Interdisciplinary parametric design: the XXL experience

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Abstract

Focusing on large span structures for sport buildings, the paper tackles the role of parametric modelling and performance simulations, to enhance the integration between architectural and engineering design. The general approach contrasts post-engineering processes. In post-engineering, technical performances are considered in late stages of design and tailored upon preconceived and constraining architectural solutions. Contrarily, the paper advocates the use of engineering (including structural) performances to drive creativity and innovation in conceptual design. It presents examples of research-based education, in which parametric modelling and engineering performance simulations are used in accordance to this approach.

An interdisciplinary Master Design Course is presented. The course is concerned with complex horizontal large span building structures; it is tutored by academic and professional experts; and it simulates real processes. The students work in multidisciplinary teams. In each team, a student is responsible for a discipline (architectural design, structural design, envelope design, climate design and computational design). The collaborative process occurs based on computational tools, parametric methods and interdisciplinary performance evaluations. Each specialist works on 3D parametric models, to investigate aspects relevant for the specific discipline. Each specialist also shares a number of parameters across disciplines. Individual models are then integrated into shared core models. The process involves all team members; and the computational designer of each team organizes and coordinates the process. Examples of student-works are discussed regarding how parametric modelling (coupled with performance analysis – i.e. structural and multidisciplinary performances) supports design explorations for interdisciplinary performance-based design, from conceptual to detailed design. The paper critically addresses the success and difficulties of the approach.

Keywords: Parametric Design, Interdisciplinary Collaboration, Performance Simulations, Large Span Sport Buildings.

1. Introduction

The design of large span sport buildings is challenging due to multiple aspects, both in case of top sports and recreational facilities. Structural challenges are often related to the large span. Climate control is challenging especially for controlling distribution of daylight, temperatures, humidity and airflows in large volumes. It is also challenging due to the strict requirements for athletes and audience. The functional organization is challenging, both in relation to logistics for large events and to guarantee continuity of use during different periods (i.e. of the year). When dealing with such complex projects, current architectural and engineering design practice relies on increasingly specialized disciplines and collaboration across them. Dealing with interdisciplinary collaboration implies dealing with management of people and information (Chiu et al., [2]) in a set of collaborative processes that can occur simultaneously together (synchronously) or separately (asynchronously) (Kolarevic et al., [5]). This includes communication and exchange of data among experts from different disciplines as well as possible negotiations on design solutions according to the level of satisfaction against different design criteria. Large effort has been invested in research to understand and model the collaboration among experts based on the mentioned aspects (Kvan, [6]; Simoff and Maher, [10]). Possible supports have also been variously developed to improve the collaboration (Maher et al, [8]; van Leeuwen, [13]; Kolarevic et al., [5]; Chiu and Lan, [3]). Large attention has been given to the integration of different disciplines in the advanced phase of design; while less attention has been given to the interdisciplinarity of the conceptual design phase. However, like Leon and Laing [7] point out, "effective design collaboration during the early design stages in architecture is a condition for effective overall design and construction"; and allows the following stages to have fewer design loops, thus saving both on costs and time. When focusing on the conceptual phase, testing the concepts against criteria that meet the requirements coming from different disciplines as well as feeding-back the results into the process is crucial. These feedback-loops aim at guiding improvements of design concepts or at suggesting the generation of new concepts. In this light, multiple interdisciplinary criteria need to drive the conceptual design exploration. This concern cannot be neglected in education, where professional figures coping with these challenges are trained.

This paper presents the experiences from some past editions of a Master course at Delft University of Technology. The course deals with the design of large span sport buildings, for which the students developed integrated interdisciplinary conceptual design based on computational workflows.

2. BIG+TALL: the XXL Workshop

The BIG+TALL course is a collaborative multi-disciplinary design course running at Delft university of Technology, Faculty of Architecture. It is addressed to master students in Architecture, Real Estate & Housing, Building Technology and Civil Engineering. It runs twice per year and it joins two workshops, each of which has previous tradition within the Faculty. The Highrise Workshop (TALL) deals with the design of a multifunctional skyscraper with different functions (such as offices, housing, parking, leisure, public functions). The XXL Workshop (BIG) deals with the design of a large span multifunctional building (mostly with a public nature).

The course includes multiple disciplines: architectural design, structural design, climate design, façade design, design/construction management and computational design. Topics related to sustainability run transversally across all disciplines. During the whole course, the students work in teams. Each design team is composed by 4 to 6 students and delivers an integrated design as a multidisciplinary team, from conceptual to development stage. In each team, each student is responsible for one

discipline and is tutored by (academic and/or professional) specialists of that discipline. Thereby, usually each team is composed by an architect, a structural designer, a climate designer, an envelope designer, a manager and a computational designer. The architect is expected to integrate engineering inputs in the architectural conception and during the design process. The engineers are expected to work based on close integration of specialized expertise and proactively contribute to the process, rather than dealing with post-engineering. Each discipline is asked to take inputs from and provide inputs to the other disciplines. All contributions converge into an integrated design solution that should perform well according to criteria from all disciplines. This interdisciplinary collaboration is expected during all phases of the design process and occurs at all the scales of the project (from the large scale of the overall design to the small scale of the building-components). Final deliverables from each team consist of visualizations, drawings, 3D digital and physical models of the final overall design. Additionally, each student should deliver an individual report containing all relevant information and data of the project for the specific discipline.

Overall, the workshop is realistic and matches the design process of large international projects in the competition phase. It runs for 10 weeks. The first week is dedicated to lectures by professors and external experts; a visit to the project site or similar projects; intensive courses on team-work and on parametric modelling and computational design. From the second week, students develop the design. The daily design activities are facilitated by tutors for each discipline. Each discipline has a special day/time for individual consults during the week. Until a pin-up presentation, the students develop alternative design options. During the pin-up presentation, students, tutors and external experts discuss with the students to identify one design option per team, to be developed until the end of the course. The mid-term and the final presentations are facilitated by a jury that includes academic instructors and professors as well as professionals from practice and representative from international companies and/or public (mostly regional or municipal) Dutch institutions. Feedback by the jury informs the design and the design decision process, based on discussion with the students. In occasion of the mid-term presentations, external international experts debate relevant topics also based on public lectures. After the mid-term presentations, the design is detailed with the team, leading up to the final presentations, which also occur in form of public event.

The design assignment is chosen in collaboration with external experts and institutions, and is usually related to a real project. It has an actual site where the building is planned. From 2011 until now, the XXL workshop addressed sport buildings in The Netherlands or abroad, and this will be the focus of this paper. The authors coordinated the workshops; and were in the instructors team.

2.1. Design Assignments

In the 2011 and 2012 editions of XXL, the design assignment focused on a large span structure for a football Stadium: the De Nieuwe Kuip in Rotterdam (NL). The location was in the South part of Rotterdam, in the area where De Kuip is located and used by the football team Feyernoord. The students could design a totally new stadium, in a plot not far from the existing stadium; or redesign the current stadium based on substantial interventions and renovations. Among others, external reviewers were involved from KCAP, dS+V, BAM and Arup, from the Municipality of Rotterdam and from the De Kuip and Feyernoord, acting for the students as their hypothetical client.

In the 2013 edition, the design assignment focused on a large span structure for an ice Arena and multifunctional ice rink sport venue: the New Thialf, in Heerenveen in the province of Friesland (NL).

The location corresponded to where the Thialf is located. The current Thialf is used for long track speed skating, short track speed skating, ice hockey, figure skating, and non-sports events; in the past, it hosted a number of world relevant events, including two Speed Skating World Cup events. The design assignment considered the ambition of re-boosting the worldwide attention from the international ice-skating community. A new iconic image was required for the design. Functional flexibility was required in hosting top-sport training and competitions as well as recreational activities for the local community. In order to host top-sport activities, the building should be conceived and engineered such that indoor conditions allow for achieving top-quality ice. The building should embrace principles of sustainability and innovation, allowing development and operation based on short and long term sustainability. External reviewers for the students were involved from Alynia Architecten, Arup, Thialf, Heereveen and the province of Friesland, among others.

In the 2014 and 2015 editions, the design assignment focused on a large span structure for an indoor ski-center with multifunctional areas for leisure on snow and ice, in Orlando (Florida) and in Almere (NL). For the hypothetical American location, the main ambition was formulated as designing the most unique and comprehensive indoor snow resort, sized on huge dimensions covering approximately 50.000 sqm. The overall project was meant to include a snow-concept comprising two areas: an artic landscape with a snow mobile circuit, a real snow igloo village, and other items offering amusement and educational activities on real snow and ice; and an alpine landscape featuring winter a sport area for various levels of skiers and snow-boarders. For the Dutch location, the general set-up remained the same, but the design assignment targeted a smaller project, integrated in the local urban context of the Almere Poort. Among others, external reviewers were involved from Unlimited Snow, S333, WT Partnership, Arup; and for the Dutch edition also from Almere City.

3 Computational workflow

The design process occurs in a collaborative digital design environment that supports the interdisciplinary workflow. The digital process is meant to facilitate the integration of contributions from all team-members into a design solution well performing for all disciplines. The process requires an integrated 3D approach based on BIM (Building Information Modelling) principles and includes both the generation of the geometry and the numeric performance analysis of multiple design solutions. Though students are free to choose and combine different software according to their specific needs, the common platform used for most of the interdisciplinary integration is Rhinoceros McNeel (Rhino) for geometric modelling, combined with the plug-in Grasshopper (GH) for parametric modelling; and with a number of various plug-ins and software for performance simulations and assessments.

3.1. Geometric modelling and parametric design

The students make use of various techniques to develop their projects, including hand-drawings and sketches, hand-made and digitally produced mock-ups. Focusing on the computational means for collaborative design, the elaboration of the design occurs through 3D models developed mostly in Rhino from the very beginning of the course. This process proceeds until when detailed design and deliverables are produced. For the final work on detailing, and on plans and sections, often the Rhino-models are connected to other software (such as Autodesk Revit). For each design, some aspects are explored parametrically. Parametric modeling occurs mostly in GH, which can be considered as a

visual programming software. GH is used to support design explorations for performance-oriented design, in which interdisciplinary performance evaluations are integrated in the early phase of the process. Some features of parametric modeling are especially useful for this purpose, because of the following reasons. Parametric modeling allows representing geometric entities having editable attributes, and relationships by means of associations. Attributes can be expressed by independent values, which act as input to the model; their eventual variations generate different solutions of the model. Associations allow for processing the data across the related geometric entities; this means the different solutions of the model are generated while respecting the consistency of pre-established relations among geometric entities. Thanks to these and other abilities, parametric modelling is applied to integrate engineering aspects during the architectural design process, especially when dealing with complex geometries. Three general cases are exemplified here following. First, geometric features can be automatically repeated with customized variations based on parameters and associations processed through the algorithms. As an example, this is relevant in case of tessellations for structures and claddings. Such algorithms allow avoiding manual steps that would require unacceptable time and effort during the design process. Second, elements can be modelled while guaranteeing pre-established constraints and geometric relations. Constraints and relations can include given requirements (for example, for the interface between structural geometry and cladding). They can also include deterministic processes expressed based on formulas for the achievement of wanted performances (like structural behaviour or daylight). Third, by serving the generation of geometric design alternatives, parametric modelling is used to support design explorations when deterministic approaches are not suitable. This occurs especially in combination with building performance simulation tools for the integration of measurable criteria.

3.2. Parametric models across specialized roles

The whole parametric design process is based on a collaborative approach. The workflow is meant to respect the needs of individual (parametric) design explorations of each discipline; and the need of sharing information and integrating decisions across all disciplines. Operatively, this results in a distinction between individual (parametric) models and a shared core model.

In most cases, individual models are based on GH models. The individual models are handled independently by the team member according to his/her discipline and are used by each discipline to explore design options. Each student can work on partial models, which are parameterized according to the meaningful strategy for design exploration of aspects relevant for the discipline. To some extent, this may occur without strict restrictions in order to freely search for good design directions. However, while a number of parameters might be relevant for one discipline only, other parameters are relevant for multiple disciplines. These latter parameters are shared across disciplines and need to be truly checked interdisciplinary before identifying the suitable solutions. This results in discussing the shared parameters across the disciplines.

In addition to individual models, the core model is used. Mostly, the shared models are asked to be one total core model that acts as reference model for all disciplines in the team. The core model is usually a Rhino model and is shared on-line, mostly in a DropBox folder (or similar facilities for on-line shared directories). The core models are shared across the whole team and actively used as a tool for interdisciplinary brainstorming and as a reference for the individual partial models. During the entire design process, the individual parametric models keep being frequently integrated into the core

model shared by the whole team. This occurs either for a check and interdisciplinary discussion or for final decision. An example of process is illustrated in Figure 1; and a number of examples are presented in section 4.
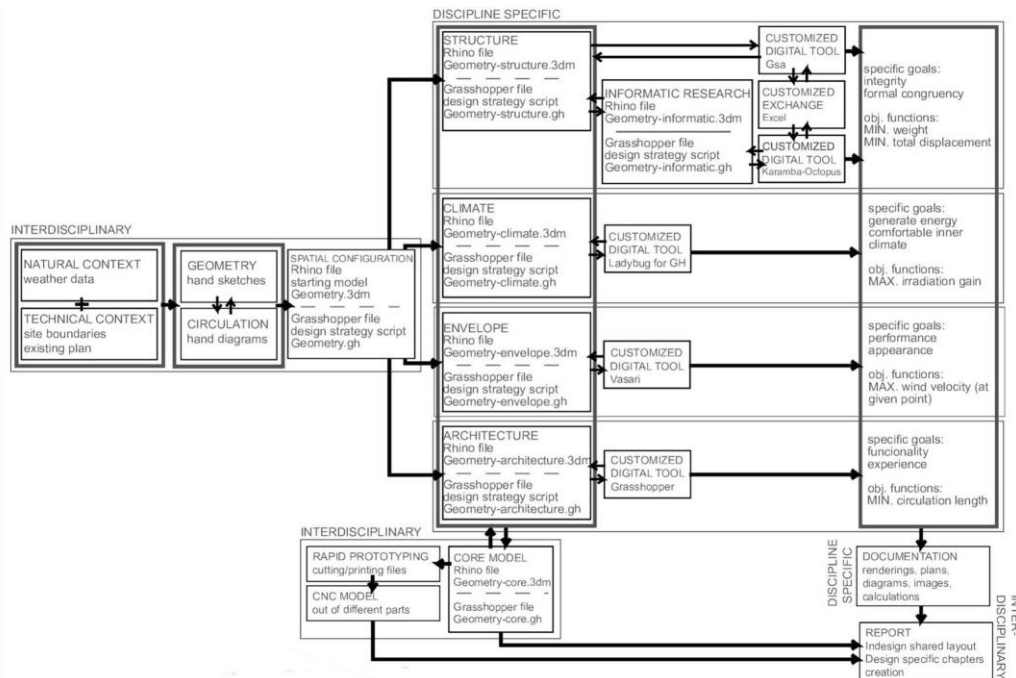

Figure 1: example of an interdisciplinary computational design process, developed by a team of students in 2013, coordinated by the student Mira Conci. (Source: Conci, [4]).

4 Examples

A number of examples are presented in this section, with specific emphasis on structural design.

4.1 Examples from structural design

In the teamwork, the structural designer is responsible for conceiving and developing the structural system, which is in it-self a major challenge due to its large span. The parametric models developed for the structure usually include individual parameters as well as shared parameters. Integration is especially required concerning architectural and envelope design. The nature of the parametric models greatly varies depending on the structural typology. Some examples are presented here following.

For the design assignment in 2013, a student-team (Osama Naij, architectural designer; Juan F. Azcárate, structural designer; Mira Conci, computational designer; Wenjia Wang, envelope designer) developed a New Thialf based on the re-use of the existing building and a new addition. The structural designer worked together with the computational designer to develop a parametric model and

optimization loop for the structure. Right after having defined a concept with the architect, the structural designer sketched a parametric concept-model, as illustrated in Figure 2, top.
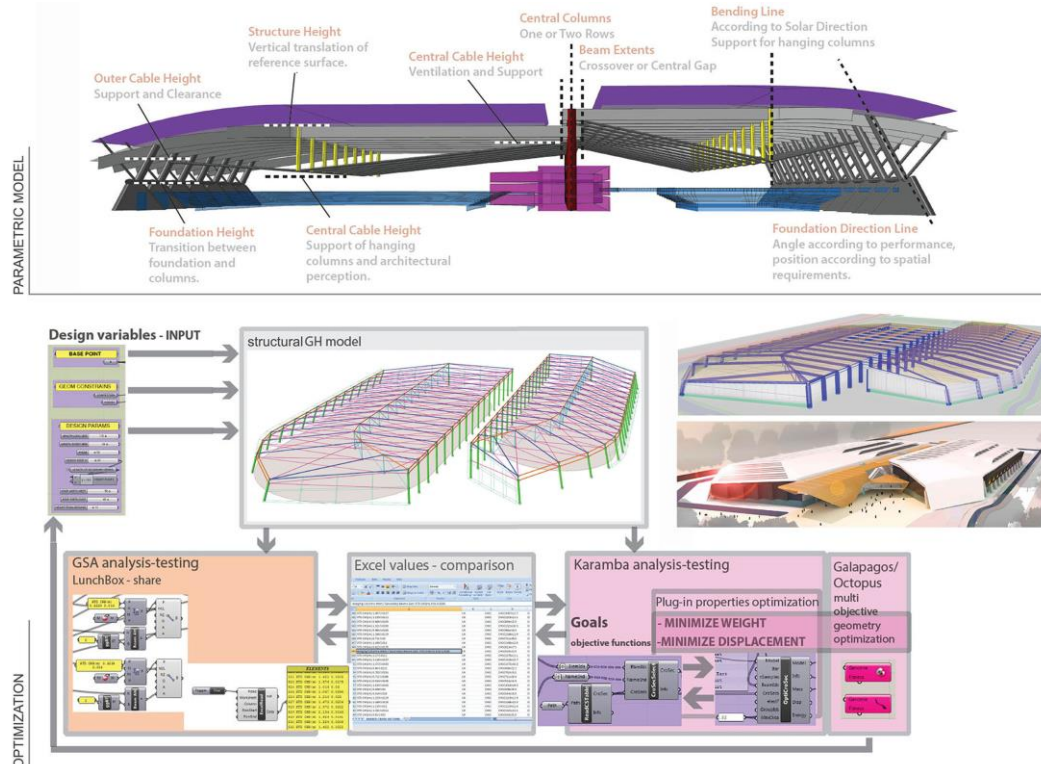

Figure 2: Process developed by students in 2013. Top: concept-model for structural design. Bottom: comparative optimizations. (Images/design by students: JF.Azcárate [1], M.Conci, O.Naij, W.Wang).

According to the student, at this stage working with parametric relations helped understanding how the primary beams could relate to the design surface generated by the climatic analysis, as well as the main heights and proportions for the architectural experience. As described in the student's report, the model incorporated parametric relations, geometric associations and constraints, such that parametric variations of the model were allowed while the relations between elements were still guaranteed. For example, in all solutions cables had to be supported on both foundations while holding the hanging central column without deviating from a straight direction. Testing different parameters allowed exploring the distance and density of the structural grid, the connections between vertical, tilted and horizontal elements, as well as to understand the location of the diagonal section of the beam, which, according to the student, resulted hard to understand without the use of a three-dimensional model. Moreover, the model allowed exploring the heights at which the cables meets the lateral columns; and the lowest point at which the central column hangs. The students realized that the lower this point could be, the better performance was expected from the cables as they would be further away from the

horizontal, however it could not be too low otherwise it would greatly affect the spatial perception of the visitors. Another example of interdisciplinary requirements regards the height of the cable's connection to the central column row and the lateral foundation columns, which should be low enough to allow a ventilation gap for climate control (Azcárate, [1]). In this concept-model, the parametric variations were generated by assigning different values to the independent parameters, chosen based on intuition and manually set. According to the students, this helped them understanding what variables could be altered according to the needs of their project. After this was achieved, an automatic optimization loop was set in Rhino/GH. Varying independent parameters changes the position of construction points and, as a consequence, the distances and angles between elements. The structural engineer and the computational designer worked together to set a cross-optimization process, to compare results from two different analysis: the one run in Karamba (a GH plugin) and the one run in GSA via Geometry Gym (a GH plugin which enables real-time communication between GH and the FEA software GSA, Oasys). The compared results were weight and maximum displacement. This overall process is illustrated in Figure 2. After this comparative optimization, a third optimization was developed by the computational designer by using Galapagos (a GH component providing optimization algorithms), and by storing data in an Excel file via gHowl (a GH plugin). This process is illustrated in Figure 3.
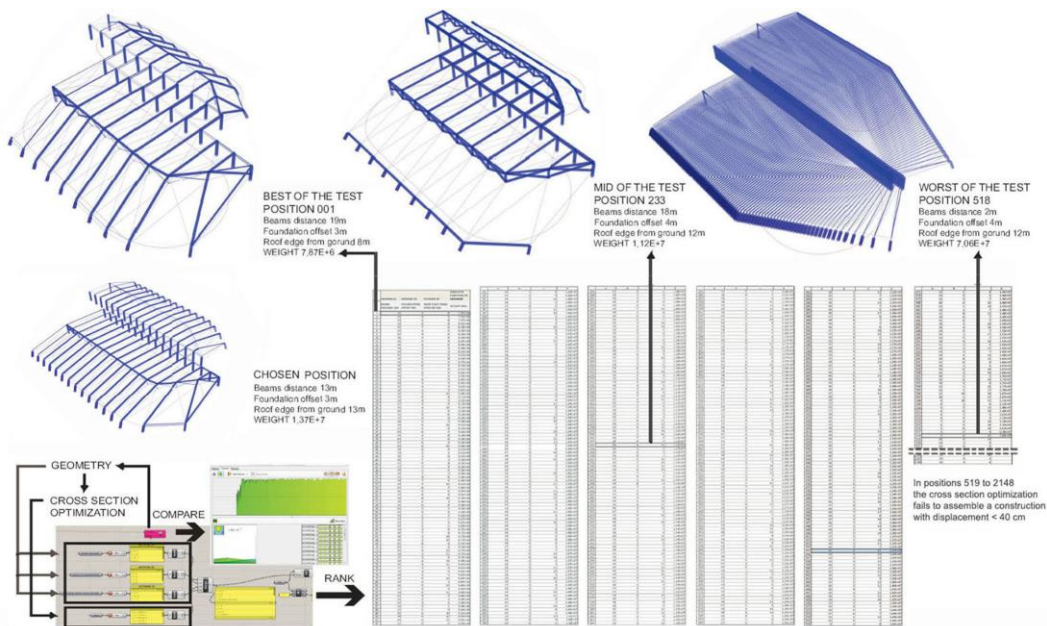

Figure 3: Optimization developed by students in 2013. (Images/design by students: J.F. Azcárate, M.Conci, O.Naij, W.Wang. Source: M.Conci [4]).

According to the students, this process helped them to understand the relations between design variables and performance results. This allowed reducing the meaningful design variables to three: distance between beams, height from ground, and offset foundations. According to the teaching objectives of the course, such attitude was appreciated. Indeed, students were encouraged to not use parametric optimizations by blindly accepting the outputs, but rather by critically using them as design exploration tools. In line with this, also the sub-optimal solutions were interactively discussed by the whole team, according to criteria not included in the fitness function and deriving from other disciplines too. The final design was developed by using a very good but sub-optimal structural solution, meaning a solution that did not emerge among the most optimal solutions.

For the design assignment in 2014, a student-team (Joost van de Ven, architectural designer; Zejun Pei, structural designer; Vivian Wijburg, envelope designer; Rusne Sileryte, computational designer) developed a snow-center based on circular large-span areas with in-between services and circulation. The structural designer organized his parametric models based on design variables from structure; and from other disciplines, such as the variable radius of the ski-dome and the dimensions of the ski-slopes. The structural solutions were explored in combination with inputs from functional arrangements, such as shape and height of the play-ground. The structural optimizations were then performed, by connecting the GH parametric models with Karamba. The computational designer coordinated this process, together with the processes from other disciplines; until the assembling of the final configuration into the core model. The process is exemplified in Figure 4.

4.2 Examples from envelope design

The envelope designer is responsible for developing a well performing skin of the building, matching the architectural vision of the whole project, properly integrated with the structural system and well performing for climate aspects. In the interdisciplinary collaboration, challenges usually concern the interrelations between structure and envelope as well as the impact of the envelope on the climate design. The parametric models for the envelope usually include individual parameters regarding paneling. They share parameters with the architectural models in relation to overall shape and functional layout; with the structural models in relation to the modularity of the structural system; and with the climate models in relation to shadings, glazed surfaces, and material properties.

For the design assignment in 2012, a student-team (Abbas Riazi, architectural designer; Erald Varaku, envelope designer; Ahmed Abbas, structural designer; Javier Zaratiegui, computational designer; Maysam Foolady, climate designer) designed a stadium near-by De Kuip, along the river. The envelope designer worked together with the computational designer to parametrically develop a quadrangular cladding tessellation designed based on a maximum allowed deviation from the flat condition of panels, for a double-curved surface. The constraint was taken from material properties (bending limit); the parameterization regarded the density of the cladding modules (and consequently their dimensions) and related to the underlying structural system (developed by the structural engineer in collaboration with the computational designer). The parametric structural model was used to generate space-frames based on various tessellations and on modules of various size; the structural performances of the alternative solutions were then simulated and compared. At the same time, the parametric model of the envelope was used to generate panels as sub-subdivisions of the various structural tessellations; the curvatures of the panels in the alternative solutions were then analyzed and compared to identify solutions that well match the options for cold-bending the panels.
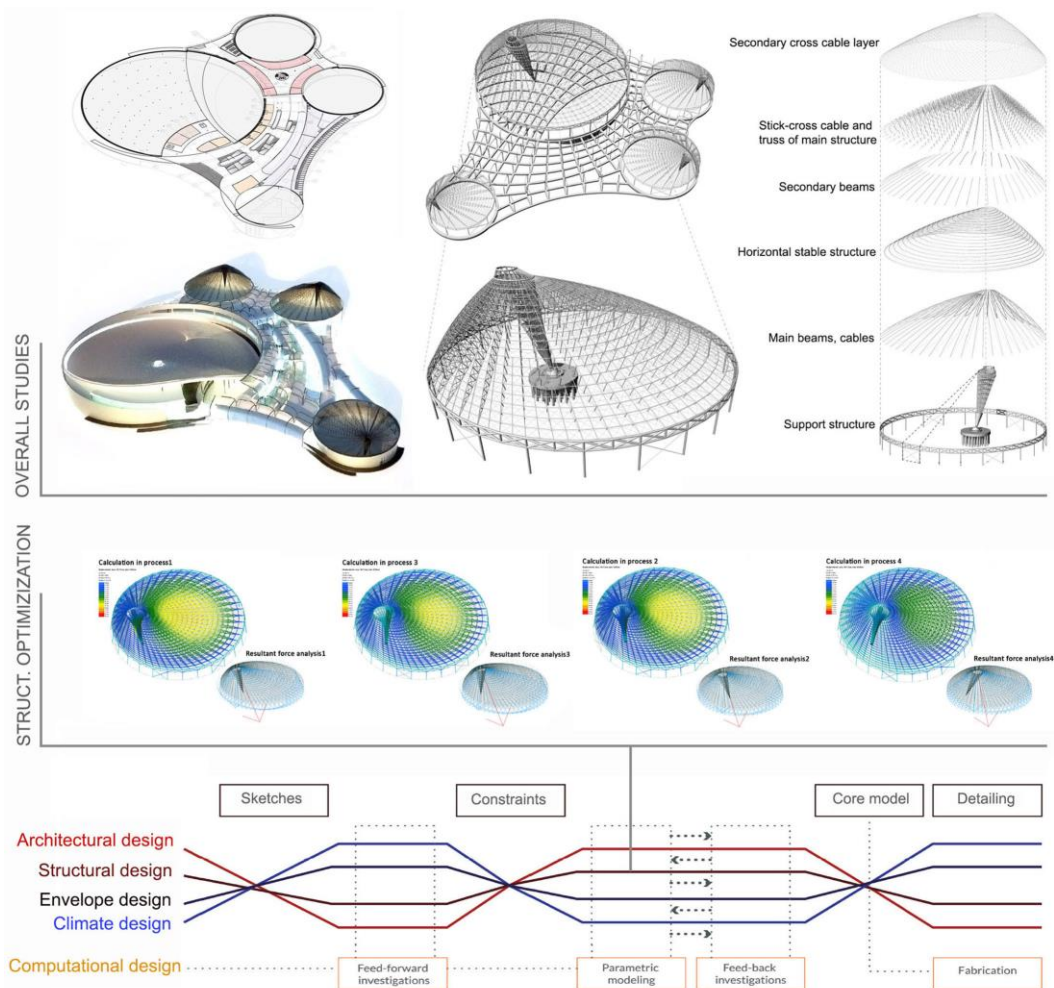
Figure 4: A design process developed by students in 2014, including structural optimizations.
(Images/design by students: J.van de Ven, Z.Pei [9], V.Wijburg, R.Sileryte [11]).

4.3 Examples from climate and computational design

The climate designer is responsible for conceiving and developing a sustainable and energy efficient climatic control (thermal and lighting comfort) of the building; and possibly an overall energy balance during use (in relation to climatic comfort). Major challenges concern the integration of the strategy into the architectural concept and the impact of the envelope. The computational designer is a design informatics expert, responsible for the entire digital process of the design. This is intended not as a technical support, but as a strategy-coordinator for interdisciplinary performance-oriented processes.

Specific tasks are the conception and coordination of the digital process for design explorations across disciplines; and the computational development of one key aspect of the process to be chosen according to the specificities of the project. While the coordination has been discussed earlier in this paper, in this section an example is provided regarding the computational development of one chosen key aspect.

As an example of parametric approach for the design assignment in 2012, a student-team (Anurag Bhattacharya, architectural designer; Niels van Dijk, structural designer; Wilton Danqing Li, envelope designer; Daniël Smidt, climate designer; Frederich Steenkamp, computational designer) developed a proposal for a stadium in the location of the current De Kuip. The overall envelope was designed in close collaboration between the climate and envelope designers, with optimized arrangements for solar panels to maximize the energy generation; by considering the orientation and inclination of each panel, the cumulative irradiation was maximized by using genetic algorithms in GH. In parallel, the computational designer developed parametric deterministic approach for the design of an adjustable roof controlling the acoustic behaviour of the sport hall when converted in concert venue. While a genetic algorithm optimization searches for well performing solutions among a large pool of possible solutions, the approach developed by the computational designer included formulas to define a correspondence between the desired acoustic performances and the resulting geometric configurations. The overall process is illustrated in Figure 5.
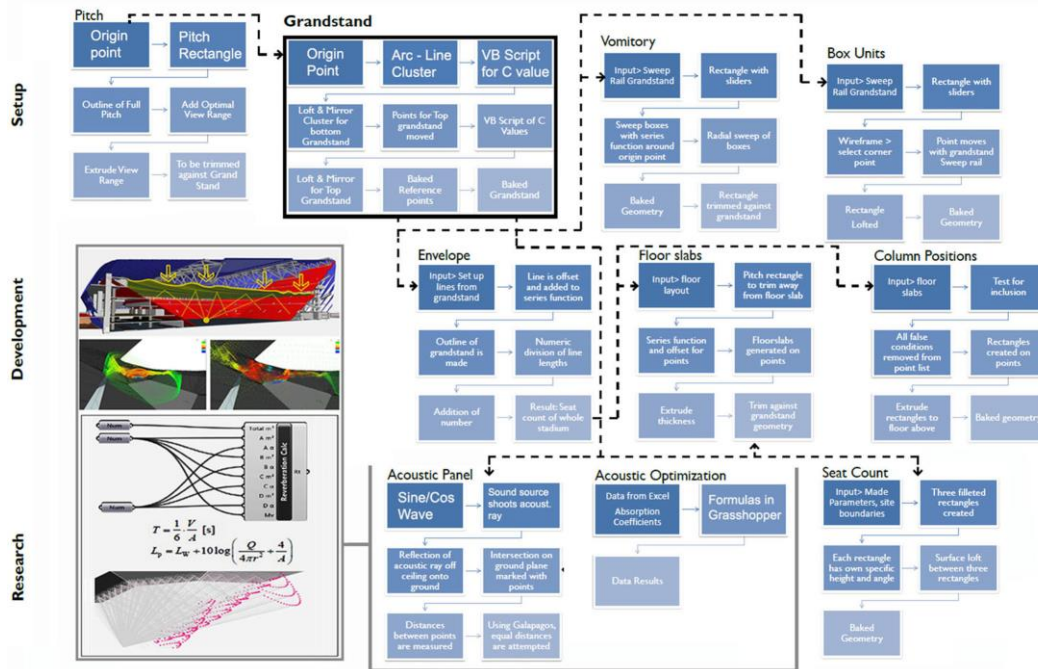

Figure 5: A design process developed by students in 2014, with deterministic process for acoustics. (Images/design by students: A.Bhattacharya, N.van Dijk, WD. Li, D.Smidt, F.Steenkamp[12]).

5 Conclusions

The paper indicates the importance of interdisciplinary collaboration in conceptual and development design, where computational tools, techniques and methods support the process. With reference to the BIG+TALL course, it presented examples from the XXL Workshop, in which students developed computational processes based on parametric design, performance assessments and optimizations. The examples show successful aspects, despite the short schedule of the course. Since students are asked to choose only a limited number of performance criteria and design aspects, their experience is simplified, but provides a model of workflow that can be eventually increased in complexity during their future experiences.

Acknowledgements

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