Computational Design and Construction
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Vision
From the historical perspective, the role of computer technology in the information age is comparable to the influence of mechanised production on industrial society, or that of land management on the agrarian society. Changes in the tools of production have always changed society – and, by extension, architecture [1]. The increasing influence of digital technologies on the conception, development and implementation of architectonic design has become particularly visible in recent years. Computers have now been introduced into almost all architecture firms, together with the appropriate programs and applications. Generative designing methods, Building Information Modelling (BIM) and digital fabrication technologies are playing an increasingly significant role in the evolution of architectonic forms. The comprehensive representation of three-dimensional design concepts permitted by digital simulations, which also permit direct interaction with the virtual model during the design process –significantly expands the designer's awareness of spatial relationships. The computer is now capable of representing the whole designing and planning process, from the first concept visualisation to the completed 3D building data set. This situation calls for an architect's classical task areas to be redefined. It requires architects to become familiar with a new language and to understand the methodology that lies behind digital designing. Recognising the potential this offers promises more than simply new designing possibilities. Above all, it restores the architect to a central role in the whole architectural production process – from the initial idea to the completed building. This development holds out the prospect of simplifying processes in many areas of architectural development through the ability to respond more quickly to changes in the design, by saving time through automation, by increasing economic viability through this saving of time, by reducing the number of interfaces and potential sources of error and through the ability to directly transfer the digital results into physical results through the use of CAD/CAM [2].

The computer is surely the most comprehensive and dynamic medium that architects have ever had at their disposal in completing their work. The possibilities inherent in digital designing methods bring new freedoms to the development of architecture. In order to benefit fully from this potential, however, those involved must recognise the computer's ability to function as an interactive instrument, and see its artificial intelligence as a creative asset. Professional handling of digital media allows architectonic quality to remain in the designer's area of responsibility from the first draft to realisation, while increasing the designer's influence on the future development of architecture.

Methodology
The three specimen projects described here are part of a series of student projects designed, developed and implemented at the Detmold School of Architecture and Interior Design, Hochschule Ostwestfalen-Lippe, over the past few years with the aid of digital tools. Aside from transmitting knowledge and expertise relating to parametric design, the assignments given to the students were geared to the onsite use of digital fabrication technologies. The students' work was created in the context of a continuous development process – from the first formal idea to the integration of functional, constructive and materials-specific aspects into the designing process, to the manufacturing processes – incorporating diverse disciplines, workshops and collaborations with external partners.

SunSys
Jens Böke's BA dissertation [3] was produced in response to the Detmold School's need to provide students on its campus with outdoor facilities, particularly for summer use. First,

parameters for the design were established by analysing onsite conditions using digital tools such as GPS tracking and sun position analysis. In particular, existing patterns and structures of movement onsite, usage timeframes and alignment in relation to the course of the sun and to changing patterns of shade were used as source data for the designing work, into which they were incorporated generatively. Analysis of pedestrian routes and shade conditions were used to find the best possible location for the pavilion, in the plaza between the main buildings. The values for the structure's graduated succession of open and enclosed sections were derived from the findings of the time-usage analysis and the sun analysis. The profiles of the different usage areas, which give the spaces their form, were created with reference to the seating elements – chairs, benches and deckchairs. Users in the secluded zones are shielded from the bustle of the campus. These areas, however, do not feel shut-off or dark. Here, the roof part of the structure is open; in the areas of the pavilion designed to function as seating areas, it is closed. Based on the analysis, the sun vector for the day timespan was used as the reference point for creating the openings in the structure. (Fig. 1)

The parametric structure model for the design that was ultimately put forward is based on a modelled output form. The individual surfaces of this output form were converted into a parametric definition, which was then given the appropriate structure. The pavilion was to be constructed from planar elements connected at an angle of 90°. The individual elements differ in shape, but can be manufactured on a CNC lathe using a single, unified principle. The structure of the openings is created solely by scaling the individual elements.

The fact that the structure is based on a formal principle means that SunSys should also be understood as a prototype for this principle. Given a different set of parameters, it would produce different major forms and different use functions, but the principle would remain the same. It is an illustrative example of the potential benefits of parametric designing and the resulting production processes. The individual building blocks, which also constitute the connective elements, are based on a formula that incorporates all parameters, but also permits endless variations in terms of combination, allowing for an ideal form with a high degree of diversity and precision (Fig. 2) [4].

Design to production

This architectural diploma dissertation by Frank Püchner took as its starting point the possibilities for producing curved surfaces using computer-assisted tools [5]. He investigated a number of construction systems in relation to digital construction variants, also implementing them as physical models. The first step was to produce the base geometry, a translation surface composed of sine curves, on the computer. This then served as the starting point for the investigation of a variety of production and construction variants.

During the next phase – the actual production phase – it emerged that changes and additions to the digital data model (in terms of values, materials, positions, details and other factors) would be required in order to implement the digital model using computer-controlled machines. In particular, it was necessary to integrate readings on production tolerances, static requirements and connection and join parameters, and the properties of the materials used (various wood types, hard foam) into the dataset involved in the transition from planning to production (Fig. 3).

To avoid having to produce the 3D model again from scratch as a result of these optimisation measures, a parametric model permitting adaptation was developed using Rhinoceros 3D software. The digital model was duly parameterised with the aid of the Grasshopper plug-in [6], enabling modifications to be applied to the model in a holistic way. This allowed all the building blocks in the process to be simultaneously controlled and altered by means of a single central file. Grasshopper's visual programming also provided a template for practical implementation of the series of experiments. This resulted in a digital process chain capable of serving as the basis for a continuous development process, from the creation of the concept geometry to the refining of the 3D model to the realisation. The parameterising process allows any construction approach to be directly adapted and optimised, and to be evaluated in design terms.

In addition to the triangulation, horizontal layering and insertion raster system production principles, Frank Püchner's architectural diploma dissertation incorporated the ZIP principle [7] as developed by Christoph Schindler, programmed as a functional dataset. As a result, these digital tools do not relate solely to a single geometry – they also allow for the production of diverse single- and double-curved geometries.

Sparkler

Sparkler is a three-dimensional interpretation of the well-known study of proportions by Leonardo da Vinci, which shows the Vitruvian man within a circle and a square. Seen from the outside, this experimental pavilion [8] resembles an angular crystal, while its interior conforms to a perfect spherical geometry. These two basic forms are interconnected by the extended edges of a regular Archimedean form – a blunted icosahedron [9] – in such a way that the resulting spatial sculpture appears as an internally harmonious shape. This also means that the structure, which is composed of pentagons and hexagons, has formal similarities to the constructions of Richard Buckminster Fuller [10].

In the first stage of the designing process, a parametric geometrical model was constructed with the aid of the Rhinoceros/Grasshopper 3D modelling software. This geometrical model allowed the base geometry for both the interior and the exterior – a sphere and a block as space-enclosing volumes – and the various interface surfaces that ultimately create the form of the body to be placed in relation to each other. This 3D model, created to serve as a designing machine, made it possible for a large number of variations on the basic idea to be produced quickly, evaluated and compared. Varying the sections on the external sides allows the pavilion to occupy seven different positions. As well as expanding the possibilities for use, this also alters the appearance of the sculptural structure in ways that are dependent on angles of perspective and on the contact area selected (Fig. 4).

Additional information relating to production was added to the parametric model in order to prepare for production of the individual components using CNC technologies. In addition to optimised cutting to size of the panels (known as nesting), integrating the material thicknesses and the required tolerances for assemblage, logistical aspects were a factor in the construction, deconstruction and reconstruction of the digital model. In addition to helping to visualise the design spatially, a scale wood model created using the laser cutter (1:10) assisted in the preparation for and testing of the subsequent assemblage process.

Because the prototypical structure can be developed in an idealised process, allowing a fundamental understanding of the methods presented, the pavilion's typology presents a suitable field of experimentation for new spatial concepts. The 90 different geometrical multiplex panel formats from which Sparkler is composed are connected by over 120 laser-cut force-fitted steel connections. This means that the structure, which is based on a "buckyball", shows statically optimised loadbearing behaviour, and also permits serial production of the identically shaped steel connectors (Fig. 5).

Innovation

Innovations that develop in other branches of industry frequently find their way into architecture at a later date. As has been pointed out by Michael Hensel and Achim Menges, the introduction of CAD/CAM applications exemplifies this phenomenon in analogy to previous technological developments: "Long-standing, traditional ways of seeing and thinking predominate, coupled with polarised positions on how to respond to the new innovations" [11]. In spite of this apparent reluctance, the influence of the digital revolution on architecture is already clearly visible. As well as changing the formal shape of our built environment and the way we perceive it, the use of the computer has also changed the way the various parties involved in architectural construction operate. This makes it all the more important to adopt an active and critical attitude in following these developments.

Currently, we feed data into the computers, defining the extent of the research and defining the fundamentals, the idea and concept. In the future, the machines will be able to learn for themselves, enabling them or their operational arms autonomously to find the best ways of creating the right form for a concept, to make an informed decision. The aim of the postgraduate Master's degree in *Computational Design and Construction* study programme at the Detmold School of Architecture and Interior Design, based at the Hochschule Ostwestfalen-Lippe, is to make use of the considerable potential inherent in these developments. It is based upon a professional profile that unites digital drafting and production methods to create an overall perspective. This means that in addition to relevant specialist architecture and interior design subject matter, the syllabus includes basic informational science and computer-aided production. One significant factor in the complexity of the planning process is the number of requirements, relating to the various specialist disciplines, which must be integrated together as one progresses from drafting to realisation. This calls for design, planning, technological, organisational and communication skills on the part of the planners. Classes place a particular emphasis on the interfaces between the various disciplines and phases of planning. This is partly in response to the increasing demand for graduates with good qualifications in the interdisciplinary field, who can bring together information technology, architecture and design [12]. (Fig. 6)

In our 21st century, computer and information technology is fundamental. Digital information has become a basic requirement for the designing, planning, construction and maintenance of buildings, and for uniting all the partners involved in the planning and realisation of architecture. The real innovative potential of digital technologies for architecture lies in the possibility of bringing together the different processes in a consistent building data model [13]. Against this background, BIM is a digital planning method that interconnects all processes involved in the designing, planning, execution and management of a building. All information is entered into a databank, and is linked associatively by means of a parametric system. Aside from graphical information relating to the building's geometry, this includes non-graphical information such as quantitative measurements, materials, time values, usages and costs. Modifications made to any one of these levels – 3D levels, ground plan or building component lists – are directly reflected on all other levels. Aside from comprehensively combining all information pertaining to the building for purposes of architecture planning, BIM also provides a connection or interface with other agencies involved in the planning process: for structural issues, for in-house systems in relation to building physics and facility management. The advantages of using this planning method include improvements to the planning process and to planning quality. The use of a shared database that is continually synchronised and immediate access to all current and relevant data results in a significant improvement in information exchange between those involved in the planning process.

At the designing phase, parametric models permit the investigation of different variants on a single principle. Constructing a data model of this kind defines the initial output situation, which can then be flexibly adapted as the process progresses. Knowledge of programming is indispensable for producing this model. Algorithms are created for the design's basic geometry; these permit the geometry and other aspects of the model, such as the materials and the construction, to be altered at a later stage. On this basis, the conditions for the design can be individually defined and manipulated. This fundamentally changes the designing method – and, consequently, the real-world implementation of the design. The impact of knowledge from other disciplines on architecture – such as IT and production technology – is increased. The really important issue will be the level of priority that is given to these areas and the aesthetic and functional results that are produced. As architects, it is incumbent on us to meet this challenge and to find an independent architectonic means of expression for our digital age.

Fig.1 Design for the SunSys pavilion for the Campus Emilie, Hochschule Ostwestfalen-Lippe
Fig. 2 SunSys, structural principle
Fig. 3 Construction variants for a translation surface
Fig. 4 Parametric 3D model of pavilion
Fig. 5 Sparkler pavilion at Campus Emilie, Hochschule Ostwestfalen-Lippe
Fig. 6 Master Computational Design and Constrcution, Hochschule Ostwestfalen-Lippe

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