An Experiment in Multidisciplinary Digital Design

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Abstract. The design and realization of complex buildings requires multidisciplinary design collaboration from early on in the design process. The intensive use of digital design environments in this process demands new knowledge and skills from the involved players including integrating and managing digital design data, developing custom design tools, and utilizing visualization and rapid prototyping techniques. In order to prepare our students for these evolving practices we have developed a multidisciplinary collaborative design studio, named XXL, where student teams work in groups and each student claims a role: architectural design, structural design, digital design, construction and cladding design, and process management. In this paper, we describe the studio, discuss the contributions of the Digital Design Manager, and relate these contributions to design education and practice.

Keywords: Multidisciplinary design; design collaboration; digital design; architectural education.

Introduction

Modern digital design environments available to almost all designers and players within the design process allow for the creation and realization of complex designs. The realization of these designs requires a strong collaboration between the disciplines involved, especially the architect, engineer, manufacturer and project/construction manager, from early on in the design process, where the influence of the design decisions and contributions of all the players will have a major impact on the final design. In addition to the complexity of the designs, there is a pressure on practitioners to complete the design process faster. Furthermore, increasing demands on performance issues such as sustainability need to be taken into account early on in the design process.

Software tools exist that can provide feedback on both formal, visual and performance aspects of design and support discussions between the players in the design process at the early stages of design, also about issues of constructability and sustainability. Furthermore, software applications that link design models to CAM processes offer immediate feedback to designers about the possible manufacturing processes and other aspects related to manufacturing such as cost and fabrication time. However, in reality, a seamless integration of such tools into the design process requires the creation of custom interfaces between the various software applications or the merger of the applications in a single software environment used by all the players, which is often not
the case. Furthermore, existing software programs often do not support specific design tasks or solve specific design problems. Designers often need custom design tools in specific situations. These design tools are created using programming and scripting, often within a digital design environment and can thereby extend the functionality of those environments within the design process.

Scripting as a means to create custom design tools is rapidly becoming widespread in design firms. Parametric design and design generation and exploration according to parameters and constraints are used by large and small architectural and engineering firms. Many large firms that use complex geometry forms as part of their formal vocabulary have created specific groups whose members are experts in creating design tools for active projects in order to support the design process of the designers in the firm. Some examples are the Specialist Modeling Group (SMG) of Foster and Partners, Advanced Geometry Unit (AGU) of Arup, and Computational Geometry Group (CGG) of KPF. Although these groups are of different sizes and operate differently, the aspect they have in common is that members of these groups have knowledge, understanding and skills of design, modeling and computation.

Scripting as a means to create custom tools in design is uncovering a new aspect of designers: ‘designer as a tool builder’ (Oxman, 2006). Time will show if this becomes a sub-profession in the building industry or an integral part of designers’ abilities. In both cases, designers need to have an understanding of scripting and algorithmic thinking in order to understand the opportunities and limitations of digital tool building and to be able to communicate with tool builders. Builders of digital design tools, conversely, need to have an understanding of the act of design and its inner dynamics in order to communicate with designers as client on a conceptual level.

**XXL: Design + Engineering + Management**

Interdisciplinary collaborative digital design practice is being included in architectural education, in bachelor as well as in master programs, in order to prepare students for the evolving practices and provide them with additional skills in building design and construction. In this context, we have developed an elective design studio, named XXL: Design + Engineering + Management, in the M.Sc. program of our architectural education. The subject of this course is the design, computation, engineering, production and management of a horizontal large span building structure and cladding. The latest design project is based on an existing development project of a large soccer stadium in Rotterdam. This design process is performed as a collaborative, multidisciplinary and digital design process in groups of five students where each student in the group has her/his own individual responsibility according to her/his assumed discipline within the group. All students in the group are collectively responsible for one single design, and each student takes on a different role. The students represent the following disciplines: architectural design, structural design, digital design, construction and cladding design, and process management. Assigning professional roles to students enables the contribution of the involved disciplines from the onset of the design process. Each team is organized along the lines of a professional design firm and develops its own design. This results in an integrated design approach that also serves to speed up the design process, highly necessary due to the limited time frame of the studio. Similar to the highly fragmented architectural design practice the knowledge of digital design environments and the vocabulary used by the actors in the design process vary from team to team and from member to member complicating communication. Similar problems occur in XXL because the disciplines are assigned to students with various educational backgrounds. The possible lack of specialist knowledge and knowledge
of discipline specific digital design environments is a major problem in the effective contribution of students to the design process during the early stages.

The studio runs for eight weeks and students work full time. Students of architecture as well as civil engineering follow the studio. The design project is an actual development: the new Feyenoord stadium in Rotterdam, located a few hundred meters from the current stadium at Sportpark Varkenoord, with a capacity of 75,000 spectators. The building should be a landmark and be suitable to host the final championship games of the World Cup in 2018. Since the project is an actual development, the intentions, goals, restrictions and regulations from Feyenoord B.V, De Kuip N.V., Rotterdam municipality, neighborhood, KNVB and the FIFA/UEFA all need to be addressed. The composition of the spectator seating and the circulation routes of the stadium are not designed by the students. An existing 3D model of the stands of the Allianz Arena in Munich is used by the students as a reference for the size and functional arrangement of a similar sized stadium. In the first two weeks of the studio each group develops three alternative sketch designs. At the end of the second week a pinup review results in the selection of one of these alternatives per group. The groups continue working on their design for the rest of the studio and manufacture scale models. The teams are evaluated on the quality of the design process and the product, weighted equally.

The students investigate a wide range of topics within the design process: the complex relationships between function, form, performance and manufacturing, and their integration in the design process. In this context, the interaction process between design, engineering, analysis, manufacturing and construction, the influence of (new) production methods on design and engineering processes and coherent management, and the social, economic and management consequences of changing production methods and production and construction processes are also considered.

The digital design manager

Effective collaboration is paramount within the complex multidisciplinary design environment of XXL. This is not only due to the tight timeframe of the course which necessitates an integrated design approach and thereby tries to minimize major design iterations in the later stages of design, but also the structure of the course dictates a contribution of the students based on their discipline from the start of the design process.

The contribution of the ‘Digital Design Manager’ (DDM) within the interdisciplinary design team focuses on the digital design data management and advice on and implementation of digital design environments in a collaborative design environment. In this context, the digital design manager must acquire an intimate knowledge of the properties of design geometry and its representation in relation to the functionality of digital design environments.

The task of the DDM varies throughout the different stages of the design process. However, there are four main areas in the design process where the DDM contributes:

1. Managing the digital design data in a web-based environment and in a condensed form, managing (extracting and integrating) digital design data in the 3D master design model: The DDM develops digital communication and data management strategies for formal and non-formal digital data. The data management and communication support role of the DDM in the collaborative design process is facilitated by a web based database called InfoBase where formal and non-formal digital data can be stored (Stouffs et al., 2004). The easy access to the centralized data assists the DDM to communicate and organize the design data and offers the other members of the design team an opportunity to share information and keep track of the various stages of the design process and the latest design data. The formal design data is condensed in a shared building model in support of the collabora-
The master model is not only used as a shared up-to-date design representation but also as an up-to-date source for analysis and simulation by all members of the design team. In support of an effective cross discipline communication of the formal digital design data a common representational vocabulary (NURBS) is introduced to the students at the start of the studio. Besides this intensive training at the beginning of the studio to enhance the knowledge of the students regarding their specific discipline, the DDM also focuses on pre-rationalized digital communication protocols in support of effective cross-discipline communication between the team members. The DDM is responsible for helping to define and for maintaining the master model in support of design flexibility and formal digital design communication and exchange.

2. Advising and mediating between the users of digital design environments within the larger collaborative design environment: The role of the DDM in this is not only one of support for the members of the team in their efforts to come to terms with their digital design environment but also to act as a cross-discipline mediator in support of the integrated digital design process. As the studio proceeds, the DDM is able to integrate the in-depth knowledge and experience she/he has gained on the functionality of the digital design environments, the 3D digital geometry properties and file conversion into the digital communication protocols. Insight into the digital geometry type properties within the context of the functionality of the digital tool enables the DDM to determine and advise on a modeling strategy for the formal digital design data in the early stages of design when design flexibility is paramount. However, the collaboration in this multi disciplinary digital design environment is inherently difficult as conceptual and technological barriers can frustrate the design process (Fisher, 2004).

The DDM advises, if possible, on a modeling strategy based on the parametric properties of the digital design environment in order to maximize design flexibility. This advice takes place in the context of the capacity to extract and re-integrate formal data from the master model in support of design interaction between the members of the design team. However, due to the nature of the design task, the advice of a modeling strategy can be hampered by the limitations of the digital design environment. The possible complexity of form but also the large amount of non-uniform building elements drastically complicates the design process.

3. Developing and applying digital design and manufacturing support tools within the collaborative design environment: Additional tools for solving specific problems or exploring specific issues may have to be developed in order to extend the functionality of the digital design environments used in the studio. In this case, the role of the DDM as advisor and manager changes into a tool builder. The role of tool builder requires an expansion of digital design geometry knowledge in relation to digital design environments with specific knowledge about scripting. The DDM uses available knowledge and insight of the design environment and takes advantage of her/his central position within the design team already developed through her/his advisory role. The scripts can be developed in the context of multi-disciplinary design, taking into account various multi-disciplinary design criteria, resulting in tools that originate from the needs of and that can be used by all disciplines.

4. Utilization of visualization, rapid prototyping techniques and digital manufacturing within the integrated multidisciplinary design environment: Besides the generation, transformation, modification and communication of formal digital design data the DDM advises on various possible outputs based on the formal digital design data.
These outputs are used in the design process in various stages by all participating disciplines. This can entail the implementation of rapid prototyping techniques, visualization and digital manufacturing. However in this course where the final design of the students has the status of a preliminary design, the implementation of digital manufacturing techniques is limited to a rapid prototyping role. Depending on the availability of the hardware the students decide what technique, if any, will be used during what stage of the design process. With 3D printers, laser cutters and a 3-axis milling machine available there are various options of supporting the design process in various phases.

**The digital design manager and the design projects**

The XXL studio contained two multi-disciplinary design teams. These teams called themselves ‘NewKuip’ and ‘Icono’. In this section the design processes and projects of these two groups are comparatively described with a special focus on the contribution of the DDM to the process and project.

At the start of the course the DDMs of both teams provided their team members with a data organization structure similar to most professional offices. The centralized storage of digital data was supported by a customized folder structure on InfoBase made by the DDM based on the various disciplines, type of data and purpose of the data. In order to streamline the communication process both groups used a variety of conventions regarding the use of layers, object and file naming and use of pen colors.

The design support of both DDMs was focused primarily on three areas of the design process. The first was related to the use of the master model which was constructed in Maya. Although the use of a centralized 3D model proved effective in supporting the communication process, it provided them with additional work, which varied between a large amount of time spent on file conversion (Icono) and maintaining the Maya master model (NewKuip). The second area where the DDM’s focused on was general design support in the early stages of design to speed up the process. The third main area where the DDM’s focused on was scripting. The generation of customized tools was a major task for the DDMs. This role however was complicated by the fact that both DDMs had no prior experience in scripting. In order to tackle this problem the DDM’s started using and analyzing existing scripts in combination with scripting consults with the instructor. These modified scripts were used to support the sketch concept design phase in the first two weeks. This process provided the DDMs with more insight into basic scripting and on how these self built tools could support

![Figure 1](#)
Team NewKuip: Left: The outer envelope of the stadium; Right top: The structure supporting the roof; Right bottom: Diagrams showing the outer envelope with the circulation route and the structural elements.
the design process. The DDMs were able to build on that knowledge with the help of the instructors and developed various tools that played a major role in the design process of both teams.

Although both DDMs used scripting in support of the design process, the function and amount of scripts varied. In both cases scripts where produced to investigate variations of the design and support the generation of a given overall 3D geometry. The DDM of NewKuip first focused on support of the design of the diabolo shaped envelope in order to kick-start the design process (Figure 1).

One of the first scripts developed by the DDM of NewKuip was for defining the shape of the diabolo and determining the esthetic effect of the structure in relation to the shape. Further scripts were developed to optimize the dimensions, amount and size of structural elements within the context of the overall appearance of the building. Due to the typical form of the envelope a variety of scripts where developed to create floors and elevators. In contrast to Icono the rationalization process was dictated by the form and esthetic appearance of the envelope. A total of ten different scripts were produced ranging from a layer generation script to a special script to generate the roof trusses in such a way that it was optimized for structural analysis (Figure 2).

The Icono group used the concept of stacked containers to describe the envelope of the building, as a reference to the seaport function of Rotterdam (Figure 3). Due to the complexity of the shape, the amount and resulting variation of the ‘containers’, it was decided to build a tool which would support the design of the envelope. Knowing it would take weeks to finalize the script the team decided to go ahead anyway. The script was developed based on a rationalized form of the envelope, based on a construct of arcs, and would support the manipulation of the dimensions of the containers, the amount of layers, the pattern and the horizontal and vertical radii of the arcs. A graphical user interface provided the designers with the option to change the layers and the sizes of the containers. Additional changes in pattern and surface radii were only possible by changing the script. The result was a 3D model of a rationalized envelope where the containers were correctly skewed, in order to compensate for the inner and outer radius of the envelope, and connected. During the development of the script the other members kept working on the functional, structural and architectural design of the envelope and the rest of the building. A second script was created to support the generation of geometry from a set of curves. This script was based on the provided rafter script and was used to generate the 3D structural elements.

The tight time frame of the course inhibited the use of available rapid prototyping techniques until the final presentation model. Unlike the Icono group, the NewKuip group used the laser cutter in the beginning of the design process to make a simple
model of the stands. The model was used to gain scale reference of the stands in comparison to the diabolo. The final presentation model, a complex 1:500 scale cardboard model, was also made with the help of the laser cutter (Figure 4). The roof was not made, due to the complexity of the form. Although the plan was to mill or laser cut the roof, the final shape was defined too late in the process to leave time for rapid prototyping.

The Icono team started quite early with their preparations for the final presentation. As soon as the design support tools were completed and the envelope was finalized with the help of the scripts the DDM focused on the techniques that could be applied to generate a scale model (Figure 5). The laser cutter was used to cut the floors, containers and rafters. Correct name giving and cataloguing was paramount due to the large amount of objects. The roof was partially made of a transparent vacuum formed plastic material. The form was milled in foam and was based on a rhino 3D model of the roof.

Conclusions

The DDE is evolving in the building industry as an indispensable member of a design team, and we are educating our students to gain competence in relation to the changing demands of the industry. The XXL design studio as an educational experiment is an example of a practical situation where the project team members have little knowledge and experience in designing in a digital environment and working in a multi-disciplinary design team. In spite of this lack of knowledge and experience the teams succeed in producing satisfactory design processes and projects. The teams achieve this through learning through problem solving, directly applying the acquired knowledge and testing the solutions. Learning by doing and getting specific consultations from specific experts (i.e., instructors) enable students to produce rich designs.

The description of DDM provided to the students at the beginning of the studio is relatively loose. Students cannot exactly grasp the discipline of 'digital design manager' and do not understand what is expected of them at the beginning of the studio. Although the description of DDM is loose, the students do receive a description of tasks and areas of operation for the DDM. After this initial confusion, during the progress of the studio, the DDMs operated smoothly and contributed substantially to the process and the project. At the end of the studio...
they could clearly describe their contribution as a team member. Their role in the team was very clear to them. This observation points at a natural evolution of the role of the DDM in a design team.

The contribution of the DDM was not equal in both groups, but a global description of the contribution of DDM can be defined in various stages of the design: first, a kick-off start of the design process by a description of the desired geometry; second, support of file conversion and maintenance of the 3D master model; and third, by scripting and building specific tools for specific purposes. The DDM has worked with and contributed to the work of every discipline in the team. Furthermore, the DDM enabled continuity in the formal communication of the group through the 3D master model.

There is a risk that the DDM is perceived by the remaining team members as a person who builds 3D geometry. However, the premise of the studio is that every team member should be able to work with digital design environments and construct their own design information digitally. The intensive instruction period of two full days in the first week of the course was aimed at ensuring this. In a further run of this studio this intensive education at the beginning must be longer in order to ensure that everyone in the course has a comparable knowledge and skills of digital design environments.

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References


