of contemporary arenas provides a uniform figure and identity relevant to its massive scale in urban environments, where its internal structure might otherwise seem more industrial.

For the Tele2 Arena this membrane was studied iteratively through the computational design system, where ease of construction, expression, and articulation where main factors. The geometrical principle followed a diagonal distribution of identical panels, where the fittings were adaptive for different local conditions. To ensure the architectural qualities, including the transparency facilitated through perforations of the aluminium panels, as well as buildability, a full-scale mock-up of a section of 15 full or partial panels was commissioned, again based on the *configurations** of the design system.

The use of the design system and the full-scale prototype provided a better understanding of the complexity of assembly and was the basis for a simplification of the design.

FORUMTORGET

The design development of the Forumtorget bench relied on one hand on the iterative development of the computational design system itself in terms of its advanced design modelling, and on the other on a series of scale models and full-scale mock-ups.

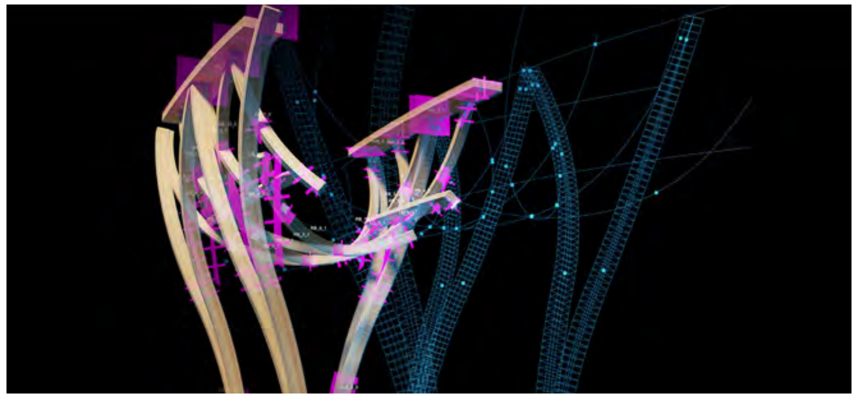
The articulation of the bench was from competition stage defined as a series of uniquely formed flat lamellas, that were always expected to be produced through subtractive CNC machining.[10] This provided the opportunity to work with laser cut models to explore design qualities as well as fabrication and assembly issues, both at global scale, and more detailed for sections of the bench. Two full length scaled models at 1:10 were also *3d-printed** for design reviews with clients and stakeholders. To develop and refine the production methods, four partial full-scale mock-ups were produced, initially in placeholder materials, but at the latter iterations in the final quarts composite and glass materials. One of these prototypes were also placed on the Forumtorget square, providing the opportunity for feedback from the community.

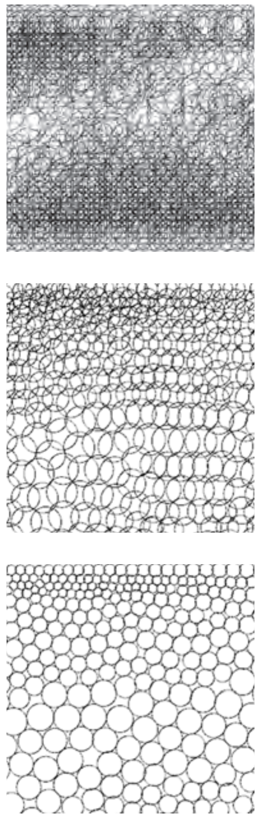
The design system allowed simplified production of all models and mock-ups, which was crucial for the design exploration and informed the final production.











Sundsvallsbron Suicide Protection with visualisation of two alternative fences generated through the computational design system and climbing tests on the full-scale mock-up (left page top left). GoDown Cultural Centre with street view visualisation, 1:50 laser cut model, single panel of cull-scale mock-up (left page top right) and steps from the *circle-packing process** (above). Magelungen Park Bridge with view of design system model and mock-ups under production and in exhibition display (left page bottom).

SUNDSVALLSBRON SUICIDE PROTECTION

This commission for a new suicide protection fence for the Sundsvall Bridge regarded full protection on both sides of the ca 1400-meter bridge. It was decided that the new railing would completely replace the existing railing, with a minimum free height of 2000 mm.

The computational design system allowed design exploration of a large number of profiles for the fence and allowed a detailed fence to be generated for the full length of the bridge for visual assessment. Given that a new design not tested in in Swedish conditions was considered, the client also asked for two alternatives to be produced as full-scale mock-ups.

The mock-ups were manufactured from documentation produced via the design system and were test climbed at a local site in Sundsvall, providing the necessary understanding to make informed decisions on the performance of new types of suicide protection.

GODOWN CULTURAL CENTRE

The façade for the GoDown Cultural Centre in Nairobi was of particular importance for the future identity of the centre. The technical solution fulfilling climatic and security needs involved a glazed façade partially covered by a perforated weathered steel panel system providing the opportunity to add articulations. After a series of collaborative workshops, it was decided to use satellite imagery of the nearby Great Rift Valley as a motif, as a play between geological perspectives of nature and culture.[11]

The design system employed the computational techniques of *circle packing** to mediate from pixelated image to aperture through *image sampling**,, followed by Voronoi subdivision[12] allowing apertures to be maximized. The design system allowed the sizes of apertures to be informed by simulations for insolation and thermal comfort, as well as the automated generation of panels.

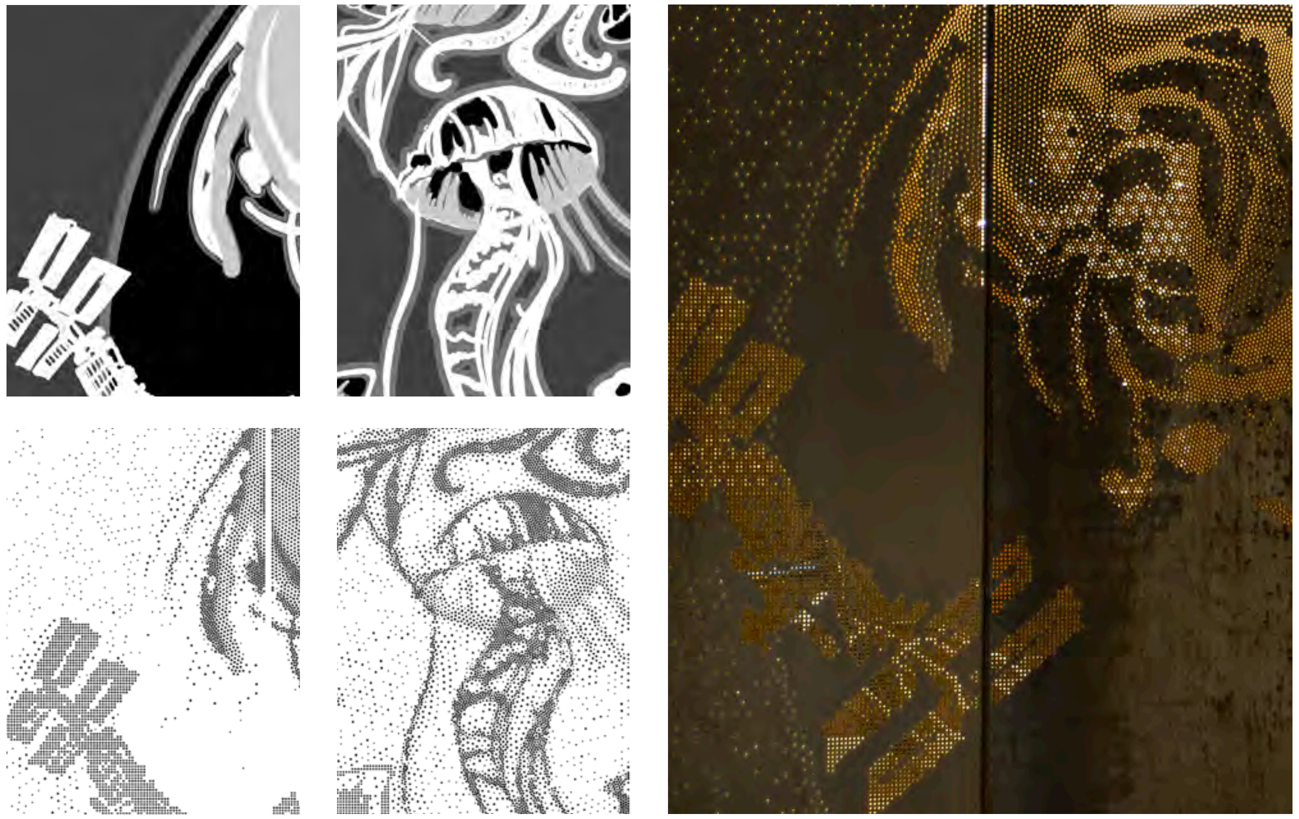
In order to fully understand the visual performance of the façade, a series of scale models and full-scale mock-ups were produced, directly from the design system. The use of physical models and mock-ups allowed an improved understanding of the expected visual and aesthetic performance of the façade.

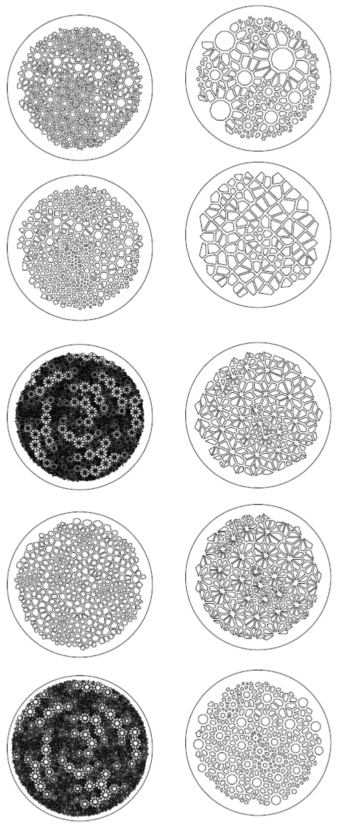
MAGELUNGEN PARK BRIDGE

The development for the Magelungen Park Bridge was conducted in collaboration with an external research partner as part of the InnoChain Training and Innovation Network.[13] This allowed on one hand that simulation procedures for the material curvature in glulam beams at individual sheet level could be integrated into the computational design system, but on the other it also opened the possibility to work in performative physical models.

To explore the limitations of curvature, an alternate design was developed by the researcher, with bespoke fittings and more extreme use of curving glulam beams. An important part of this development was the production glulam a series of scaled mock-ups in which lamination processes and detailed fittings for curved elements, first in the design system, then in the material mock-up. The mock-up was presented as part of the final InnoChain exhibition and appended as references in the design program for the bridge.

The production of full-scale mock-ups further informed the design decisions in the project, and the computational workflows have also been published in several academic publications.[14]





Sediment with photograph of one of the 16 installed screens, and two samples of artist image and cutting pattern generated through the computational design system including dynamic and orthogonal grids (left page top). Woodland Table with photograph of three versions of the table at different heights and cutting pattern for 10 alternative versions (left page bottom).

Design for Manufacturing

Manufacturing aspects can be a factor in development already from the concept stage of a project, or it can be a later translation of a design proposal to manufacturing data. In the final stage, all relevant manufacturing documentation can be automatically exported through a well-developed computational design system regardless of when they were introduced.

Design for manufacturing considers the specific production principles for digitally controlled production tools and the necessary workflows and management surrounding this as assets in the design process. *Computational design systems** can automatically produce the relevant production data and document how individual elements are to be assembled. In extension, this approach can provide opportunities for alternative contracting processes or even business models.

SEDIMENT

Sediment is a public artwork if 16 screens located along a 300-meter walk cutting through the campus area of Luleå University of Technology. Drawing inspiration from Charles and Ray Eames's short film Powers of Ten and science communicator Carl Sagan, the series presents a story of a journey from the bowels of the Earth through sediments of soil, biosphere, and stratosphere, towards the solar system, the Milky Way, and the end of the known universe.[15]

The computational design system developed operated as a translating mechanism between the 16 unique images produced by the artist using, and the digital information required for production. It captures the details of the images while at times producing more neutral parts by a dynamically transforming grid through the use of *image sampling** and *circle packing**, combined with orthogonal grids.

The design system provided a rational management of the complex image data, and was used to produce the final production documentation, enabling an efficient manufacturing process of the 16 weathering steel installations.

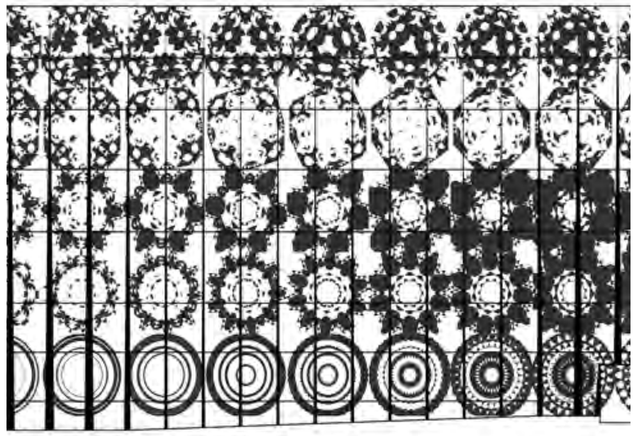
WOODLAND TABLE

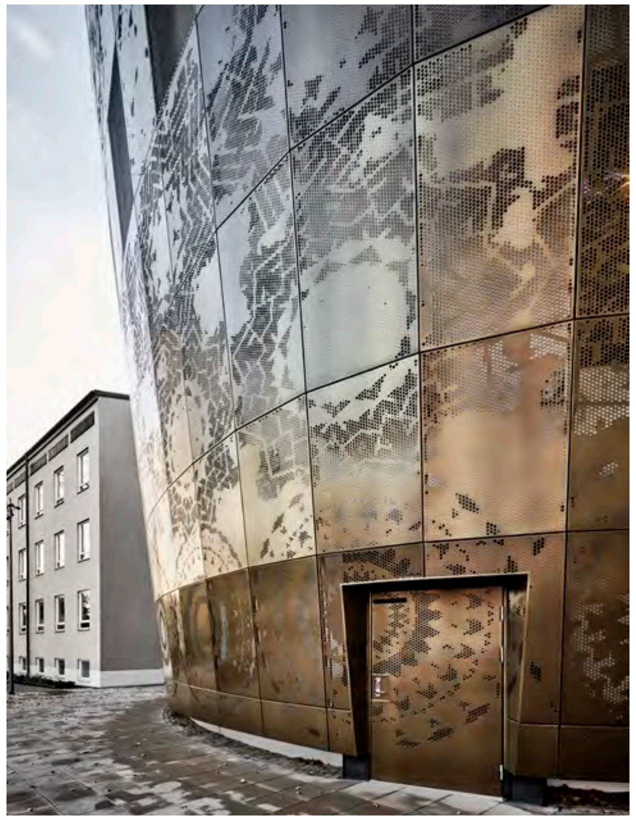
Developed specifically for an exhibition on the use of timber, the Woodland Table was designed to represent the inner fibres of timber through a projected pattern on a wood composite tabletop. The computational design system provided a series of unique perforated patterns, controlled to have a maximum aperture size not to allow objects to fall through. The tabletop and its pattern, as well as the table legs were produced in a 3-axis CNC-router[16] directly from the digital model.

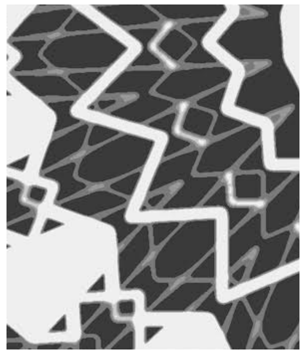
The principle of production where all elements were produced from flat wood fibre panels (MDF), also allowed the table to be delivered as flatpack, to be assembled on site. Additional instances of the Woodlands Table were produced after the exhibition.

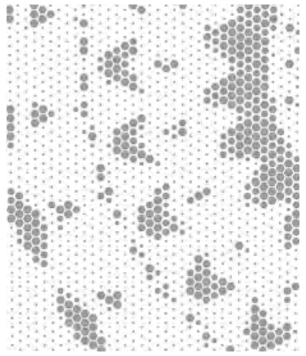
The design systems provided a direct and automated workflow from table pattern design to final production, enabling an efficient yet bespoke delivery of the tables.

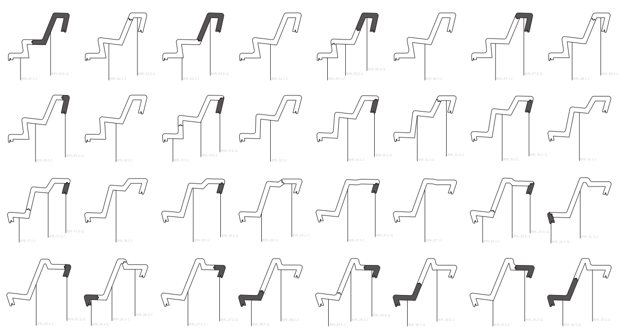
DESIGN FOR MANUFACTURING



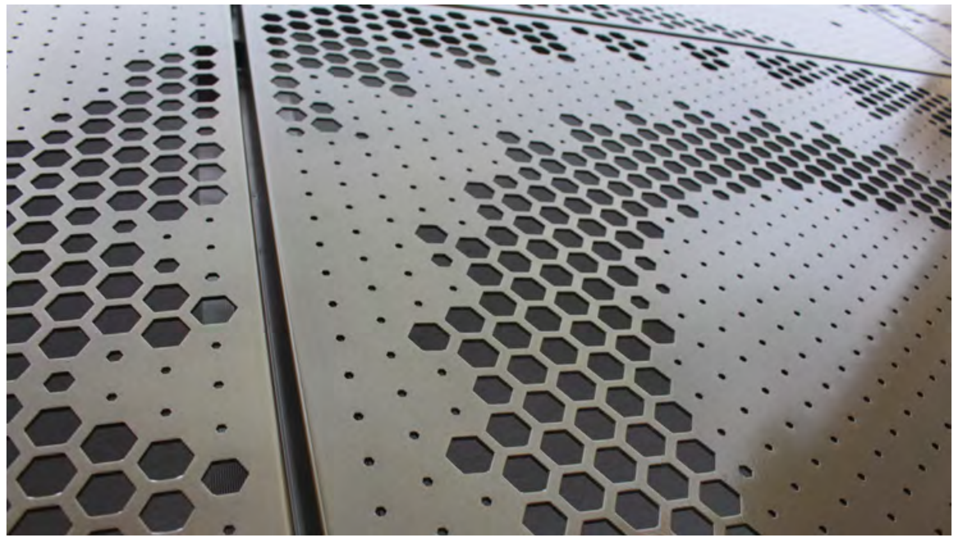








Humanistiska teatern with photograph of final façade, the pattern translated to the façade geometry in elevation, and samples of prepared artwork and generated cut pattern (left page top), and detail of perforations (above right). Forumtorget with annotated cut patterns for lamellas, quarts lamella production in water jet, module assembly and test setup, test prototype with handrest, module installation with bespoke lifting tool (left page bottom), and selection of *nested** elements of glass lamellas (above).



HUMANISTISKA TEATERN

The outer façade of the Humanistiska Teatern auditorium is in itself a public artwork, where the black and white graphic artwork, derived from video stills, is translated from a line- and surface-based original to a pointillistic pattern of punched hexagons using *image sampling**. The translation of the pattern to the building brings an additional layer of concretion – relating to building shape, apertures and panelization.

The computational design system was set up to translate the artistic intent of sharply edged abstract geometry to the medium of coarsely patterned building façade and was developed iteratively in order to define appropriate pattern dimensioning and the adaptation to the slightly conical form of the building through the use of a non-orthogonal tapering grid. Alignment with the artist were conducted through visualisations as well as physical prototyping, and final production documentation was produced directly from the system.

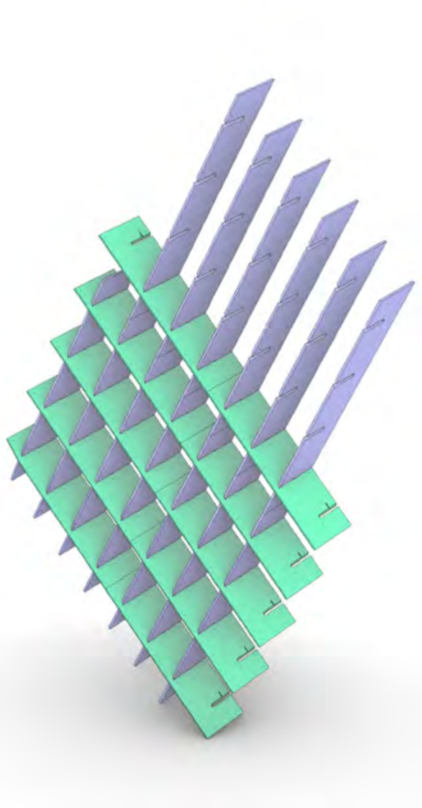
The development and use of computational design systems allowed for the production of bespoke façade panels with no negative interference on the overall building construction process, and the high level of refinement contributed to the award of Design S in 2018.

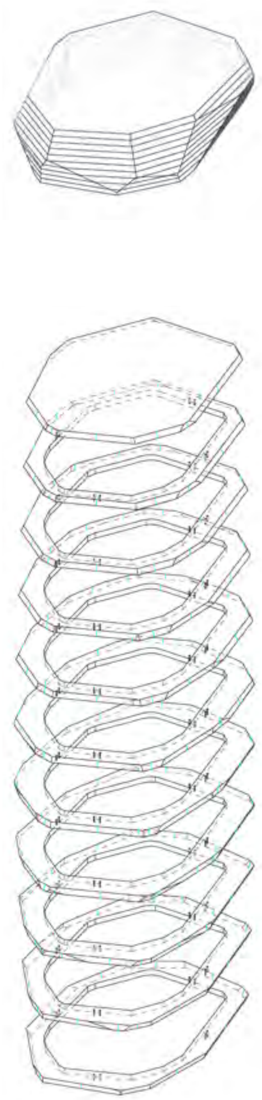
FORUMTORGET

With a design process dependent on the computational design system, and series of physical scale models and full-scale mock-ups, the Forumtorget bench was designed for manufacture from the very start. It was fabricated and assembled in modules off-site, a process which included both automated fabrication principles and manual fitting using jigs.

The final development after tender, once the contractor was in the team, considered production aspects at great detail. This included the technical specifications of the CNC waterjet cutter used for element production, where production time could be shortened by the use of simplified geometrical information (lines and arcs, rather than more complex curvature).[17] The design system automatically reoriented all elements from the 3D-model in preparation for production, tagged according to the agreed upon naming convention, and the cutting patterns were *nested** to minimize material waste. In parallel, assembly instructions were created to facilitate a smooth assembly process.

The inclusion of manufacturing requirements in the design system allowed for a preparedness for production already at earlier design stages, a rapid production of tender documents, and simplified final adjustments once the contractor was in place.





QUALITY HOTEL GLOBE

The interior cladding system for the Quality Hotel Globe foyer consisted of intersecting lamellas and required that lamellas would cross at non-perpendicular angles. The solution was to develop the intersections in following a half-in-half connection, with cut-outs fitting each other.

The design system managed all the intersections, as well as necessary fitting details for the production – the used foam board needed to be mounted for the 5-axis CNC milling procedure. The system also managed the division into modules of 8 to 10 intersecting lamellas, as well as the documentation for final assembly on site. The assembly was tested in full-scale mock-ups, including the rods allowing mounting at a distance from the wall of the volume to be clad.

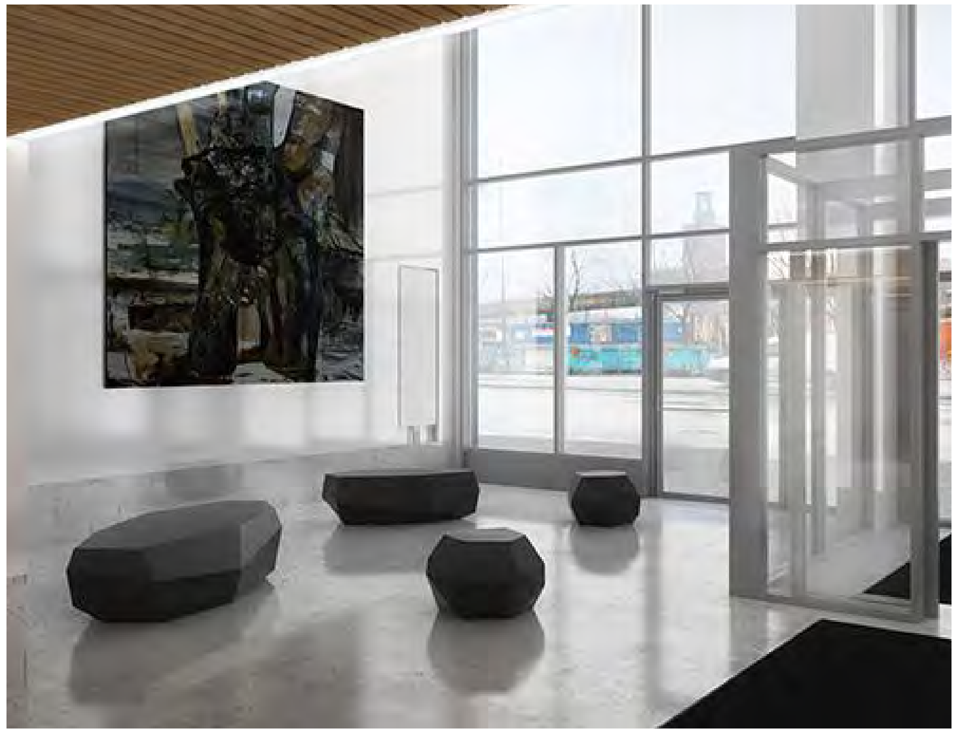
Given that the decision to include the cladding system was taken at a late stage of the project development process, the system also needed to be adapted to various elements of the overall project, which meant a large number of special details, also managed through the design system.

KLARAPORTEN ENTRÉ

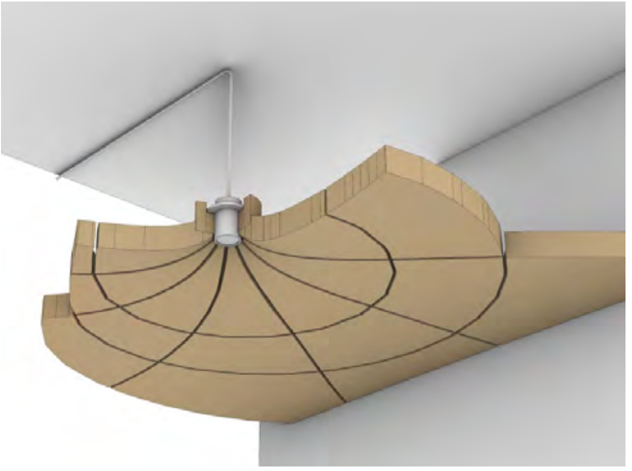
A bespoke series of seating elements informally named Stubborn was developed as part of this commission. The faceted form was first studied by the designer using small scale material models – in blocks of foam sanded to desired form.

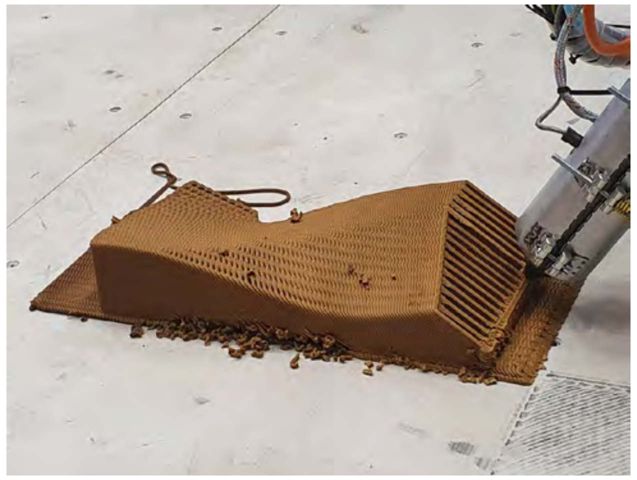
The computational design system used a 3d-voronoi[18] principle for controlling the geometry of the series of unique elements, conceptually carving out the form from a single block. Several manufacturing methods were considered, with a final selection of CNC-machined solid wood elements produced in parts with a hollow interior to decrease weight. The final forms were sectioned, hollowed out, and prepared for machining.

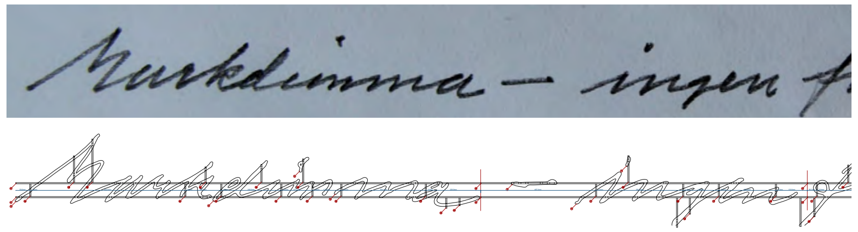
The collaborative process was conducted as a conversation between the computational developer and the designer, where the *design exploration** of the design system was conducted in parallel with the physical models.

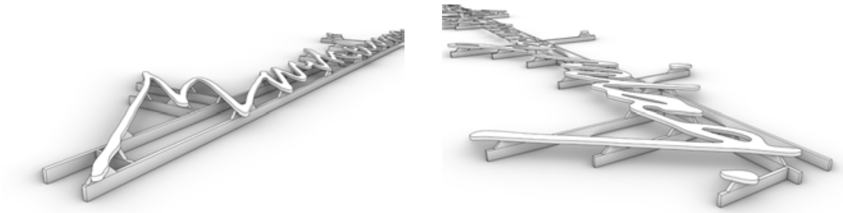


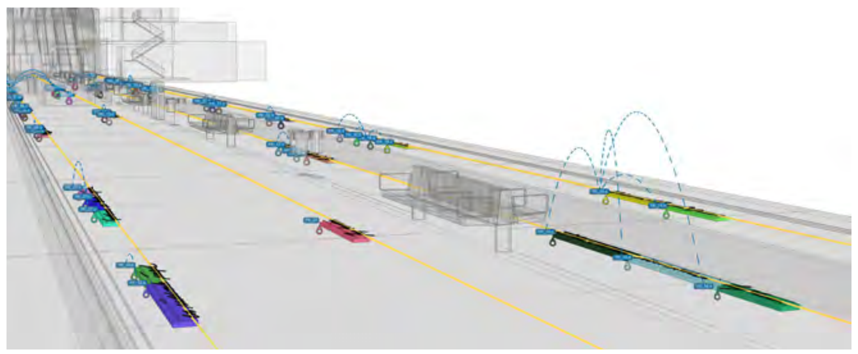
The intersection principles for Quality Hotel Globe, a mock-up module testing the rod system, and a completed module of the cladding system (left page top). The final Stubborn element and its conceptual system for generation (left page bottom), and the layered production principles (above).











DESIGN FOR MANUFACTURING

WOULD WOOD

The Would Wood innovation project was conducted in a consortium with several partners, with the shared ambition of developing design and additive manufacturing methods using biocomposite materials produced from residual material streams from the timber and agricultural industries.

The developed design systems managed the connection between *design models** and production data, ultimately providing the designer control over robotic toolpaths. The process was conducted through a series of demonstrators, each with its separate sets of conditions. In the presented interior cladding demonstrator, the ground floor corridor of a project provided by the contractor partner was used as context, and the cladding system was articulated and adapted to technical installations such as sprinklers and light fixtures.

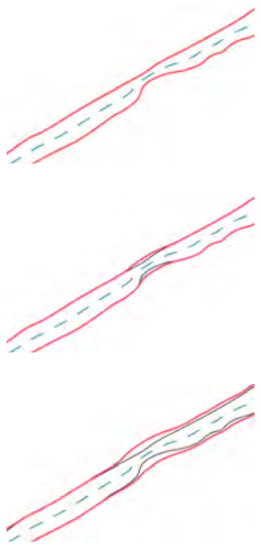
Several design options were explored in the development, with a proposal employing a conceptual magnetic field as an analogy to form a patterned effect in the ceiling. The technical installations were used as poles to generate the field, which also guided the division into individual panels.

BARKABY SUBWAY PUBLIC ART

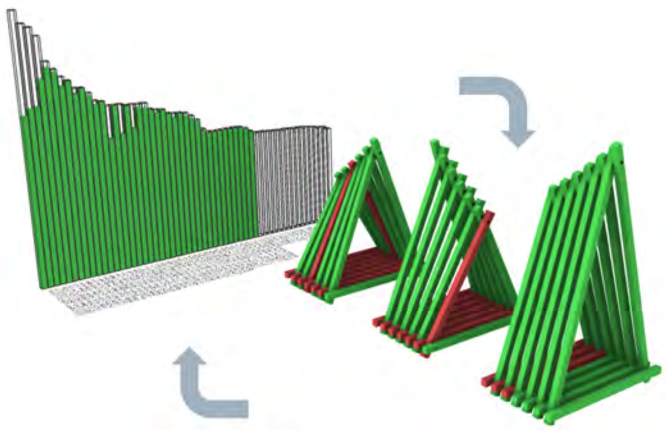
The artist commissioned for the public artwork in the Barkaby subway station, developed by White Arkitekter, is using citations from retired pilots who were based at the Stockholm-Barkaby military airfield to be inserted into the Terrazzo paving on the platforms.

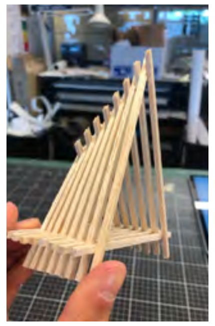
The developed computational design system was used to process the handwriting from scanned papers to vectorised production documentation. It included a refinement process that on the one hand ensured that each letter was wide enough to managed during the casting process, and on the other retained the qualities of the original handwriting. It also automated* the generation of the necessary substructure, adapted to each word and sentence, and provided workflows for the production documentation as well as the integration in the BIM model of the overarching station project.

The art commission included the production of templates for the original citations, as well as all steps in the process, and a first prototype was produced and cast as a proof-of-concept.



The design models and produced demonstrators from the Would Wood interior cladding demonstrator (left page top), and the robotic production unit with additional Would Wood demonstrator (above). The original handwriting and processed vectorised cutlines, generated substructure, deployment in the BIM model and prototype for the Barkaby Subway Public Art commission (left page bottom), and the processing steps for ensuring element width and a rendered vision for the final station (above and right).





The Järvsö Pavilion with conceptual physical model, design system interface with design model and material library, and photographed on the final Järvsö site (left page top). Karstadt am Hermannplatz with visualisation of courtyard, design system interface for ceiling elements (left page bottom) and visualisation of ceiling elements (above).

Design for Reuse

The increasing focus on circular approaches and the reuse of materials and buildings elements provides both new challenges and opportunities. The work with limited sources and project specific material banks can be enhanced through computational approaches, where the designer gets information of the implications of each design decision.

The ReMake framework is a set of *computational design systems** that allow the direct link and real-time feedback between design models and material libraries. Developed iteratively through several projects and commissions, it provides a continuously growing toolkit.

THE JÄRVSÖ PAVILION

This pavilion project was developed inhouse as a response to the opportunity to reuse oak beams from a dismantled sawmill in Järvsö, combined with the need for an event space as part of an architectural festival.[19] The pavilion was reused at several events, and finally returned to Järvsö as a permanent wind shelter for hikers.

Given the unknown status of the beams until just before the event opening, a computational design system was developed to allow the design to be readjusted with short notice, still providing the necessary production documentation to facilitate the assembly of the pavilion. The system combines the design model with a geometrical representation of the material library – in this case a set of oak beams with known cross section, but where the lengths and amounts were not fully known. The design concept was formed through a principal setup of the beams, and the design model allowed the parametric variation of the specific *configuration** through *direct manipulation**. With each change, the material library was queried for available lengths, and feedback was provided through colour indication. Once the material state was known, the library was updated, and a final design configuration was selected.

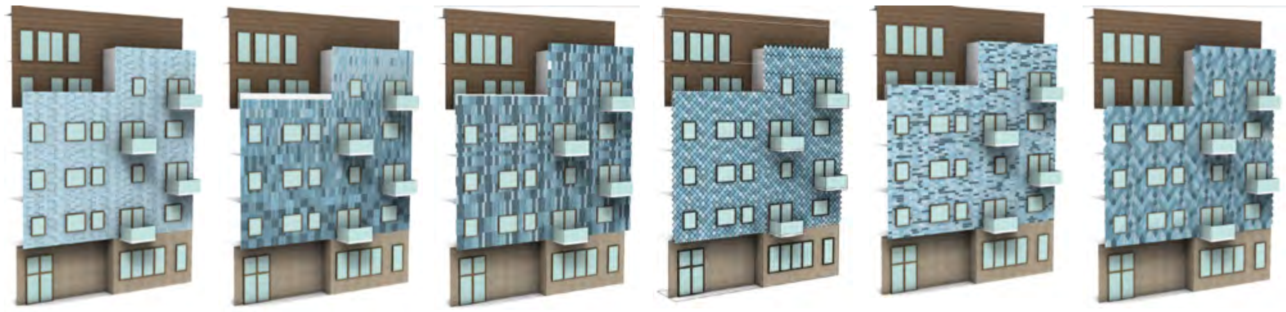
The pavilion project allowed the first development steps of the ReMake design system and identified the matching between design model and material library as a critical function.

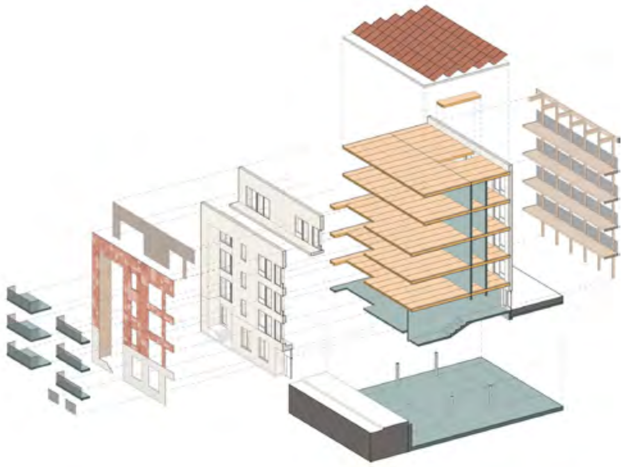
KARSTADT AM HERMANNPLATZ

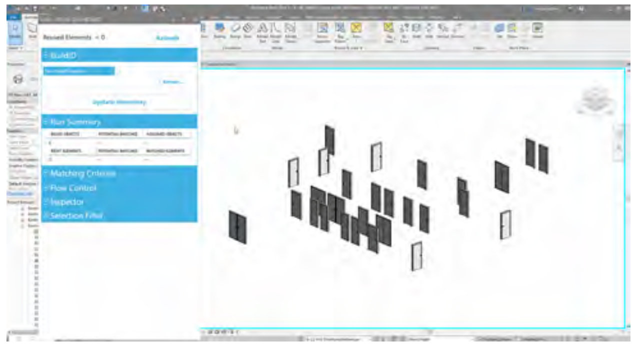
This second prize competition proposal responded to a brief where a locally documented material library was provided as an asset and requirement, with the scope of transforming a commercial property in Berlin. Prototypical workflows were set up as part of the competition entry, with plan for full implementation in the design process pending a competition win.

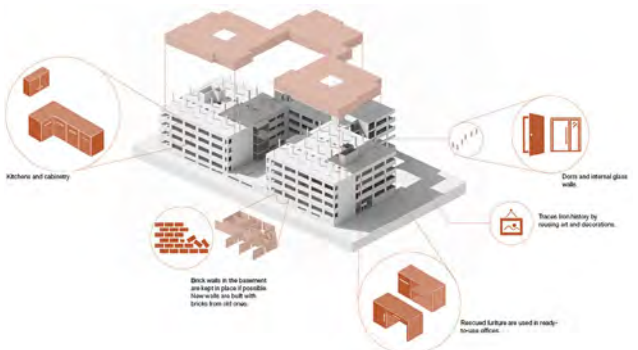
The ReMake design system was set up to process the data from the given library of materials and building elements and allow several designers in different design models to check in and out materials in real time, while providing feedback on the carbon footprint effect of design decisions. The design system also allowed for generative approaches for specific building parts, explored through the automated deployment of alternative ceiling elements across the complete proposal.

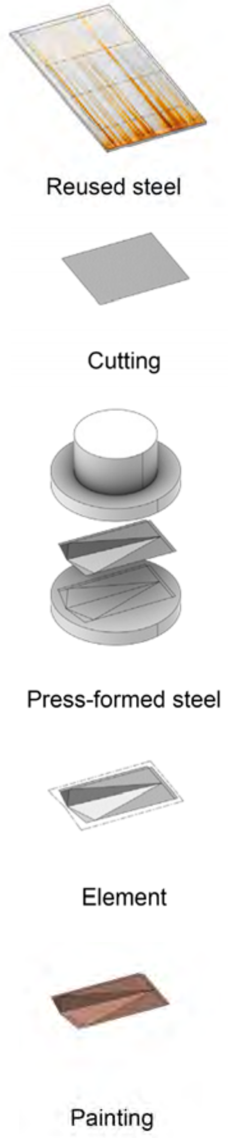
The development in the Karstadt am Hermannplatz competition showed the possibility of developing bespoke and automated reuse workflows within the constraints of a competition project.











Kvarteret Ankan with construction system overview, six instances of the generated façade system and elevation (left page top), and the proposed refurbishment steps for steel panels and competition visualisation of final proposal (above). Lumi with photographs of original building, visualisation of new proposal, overview of reuse strategies, and the design system interface for reused doors (left page bottom).

KVARTERET ANKAN

This second prize invited competition proposal addressed a new build residential project in Norrköping, and conceptually employed the idea of a donor building that could provide the material resources for reuse.

The ReMake approach as applied primarily to the façade, where reuse and refinement of steel panels in frequent use for industrial building where under primary consideration, due to the expectations of an excess of these elements from due to demolition in the near future. A principle production process for the refurbishment of steel panels were included in the competition proposal.

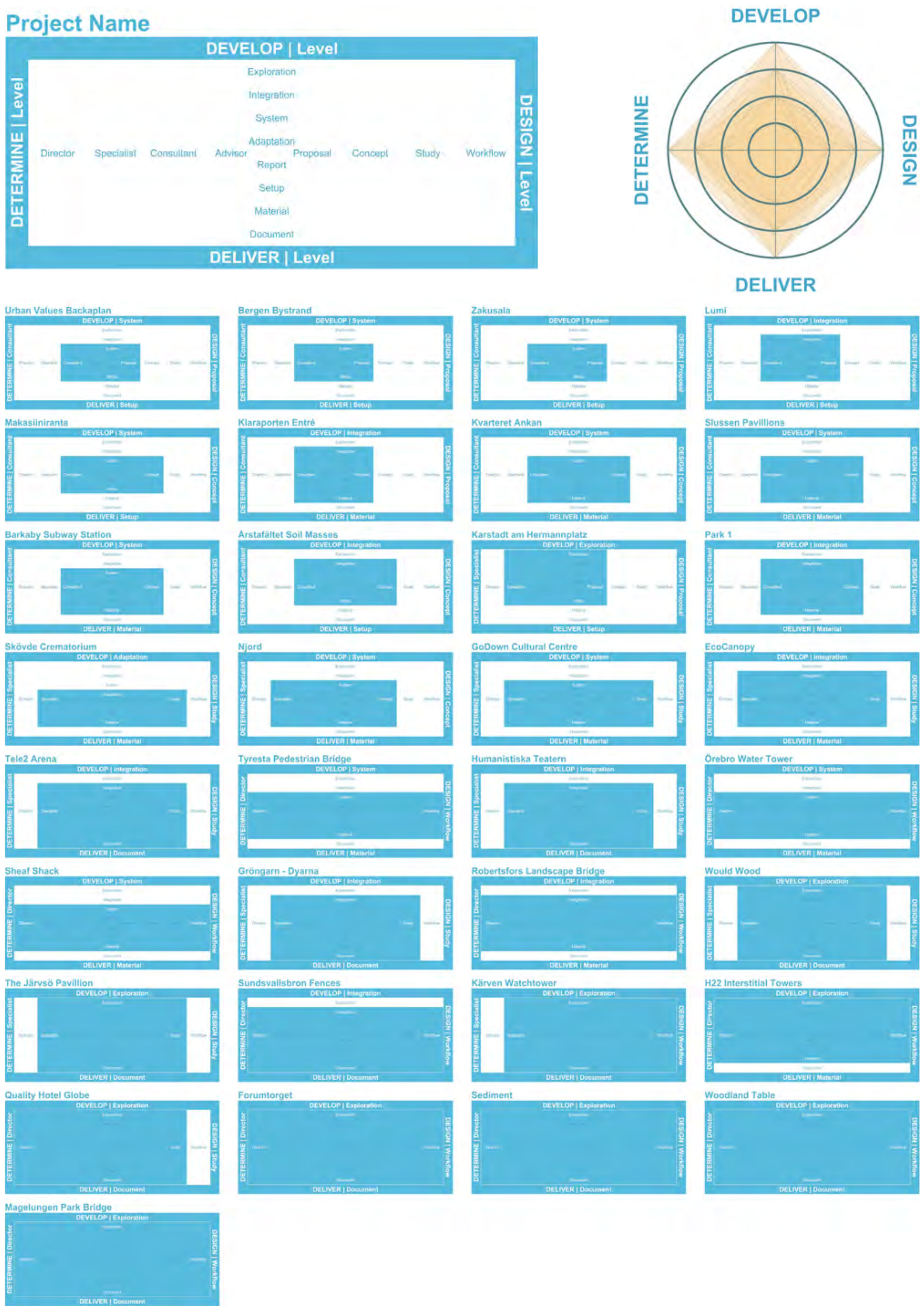
The ReMake design system was primarily used to visualise alternative designs and *configurations** of these panels, including geometrical transformation through folding, and coloration. The system was used as an asset in the production of competition renderings and drawings.

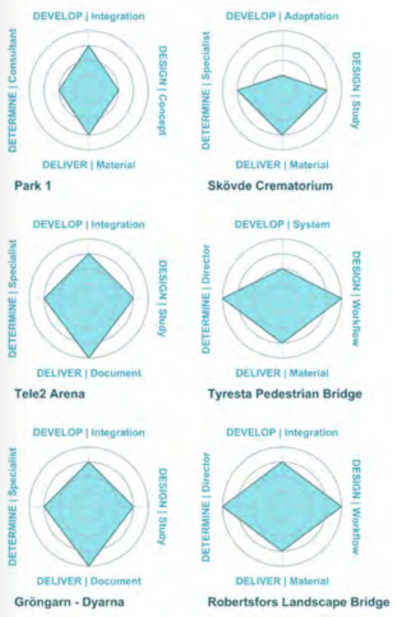
LUMI

The Lumi project entails a transformation and extension of parts of an existing office complex in central Uppsala, where the retaining of the concrete structure already provides great benefits from a climate perspective. In this case, the project faced complex issues of management when a large set of interior doors were to be reused, especially given the variation in their dimensions, classifications, and status.

The ReMake design system was here used to match already places doors in the new design proposal, with the data base of inventoried doors available to reuse. The system provides an interface for the designer where the database can be queried for best matches according to ten different parameters, and optional solutions are provided. Once a preferred alternative was selected, the designer could save this, which would append the relevant data to the database as well as the design model.

The ReMake design system development in Lumi showed the potential of bespoke deployment also at later stages of the design process, where previously unforeseen challenges can be identified.





The Project Development Matrix with the four axes Develop, Design, Deliver and Determine, with all presented projects mapped ordered by complexity levels, and an alternate multi-dimensional graph (left page and above).

Commission Developer Roles

The computational design developer is a new role in architectural design teams, and as such, clarifications on ambitions, expectations, responsibilities, and mandates can be necessary. The Project Development Matrix is a tool for this.

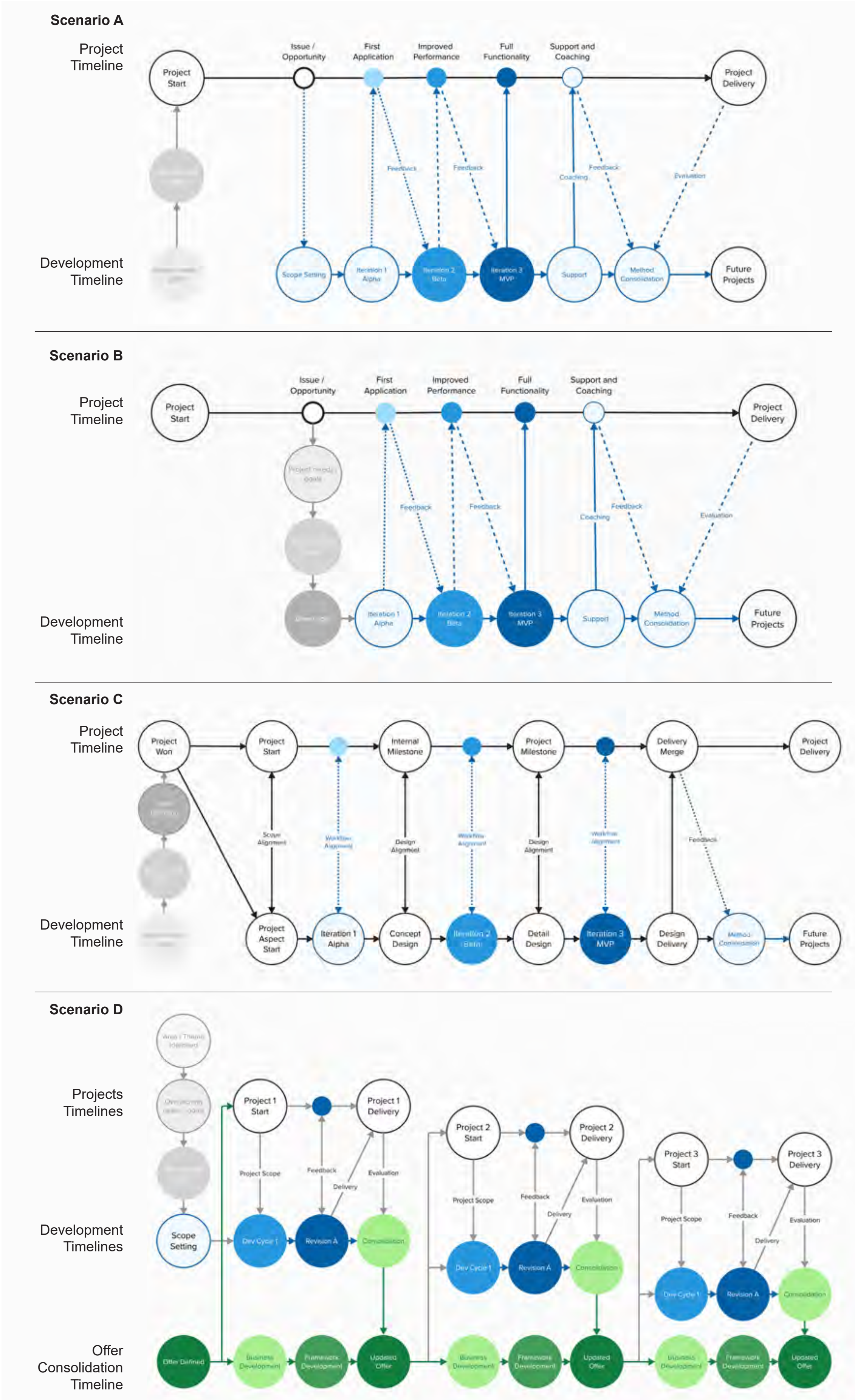
The Matrix is used as an aid for the discussion between the development team and the leads of the overarching project, when determining the scope of the development engagement. In essence, it sets the level of engagement regarding four distinct aspects of responsibility. The matrix describes four axes of responsibility; development complexity (Develop), design process leadership (Design), integration of deliverables (Deliver) & determination of project responsibility (Determine); each graded in four levels of increasing commitment. The graphical nature of the matrix also makes it suitable as a condensed description of the project engagement context. A minimal engagement in all aspects results in a smaller blue rectangle, and a full engagement completely fills the diagram – with all combinations available in between.

Develop sets the ambitions and requirements in relation to the expected method development challenges and addresses the anticipated uncertainty of the proposed development. At the most basic *Adaptation* level, existing workflows are adapted for use within the project. At *System* level, a separate but full design system is developed specifically for the project. At *Integration* level, the design system is integrated with other workflows. The *Exploration* level indicates that the design system is developed completely from scratch, with no prior methodology.

Design indicates the mandate and responsibility over design process and design decisions. The *Workflow* level implies a purely technical assignment that the project employs to articulate a design concept. The *Study* includes the development of a design system to explore a design concept formulated in the project. At *Concept* level a design concept and design system is developed to be further developed within the project. The *Proposal* level indicates a full proposal to be developed and aligned with the project.

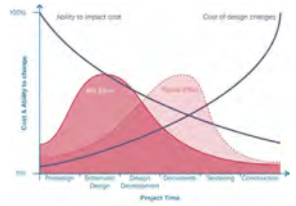
Deliver sets the expectations on the deliveries towards the project goals, ranging from free-standing reports to fully integrated project documentation. At *Report* level, findings from specific tasks are reported back to the team. At *Setup* level, a workflow is created especially for the project design team. At *Material* level, the developer delivers working material in specific formats and following set quality assurance routines. At *Document* level, final project documentation is delivered following relevant standards and quality assurance routines.

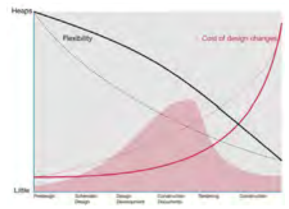
Determine regards the general responsibilities in relation to the overarching project management. As *Advisor*, the developer is a speaking partner. As *Consultant* specific tasks are performed. As *Specialist*, the development team manages more complex tasks. As Director, the developer also manages the overarching project process, and coordinates with external parties.



Commission Development Workflows

Compared to conventional project processes, computational design development has a different pace and allocation of resources over time. When development is conducted as part of architectural commissions, special care is needed to facilitate a balance between computational development and the general progress of the project.





The four scenarios for computational development in commissions. In each scenario, the general project process is simplified into one timeline at the top, and the development process at the bottom. (left page). The MacLeamy curve indicating that design efforts should be located at early stages, and an adaptation where computational design instead extends the intersection between flexibility and cost to later stages (above).

The MacLeamy curve indicates the different conditions for doing design changes, and their cost, in early or late design stages, analogues with the common notion that it is important to make key decisions at early stages, where changes are less costly.[20] It can however be argued that computational design through its parametric nature can allow key changes to be made much later in the process, without facing serious changes. Project specific development of *computational design systems** at early stages can in this sense enable later design changes within certain constrains.

This development can be carried out in different ways. The alignment with the needs and potentials of the project is key, but there must also be a provision of adequate development time. The experiences from commissions within Dsearch can be condensed into four distinct scenarios that cover most frequent situations. Each scenario includes a single developer, or a development team, and a general project team. In diagrammatic form, the overarching project is represented as a single project timeline as a place holder for the more complex process, the development timeline indicates iterations, and the interactions between the two represents the alignment.

In Scenario A, the need for development is identified prior to the start of the project and can be included in project planning. The developer(s) is/are working separately to provide teams with methods and tools that enhance their process, while not directly involved in project deliveries.

In Scenario B, the need for computational design development is identified at some point after the project start, requiring careful consideration of scope and resources before tool development is initiated.

In Scenario C, a certain part of the project has been identified as beneficial of advanced computational design development, and a developer team is formed prior to project start – followed by a parallel but aligned design and development process.

In Scenario D, the identified issues are related to previous cases. This is an opportunity to develop rigorous and well-functioning design methods over time, and over several projects, reducing risk and increasing the level of delivery.

In all cases the development cost needs to be set in relation to the value provided – in some cases this can be covered within the project, while others may require additional investment.

Reflections

This paper provides an overview of how computational design has been applied in architectural design processes through a series of cases and a set of strategic frameworks. The intent is to provide evidence that there is a role for architectural practices as developers in an industry where technology often is regarded as a key future asset.

In a world faced with extreme social, cultural, and environmental challenges, there is a tendency to regard technology not only as a resource, but also as a challenge in itself. New actors from other fields are seeking to provide automated design services. AI has entered the stage and has already proven to be the next stage of technological advancement of society. At the same time, the origins of programming and computation are material and architectural – the material programming of the Jacquard Loom, the systems thinking of Buckminster Fuller, the pattern language of Christopher Alexander. For us as architects, it is natural to have a resonating approach to development where technical, social and cultural achievements are mixed. Computational design is such an approach, in the sense that it combines designerly approaches with programmatic abilities, or in other words intuitive abilities to synthesise many issues with the competence to systematise these in a creative way. Furthermore, it opens architectural discourse to influences from computer science, mathematics, geometry, and engineering – as well as from other creative fields engaged in coding and computation.

Our contributions to the field are on the one hand the examples from architectural commissions presented here in a very short format – all project cases have their own much longer stories. On the other hand, we propose strategies for how architects, clients and collaborators together can use computational design to adaptively redefine our project-oriented processes in a way that responds to the urgent needs of society. In our practice, this happens in two different ways.

This paper primarily presents our experiences of developing our design methods while at the same time conducting our obligations within our commission – providing opportunities for project specific innovation. It shows how digital innovation can respond to the requirements of the independent project, and new workflows can be developed in a rapid and agile way. This requires computational developers with architectural expertise and experience of current project processes.

The second approach is to identify reoccurring issues in the design process, and over time develop methods and workflows that can support those issues. This requires a generalisation of problems and a systematic approach to development similar to general software development. In this approach, it is relevant to distinguish between the roles of users and developers, where the line (architects in commissions) and the backend (the developers) are in iterative contact. Both these approaches are present within the practice of White Arkitekter.

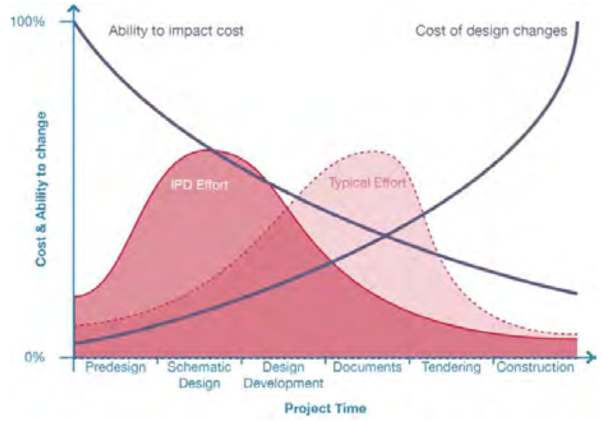
The wall cladding system for the Quality Hotel Globe foyer used computational design systems for the design of the geometry and the management of fabrication and assembly processes (left page).

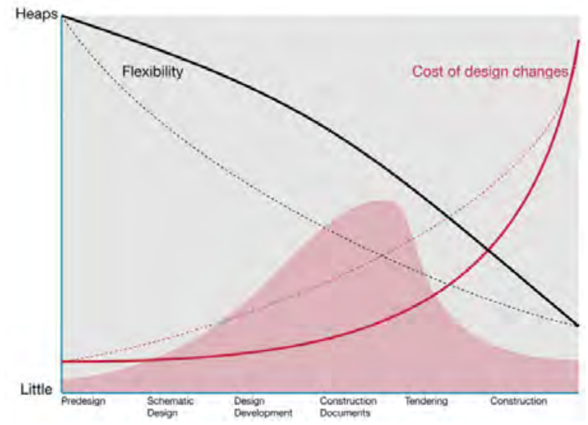
REFLECTIONS

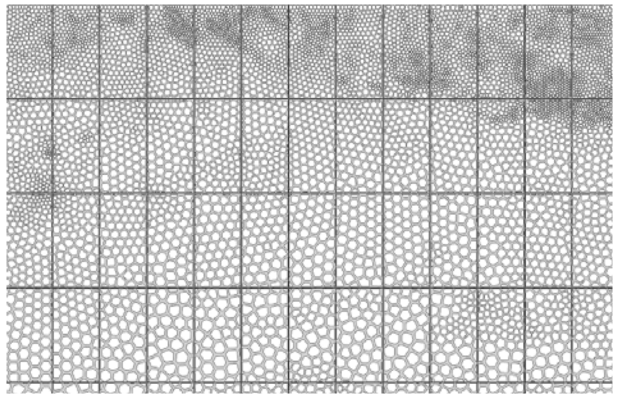
The envelope for Tele2 Arena was developed through computational design systems, providing a rational process for the design, production, and assembly (left page and above).

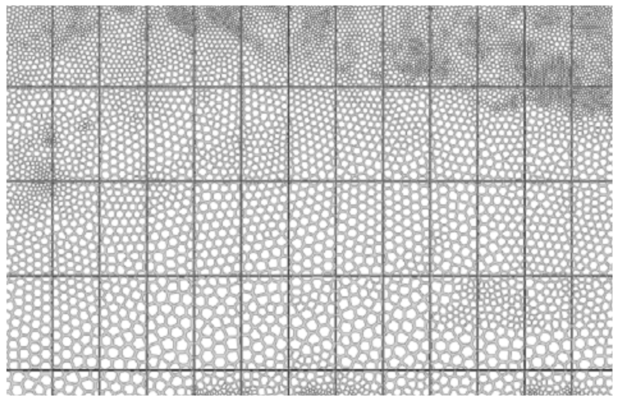
The ambition of this white paper is to indicate that innovative approaches employing computation – the core of AI – can be conducted in the context of the architectural project and commission, by developers combining architectural and computational competence. In extension, this indicates that there is a continued agency in the profession of the architect – a profession that has existed for millennia in one form or the other. The architect's ability to continuously assimilate contemporary technical development into holistic design processes is not new, and computational design is simply a next layer of the development of the profession. Here, the combined approach of design and computation allows meaningful and relevant applications of technology in society in response to urgent needs. This documentation is in this sense an architect's contribution to the current rapidly developing field of the industry, where series of commissions have been used as steps that always fulfil the expectations of the commission, and at the same time anticipates near future needs. We are convinced that it is possible to combine the holistic expertise in spatial design and societal development can be combined with innovations in techniques and technology – in order to ensure a continued relevance and agency of the architectural profession.

Ultimately, computational design is a way to combine the traditional expertise of the architectural designer with the systematic approach of the programmer. This entails an agile and adaptive approach in which innovation can happen also during the duress of the commission as part of daily professional activities.









The original MacLeamy curve, and the altered curve proposed by Daniel Davis (left page, top left). The generated Voronoi tessellation for GoDown, with two instances with variations of the smoothness of the Voronoi cell (left page, top right).

1 The Dsearch graphic standards for visual scripting include principles for how nodes in visual scripts and modularised, as well as a colour coding for different parts of scripts, to simplify collaborative development. It has been published in:

Runberger, J., Magnusson, F. 2015. Harnessing the Informal Processes Around the Computational Design Model. In: Thomsen, M., Tamke, M., Gengnagel, C., Faircloth, B., Scheurer, F. (eds) Modelling Behaviour. Springer

2 The 3d-scanning for the Magelungen Park Bridge was conducted manually, and the resulting point cloud of sampled geometry was used as a reference in the design model.

3 The Finite Element Method (FEM) is a method for solving differential equations used in engineering and mathematical modelling, including structural analysis. In FEM larger elements are subdivided into smaller units – finite elements, implemented in the construction of a mesh of the analysed geometry.

4 The Interstitial Towers speculative design project was developed as part of the Beyond Efficiency research project, funded by the Swedish Energy Agency, through a collaboration between Chalmers ACE, KTH, SLU and Konstfack. The Interstitial Towers project was conceived by Jonas Runberger and has been further developed in terms of regional analysis and physical prototyping at White Arkitekter.

5 Geographical Information Systems (GIS) are used to analyse and display geographically referenced information. In the H22 Interstitial Towers project the application QGIS was used for this process.

6 In Multi-Objective Optimisation the optimisation process can address several parallel goals, which often can be conflicting. This means that trade-offs between different aspects being analysed needs to be conducted.

7 Parallel Coordinate Plots are used to visualise and analyse datasets with multiple dimensions. Within Multi-Objective Optimisation the plots are used to assess multiple solution instances, each with several aspects. Each line in the plot represents one solution, while each column provides the value of all solutions for that particular aspect. The plot can here guide the developer in the necessary trade-offs between different objectives.

8 The Vertical Sky Component is a measure of light provided by an overcast sky on a specific point in space. It is a frequent method for prediction of daylight provision at early design stages. At White, the Honeybee application is frequently use for this method.

9 The spatial efficiency of the Maakasiinranta structural grid was assessed through a geometrical analysis of the areas created in the grid, evaluating the angular and proportional regularity of each area and assigning an index between 0 and 1.

Endnotes

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

10 Subtractive processes means that material is removed from the elements. There are several Computer Numerically Controlled (CNC) production technologies for this purpose, including laser cutters, CNC routers, plasma cutters and waterjet cutters. They all depend on similar production documentation, where lines and curves are provided for the cutting tool paths.

11 The Great Rift Valley is a ridge system that runs through Kenya from north to south, as a branch to the East African Rift. Important paleoanthropological discoveries suggests that this is the cradle of mankind, where our species evolved and diversified.

12 A Voronoi diagram is a type of tessellation pattern in which points scattered on a plain subdivides the plane in the same number of cells, enclosing a portion of the plane closest to each point. The pattern can frequently be found in nature, is readily available as a computational procedure, and has often been used for pattern creation. In the GoDown project the Voronoi procedure is used to parametrically control of the area of apertures, using the centre-points of circles as input.

13 The InnoChain project was an EU research training network funded through the EU Horizon 2020 research and innovation program and facilitated the training of 15 early-stage researchers (PhD candidates) in research methods in academia and practice. White Arkitekter was an industrial partner, and Tom Svilans (CITA/KADK) was the researcher involved in the Magelungen project.

14 The following publications presents the findings in the Magelungen project:

- Runberger, J., Ondejcik, V., Svilans, T. 2018 (2). 'Early Stage Material Performance Modelling.' Poster presented at the Advances in Architectural Geometry conference, Chalmers ACE
- Svilans, T., Antemann, M., Raamsgaard Thomsen, M., Tamke, M., Strehlke, K., Runberger, J. 2019. 'New Workflows for Digital Timber.' Chapter in: Bianconi, F., Filippucci, M. (Eds.). Digital Wood Design: Innovative Techniques of Representation in Architectural Design. Springer International Publishing
- Svilans, T., Runberger, J., Strehlke, K. 2020. 'Agency of Material Production Feedback in Architectural Practice.' Chapter in: Sheil, B., Raamsgaard Thomsen, M., Tamke, M., Hanna, S., Design Transactions: Rethinking Information Modelling for a New Material Age. UCL Press

15 The Powers of Ten are two documentary films written and directed by Charles and Ray Eames, depicting the relative scale of the universe according to an order of magnitude based on a factor of ten.

16 A 3-axis CNC router has freedom in 3 directions and can be used for cutting 2-dimenstional elements as well as forming 3-dimensional surfaces.

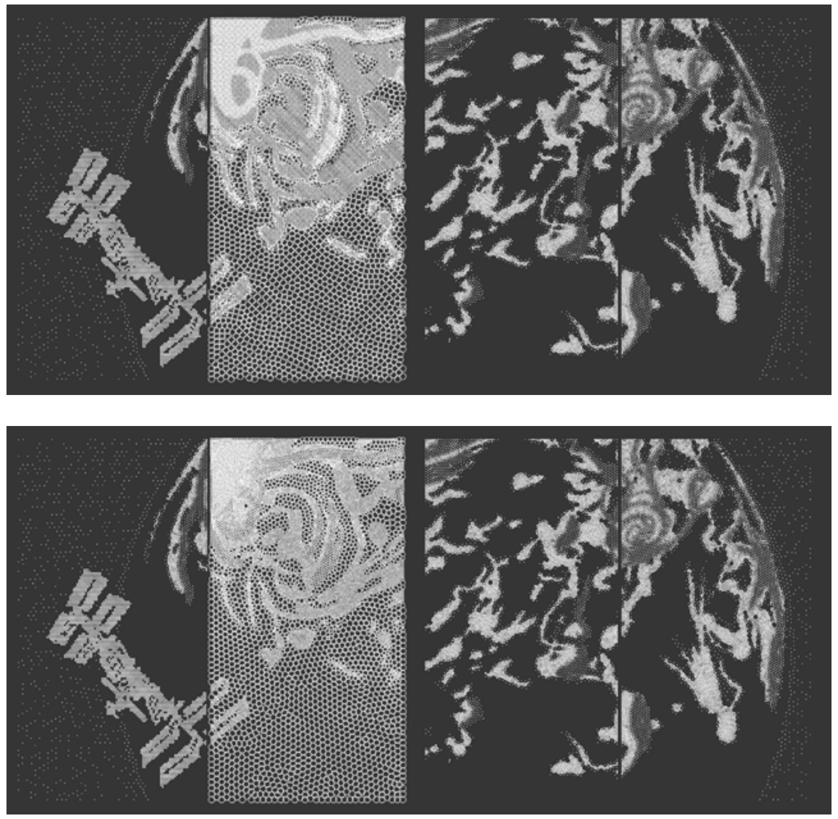
17 A CNC Waterjet Cutter allows industrial cutting in a wide range of materials through high pressure jets of water mixed with abrasive substances. The geometrical principles of the Forumtorget bench lamellas, where the curve geometry was limited to lines and arcs, allowed the use of an old model, which would have difficulties in processing more complex geometries.

18 The 3d-Voronoi follows the same logic as the the 2d-Voronoi diagram, but in 3 dimensions.

19 The reused oak beams reused from the Järvsö sawmill were also used in a commission for the interiors of a store space, in parallel to the pavilion development.

20 The MacLeamy curve was presented by Patrick MacLeamy, later CEO at architectural practice HOK, in 2002 but built on a previous sketch by construction manager Boyd Paulson in 1976. In essence, both versions suggest that design decisions primarily influence architectural projects at early stages, where the cost of changes still are low. This indicates the need to front-load projects, meaning to resolve as much as possible at this early stage. This approach may make later changes even more expensive however, which can be a critical issue if the conditions for the project changes. With the introduction of parametric modelling the idea of flexible models was introduced, further extended within the field of computational design. Daniel Davis suggested that computational design, and the use of flexible models (or flexible design systems) in effect can alter the MacLeamy curve, extending the time when changes can be done at lower cost into later stages of the project.

Davis, Daniel. 2013. Modelled on Software Engineering: Flexible Parametric Models in the Practice of Architecture. PhD dissertation, RMIT University.



Two instances of the circle packing translation process for Sediment, where image sampling directs the sizes of circles, and their centre points are defining the grid for apertures, with sizes again guided by image sampling (left page).

Glossary

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

3d-printed model
The 3d-printed scale models referred to here have been produced inhouse through either fused deposit modelling (a thermos plastic extrusion process using filament material) or binder jetting (depositing binder on a powder bed). In all cases, the digital model used as basis for printing has been produced through *computational design systems**.

Algorithm
An algorithm is a set of rigorous instructions that forms a procedure for executing a task. In this context, it refers to the instructions provided by a developer through a *script**.

Associative Design Model
In an associative model all geometrical elements and their meta-data are related to each other. In computational design systems, these relationships and their dependencies can be defined and organised in a bespoke way, allowing project specific automated functionality.

Automation
In this context automation refers to bespoke workflows for the creation and modification of geometry or data created through computational design development, providing the functionality of the computational design system.

Circle Packing
In geometry, circle packing is the arrangement of circles of equal or varying sizes on a given surface with no overlapping, and in a way that no circle can be enlarged without overlaps. In computational design circle packing *algorithms** are frequently using *physics engines** to iteratively generate the final pattern. The size of the circles can be predefined but could also be controlled locally through image sampling, which is the case here.

Computational Design
Computational design entails a combined mode of design and programming and is dependent on the developer's multiple competencies. For the purposes of this white paper, computational design development is conducted in response to specific challenges in architectural commissions and requires an iterative approach where design steps are taken in parallel to the development of computational *algorithms**. The main platform for computational design development in the presented project cases is the visual scripting* platform Grasshopper, enhancing the modelling platform Rhinoceros 3D.

Computational Design System
Computational Design Systems, or Design Systems for short, is a definition within White Arkitekter for the combined assets resulting from computational design development in response to a particular challenge or task. The design system combines developed scripts, design models, and associated workflows that are used to fulfil the specific task. A design system may address project specific situations but can also be adapted for generic use. The design system can be used by the computational design developer to complete the task, or it can be used by a non-developer through an integrated *user interface**.

Configuration
A configuration entails the specific settings of a flexible and parametric design model, providing one instance of many as a design solution.

Control Mechanism
Control mechanisms are various of controlling the input for the computational design system. This can include geometrical input such as control curves that are directly used in the *associative design model**, or indirectly through the processing of data. It could also be simple numerical input, or the use of images through *image sampling**.

Design Exploration
Design exploration here indicates the development and use of computational design system to explore a larger set of potential design solutions.

Design Model
The design model here indicates the digital model where design solutions are explored, normally controlled through the computational script. The main platform used is Rhinoceros 3D, but many other modelling applications can be used.

Direct Modelling or Manipulation
Direct modelling concerns the manual modelling of geometries within the design model, using standard modelling techniques. Direct manipulation involves the manual editing of geometrical control mechanisms that can be used as inputs for the computational design system.

Form-finding
Computational form-finding as a method that simulates material behaviour to adapt geometry to more optimal forms. It entails an iterative process where feedback from the simulation provides new input to the geometry and is usually conducted through the use of *physics engines**.

Image Sampling
Image Sampling here involves the conversion of a digital image into numerical data storing values at specific sample points. Through image sampling the information of single pixels, such as the grayscale value, can be processed to control corresponding locations on an associated surface.

Informed Design
Informed Design here is an approach where designer can be informed through feedback, such as simulation results or processed geometrical data, providing the designer with a better understanding of the repercussions of individual design decision.

Interpolation
Interpolation is a process where new data is generated from an existing discrete data set, such as new points located between existing points in a digital model.

Meta-Data
Meta-data can be defined as data providing information about other data, here often through numerical data directly referencing geometrical objects in a digital model.

Nesting
In manufacturing nesting refers to the process of laying out cutting patterns efficiently to minimise material waste.

Physics Engines
A physics engine is a computational system that provides a simulation of physical systems in real time, such as particle dynamics, where the forces acting on a body can be simulated to approximate their effects.

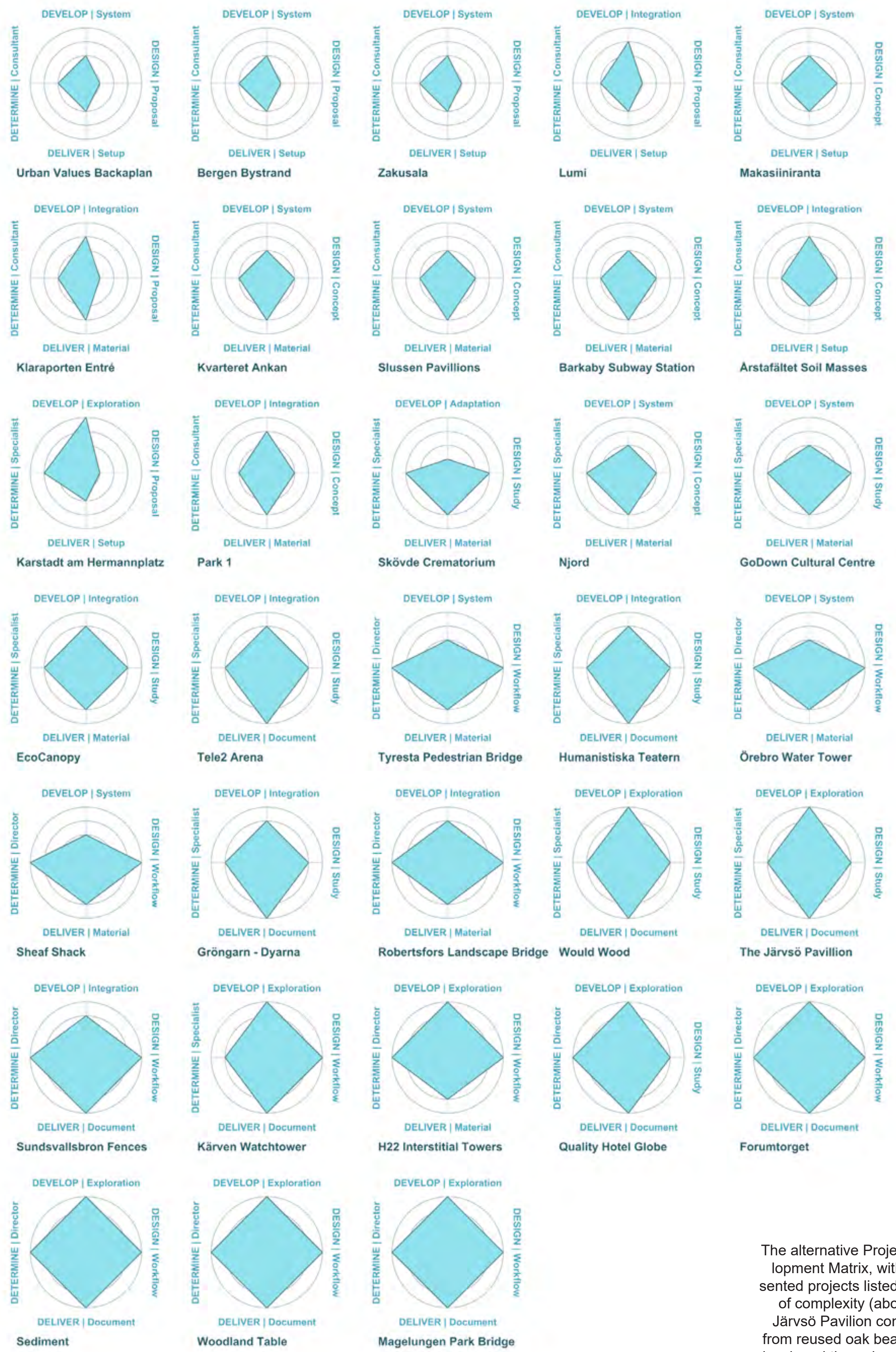
Project Development Matrix
The project Development Matrix is a tool for identifying and communication the role of a computational design developer in relation to an architectural commission, developed by Dsearch.

Project Specific Innovation
Project Specific Innovation here indicates the activity to provide more efficient and value adding workflows to a design process, within the constraints of a particular commission.

Script
A script here indicates the instructions for a computational process, a key part of the computational design system. This can be through a visual script, where functions can be organised in a graphical way, or through text-based code. A majority of the project cases presented in this paper are using visual scripts developed in Grasshopper, enhanced by integrated text-based code developed in Python.

Solver
A solver is a computational system that calculates solutions to specific problems.

User Interface
The user interface here refers to graphical interfaces providing non-developers ways to interact with the computational design system, usually through displays and parameter controllers over layering the design model.



The alternative Project Development Matrix, with all presented projects listed in order of complexity (above). The Järvsö Pavilion constructed from reused oak beams, was developed through a bespoke computational design system for reuse (back page).

Project Credits

Projects with key actors for the computational design development are listed in order of appearance.

Sheaf Shack
Client: RAW Design, the Toronto City Councillor
Project Lead: Niels de Bruin
Developers: Jonas Runberger, Vladimir Ondejcik
Tyresta Pedestrian Bridge
Client: Tyresö Municipality
Project Lead: Mattias Nordström
Developers: Jonas Runberger, Lukas Nordström, Vladimir Ondejcik
External Collaborators: Sweco Engineers
Photographs: Anders Bobert
Örebro Water Tower
Client: Örebro Municipality
Project Lead: Jonas Runberger, Stefan Forslund
Developers: Jonas Runberger, Vladimir Ondejcik
Illustrations: Anni Stockeld
Forumtorget
Client: Uppsala Municipality
Project Lead: Gustav Jarlöv, Jonas Runberger
Developers: Vladimir Ondejcik, Hamia Aghaiemeybodi, Pedram Seddighsadeh, Lotta Lindh, Theodor Tsesmatzoglou, Jonas Runberger
External Collaborators: Mikael Malmborg (LYX), Jonas Wannfors, Rosskopf + Partner, Designtoproduction
Photographs: Anders Bobert
Robertsfors Landscape Bridge
Client: Trafikverket
Project Lead: Gustav Jarlöv, Jonas Runberger
Developers: Jonas Runberger, Vladimir Ondejcik
External Collaborators: ELU
Magelungen Park Bridge
Client: Exploateringskontoret Stockholm
Project Lead: Gustav Jarlöv, Jonas Runberger
Developers: Jonas Runberger, Vladimir Ondekcik
External Collaborators: Tom Svilans (KADK), Blumer Lehmann
EcoCanopy
Funder: The Swedish Environmental Protection Agency
Project Lead: Sandra Sydbom, Barbara Vogt
Developers: Jonas Runberger, Vladimir Ondejcik
External Collaborators: str.ucture GmbH
Park 1
Client: Stockholms Fastighetskontor
Project Lead: Linda Thiel
Developers: Jonas Runberger, Hania Agahmeibodi
External Collaborators: AKTII
Illustrations: MIR
Quality Hotel Globe
Client: Stockholm Globe Arenas
Project Lead: Magnus Croon
Developers: Sander Schuur, Jonas Runberger, Hamia Aghaiemeybodi, Pedram Seddighzadeh
External Collaborators: C&D Snickeri
Photographs: White Arkitekter, Thomas Zaar, Örn Erlendsson
Skövde Crematorium
Client: Parish of Skövde
Project Lead: Magnus Brunner
Developer: Lukas Nordström

Barkaby Subway Station
Client: Ramböll, Stockholm Stad
Project Lead: Dirk Noack
Developers: Vladimir Ondejcik, Jonas Runberger
Kärven Watchtower
Client: Varberg Municipality
Project Lead: Kenneth Malmqvist
Developer: Lukas Nordström
External Collaborators: Ramböll, WSP
Gröngarn - Dyarna
Client: Enköping Municipality
Project Lead: Cecilia Jarlöv
Developers: Lukas Nordström, Hossam Elbrrashi, Isac Mjörnell
Slussen Pavilions
Client: ELU, Exploateringskontoret
Project Lead: Charlotta Wallander, Magnus Croon
Developer: Vladimir Ondejcik
External Collaborators: Foster + Partners
Slussen Facades
Client: ELU / Exploateringskontoret
Project Lead: Charlotta Wallander, Magnus Croon
Developer: Hossam Elbrrashi
External Collaborators: Foster + Partners
Zakusala
Client: Zakusalas krastmala 19, SIA
Project Lead: Oskar Norelius, Robert Schmitz
Developers: Hossam Elbrrashi, Martin Johnson
Bergen Bystrand
Client: Bergen Municipality
Project Lead: Gina Bast Mossige, Pål Dixon Sandberg
Developers: Hossam Elbrrashi, Libny Pacheco
Årstafältet Soil Masses
Client: Exploateringskontoret Stockholm
Project Lead: Paula Mackenzie
Developers: Lukas Nordström, Jonas Runberger
Urban Values Backaplan
Client: Backa Fastigheten, Balder Projektutveckling
Project Lead: Erik Nygren, Johan Lundin
Developers: Frans Magnusson, Hossam Elbrrashi
H22 Interstitial Towers Site Location
Funder: Swedish Energy Agency
Project Lead: Jonas Runberger
Developer: Ossama Gabrallah
External Collaborators: NCC, Chalmers ACE, KTH, SLU
Njord
Client: Archus Husarkitektur
Project Lead: Ossama Gabrallah
Developers: Ossama Gabrallah, Hossam Elbrrashi
Makasiiniranta
Client: Niam VIII Service
Project Lead: Fredrik Källström
Developers: Hossam Elbrrashi, Martin Johnson
Tele2 Arena
Client: Stockholm Globe Arena Fastigheter, PEAB Sverige
Project Lead: Monica von Schmalensee, Fredrik Källström
Developer: Raimo Joss
External Collaborators: ARUP

Sundsvallsbron Suicide Protection
Client: Trafikverket
Project Lead: Niels de Bruin, Anna Eklund
Developers: Jonas Runberger, Hossam Elbrrashi
External Collaborators: Tyrens
GoDown Cultural Centre
Client: The GoDown Arts Centre
Project Lead: Ulrika Stenkula, Marta Bohlmark, Raimo Joss
Developers: Jonas Runberger, Vladimir Ondejcik
Sediment
Client: Public Art Agency Sweden, Artist Johannes Heldén
Project Lead: Jonas Runberger
Developers: Frans Magnusson, Jonas Runberger
Woodland Table
Client: Architects Sweden
Project Lead: Jonas Runberger
Developers: Jonas Runberger, Vladimir Ondejcik
External Collaborators: Nicklas Styf
Humanistiska Teatern
Client: Public Art Agency Sweden, Artist Ann Lislegaard
Project Lead: Jacob Melin, Jonas Runberger
Developers: Frans Magnusson, Jonas Runberger
Klaraporten Entre
Client: SPP Fastigheter
Project Lead: Marie Dreiman
Developers: Pedram Seddighzadeh, Jonas Runberger
External Collaborators: Källemo
Would Wood
Funder: Vinnova
Project Lead: Mikael Lindström, Jonas Runberger
Developers: Vladimir Ondejcik, Hossam Elbrrashi, Jonas Runberger
External Collaborators: Chalmers ACE, RISE, Veidekke, Phenotype Studio
Barkaby Subway Public Art
Client: Ramböll, Stockholm Stad
Artist: Helena Byström
Main Project: Dirk Noack, Anna Wretlind el-Sayed, Jerome Bedford
Developers: Hossam Elbrrashi, Jonas Runberger
The Järvsö Pavilion
Client: White Arkitekter
Project Lead: Elena Kanevsky
Developer: Vladimir Ondejcik
External Collaborators: John Pettersson
Karstad am Hermannplatz
Client: Signa Holding
Project Lead: Barbara Vogt, Fredrik Källström
Developers: Jonas Runberger, Hossam Elbrrashi
Kvarteret Ankan
Client: Sveafastigheter Bostad
Project Lead: Marcus Lindberg
Developers: Vladimir Ondejcik, Jonas Runberger
Lumi
Client: Vasakronan
Project Lead: Anders Tväråna, Alison Petty
Developer: Hossam Elbrrashi

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