FULL-SCALE MATERIAL PROTOTYPING OF BUILDING COMPONENTS IN A VIRTUAL ERA

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ABSTRACT
The Laboratory for Product Development at the Delft University of Technology has been in operation for 8 years and it is unique in architectural faculties of universities all over the world. Its function is primarily to educate third and fourth-year students about the importance of prototyping in the process of building component design and product development. In a course of 8 weeks students go through the entire cycle of design, engineering, prototyping, testing and improving. This way they get confronted with tolerances of production, real materials, production techniques and the construction of a prototype. This prototype course serves as an up to date antidote against too much faith in virtual designs, which always seem stable and faultless, but seldom are after the complete materialisation.

Keywords: Prototyping, Product Development, Building Technology, Architecture

1 INTRODUCTION

The Faculty of Architecture TU Delft has a special place in the field of architecture schools because of its decades long tradition of integration of Architecture and Building Technology. The current trend for architecture students, however, is towards conceptualisation, away from technology. To revert this, a ‘Building Technology’ graduation course was introduced by prof. Jan Brouwer in 1992. The Chair of Product Development and its professor Mick Eekhout were also involved. He is one of the rare professionals in the architectural practice who both designs and builds his experimental projects. He followed design & build pioneers like Felix Candela in Mexico, Jean Prouvé in France and Pier Luigi Nervi in Italy. His ‘design & build’ company Octatube in Delft [1] unites design, engineering, production and building in one hand; integrates architectural, structural and industrial design and continuously strives at product innovation by experimentation. Many experimental ‘arch-technical’ designs have been successfully realized in the last 20 years of its existence. More or less to this practice example the Chair of Product Development urged the need for a workshop annex prototype laboratory for Building Technology students, to give them a direct contact with materials and techniques, to take away the possible cold feet and to show the positive influence the material world has on design and engineering. In 1995 this laboratory has been opened. It existed for 8 years in an old workshop at the TUDelft, but moved finally into the building of the faculty of Architecture last year, next to the large “Vormstudie” Hall. Many prototypes have been built in the last 8 years. The last one will even function as an international beacon: the reconstruction of the prototype of the famous Maison d’Artiste as designed by Theo van Doesburg and Cor van Eesteren in 1923. From this research project historically new knowledge and insights in sizing (up to 15% difference) and a revolutionary different scheme of colours were deducted. A public debate on these topics will follow.

Figure1-2. Built prototype of the 'Maison d'Artiste' at the Faculty of Architecture, Delft (Fotografische Dienst Faculteit Bouwkunde, TUDelft)

2 CURRICULUM

The Chair of Product Development is responsible for education and research in the development of new building products in general. The existence of the chair is strongly connected with the overall increase of prefabrication in the building industry. Product development of industrialised and pre-fabricated building components results in 3 main product types:

- Special one-off components;
- Repetitive building system products;
- Standard building products.

These three main types of products differ in their development to other capital goods in the market like complete buildings in their complexity, but their particular development processes are distinctly compatible. In the design process for all three types of building products a relation diagram can be drafted like figure 3. In order to position the need for prototyping, the different related fields of study are represented in this nucleus. The nucleus of Product Development (PD) engages the design of the three main types of components as to function:

- Structures of buildings (load bearing structures, like façades);
- Constructions of buildings (secondary structures, like the building skeleton);
- Climate design components of buildings (like PV-cell glass roofs).

These three functional components are overlapping partly and together form the technical composition of the building as the final artefact. The PD nucleus is encircled by three orbits of different character:

In the first orbit the related basic sciences are represented:

- Applied Mechanics,
- Building Physics and
- Materials Science.

The second orbit contains the servicing items:

- Development Methodology
- Design Management
- Informatics

The third orbit is the industrial environment. The three industrial fields of interest are:

- Production Technology,
- Production Assembly and
- Site Installation.

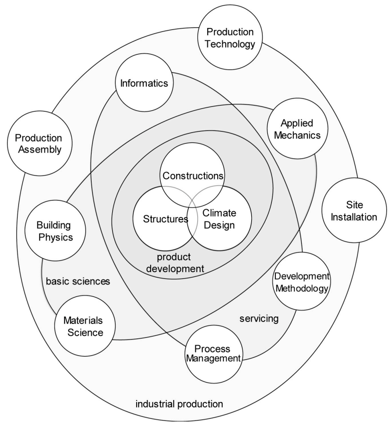

Figure 3. Product Development (PD) and related science fields nucleus

The PD nucleus and the three orbits contain the arena of Building Product Development, which is one of the vital ingredients of the Masters of Building Technology (MSc BT). This Masters course is one of the four Masters at the Faculty of Architecture: Architecture, Urbanism, Building Technology and Real Estate.

As a consequence the Chair focuses on the design & development process from the concept design of building components, the preliminary marketing, full-scale prototyping & performance evaluation, final marketing and the preparation of real production (see figure 4). This curriculum part is compulsory for students in the MSc BT and optional for students in the MSc Arch.

In general, contemporary architects and architectural students are focused on conceptual architectural design and much less on building technology to realise this. Often an architectural design concept of an architecture student is not in any way materialised, apart from the selection of materials in tactile or visual regards. In our view this opens a possible erosion of the architectural practice and of the central role that the architect played in the building process, derived from the historic role of the 'Master Builder'. This growing emphasis on conceptual design explains the numerical minor position of Building Technology in the curriculum of the MSc Arch nowadays. In the architecture curriculum students are educated in traditional building methods and materials of the past. However, the Chair of Product Development has always been focused on characteristics of new materials and building methods within the process of building development, specifically of building components. Even transfer of technology from other designing faculties like industrial design, aeronautics and naval engineering is encouraged. We are afraid that most of this knowledge is not yet studied in the Msc Arch.

From the start of the Chair in 1992 education of industrial production methods and the selection and science of new materials including the certification processing for new materials, products and systems, have been a main issue. As a consequence the Chair needed a laboratory in which students could get in contact with industrial production methods and could experience the making of material elements and components for building products according to their own design, and the relationship of design & engineering versus real materialisation.

The process of setting up the required Laboratory of Product Development ('Laboratorium voor Product Ontwikkeling' or PO-lab for short) was a long and winding one. Up to 1995 the Faculty of Architecture was clearly not ready for the costly

implementation of a technical laboratory in which full scale material prototypes could be created and tested. It took threatening with resignation of the professor to force the faculty to invest in the set-up of the laboratory. Working with much smaller and cheaper card board 1:100 scale models and drawings that present the design of a building as a finished product still remains the standard procedure at the Faculty. After three years of discussion and several proposals the PO-lab was available in September 1995.
Here students consider it a formidable challenge to actually build their own designs, using various production processes. The prototype semester is the highlight of the MSc BT. After completing this part of the curriculum, students have started to experience the art of prototyping. They do understand the impact of material selection, manufacturing processes and assembly procedures on design and engineering. Some of them have been encouraged to apply for patents. In this way Graduates of the MSc BT are well prepared for future jobs in architectural practices or in the building industry that are more and more focused on prefabrication of building components. They can follow the industrialisation developments taking place outside the view of architects. And know what the consequence of new injections are.

3 PRODUCT DEVELOPMENT OF BUILDING COMPONENTS

Naturally the product development of building components is organized along the lines of the iterative cycle of the design process: program of demands, analysis, synthesis of the constituent parts, synthesis of the complete product and at last testing and evaluation of the design. The methodology of Eekels/Roozenburg is frequently studied [2]. Each iterative loop producing information on whether to go back and improve or to proceed. Core of the process is the Organogram of Product Development (see figure 6) [3]. Building products come in several flavours. But in all cases the building and testing of a real material prototype is a crucial step in the development of building products, as it is in the development of other industrial products.
Firstly, prototyping makes it possible to speed up the product development of building components. A skilled and creative designer knows perfectly well that his design meets formal and functional requirements, but an ultimate test is making a prototype early in the product development process, be it of an essential part first and the total product later. As mentioned earlier, this involves a confrontation between the essential feature of a concept and various materials and production methods. This is *prototyping for designing.*
Secondly, a prototype demonstrates functional performance, static behaviour, methods of assembly, overall appearance, etc. To check whether a design meets these requirements a number of 1:10 or 1:5 models are made. Scale modelling is crucial in the early stage of the design process for decisions whether to make a full scale prototype. Prototyping is much more expensive than producing concept design drawings, but continuous refinement of the drawings for each building component or element, including materials and production methods, is also a time-consuming and costly affair. This is called *prototyping for performance.*
Thirdly, a prototype can be used to explore a product’s market potential, *prototyping for marketing.* The prototype gives regular and prospective clients the opportunity to evaluate a design concept. And nothing can match a full-scale working prototype to demonstrate reliability and market potential that not even perfect drawings or splendid virtual reality will show. It helps to feel products or components in hand and it is impossible to conceal failures in a prototype; clients have a keen eye and are not as easily misled as they are by a splendid digital presentation.

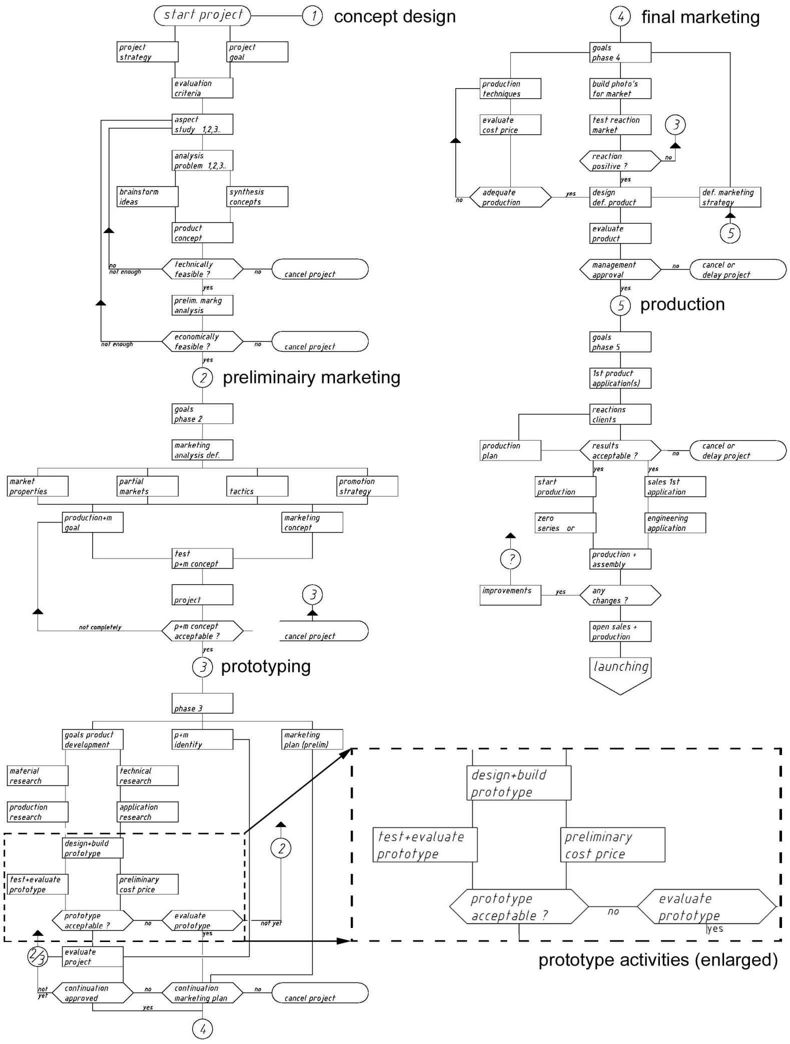

Figure 6. Organogram for Standard Building Products (position of prototyping in detail)

4 STUDENT PROTOTYPING OF BUILDING COMPONENTS

MSc BT students start with the design of a main part of a building, usually the design of a façade. This subject of the building façade is chosen because of its importance in architecture as well as in the higher degree of complexity of technology. In a short period of four weeks students are brought in contact with all essential knowledge for the design of a façade by means of the standard work of Just Renckens' book "Facades in Aluminium and Glass" [4]. With this knowledge students design a concept for a new façade segment, which in the curriculum is called their own "façade scenario".

Each student designs a scenario individually in two weeks. One example of these scenarios's expressing a specific form in relation to a specific function is shown in the pictures 7-8. After a presentation of the collective scenarios by the students the best half of them is selected to be developed to shop drawing level for a full-scale material prototype. In the next three weeks groups of two students are taught the secrets and conventions of shop drawings and of working together on these shop drawings for a material prototype. Eight years ago drawings were made on the drawing table, nowadays in various CAD software programs. The shop drawings of the material prototype are required to be drawn according to European standards, to be clear and contain all information to manufacture the desired prototype in elements and components (by others). A list of materials is included in the presentation of the shop drawings.

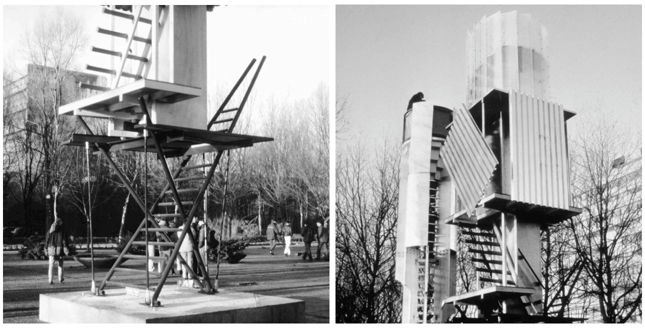

Figure 4-5. Two 10m high prototype towers made by 24 students in 1995

In the same period of study, design and engineering, the students are brought in contact with production methods with instructions as well with books. The instructions are being organised in the PO Lab and do contain instructions in several types of welding, machining milling and sheet metal forming. Eventual aluminium casting is done in other TUDelft faculties

The material purchase budget for a prototype is usually limited to € 500,- including VAT. Increase of this budget is left over to students to look for sponsors from specific industries willing to supply essential components to the undertaking students. The PO lab has a limited collection of commercial materials in stock, supplied by friendly industries.

In a second selection the best or the most interesting of the shop drawing presentations are selected to be build as a prototype. The prototypes are segments built by 4-6 students; mostly at full scale but due to economy only the most intriguing part of the façade segment is build.

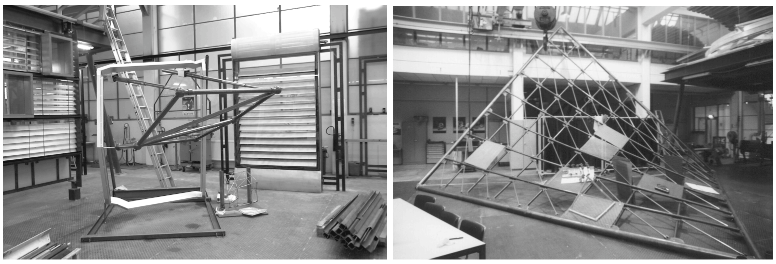

Figure 7-8. Blob Prototypes made at the previous PO-lab in the Leeghwaterstraat

5 VIRTUAL VERSUS MATERIAL PROTOTYPING

The eight years of the PO-lab have shown that because of the increasing power of personal computers and skills of students to handle 3D modelling programs, virtual 3D-modelling is becoming a very useful tool in the design process of building components as it is in every field of design. It replaces for a part the painstaking process of making prototypes. Nowadays walking in and around a new building design in virtual reality is quite possible and is even used for the smallest contracts. This development raises doubt about the future necessity of using the historical material prototypes in the design process.

Material prototyping serves an educational goal in the MSc BT. A technical designer has to develop a feeling for materials and for production methods. The best way to develop this feeling is to gain experience by working with materials and with production methods. So in our opinion material prototyping should always be a part of the MSc BT, especially, since practical work is not obligatory any more and students seldom undertake this, despite encouraging advices from their teachers.

With all the current possibilities of eloquent virtual 3D modelling, like assembly testing, testing of applied mechanics etc., one could be charmed to solely depend on virtual tools. It seems most aspects of the design can be developed sitting at a computer screen without getting dirty hands at all. Virtual design could encapsulate non-virtual design mistakes. Holistic technical experience and crossing relationships between design aspects usually are not covered in the digital design. Material prototypes, on the other hand, leave the designer no room for errors.

The important question is: “Will virtual prototyping in the future render material prototyping completely obsolete?” The wide spread use of computer aided modelling is bringing designers close to the end product of their efforts and can often be used to get very convincing marketing pictures. So why all the trouble and the costs in manufacturing a material prototype?

The first reason is of course inevitability to materialise the design at the end of the product development process. We are in the business of developing building components of real buildings. Design mistakes are hidden in virtual reality. So somewhere in the process of design and developing of building components a material try-out is obligatory for the reassurance of the producer as well as for the client and his architect and advisors.

As helpful as 3D virtual modelling really is, it is quite impossible to get a grip on every material aspect of the design with this tool. Assembly, for example, of all the elements of a building component into the final product can be much more complicated in reality than it appears on a computer screen. Building and testing a material prototype will usually reveal all kind of problems, which all have to be solved before production can start. The way these problems are solved is always influential on the design of a building component.

The elaborate use of 3D virtual modelling in the process of product development however will push the use of a material prototype more to the end of the process. In 3D virtual modelling the strength, the acoustic and thermal isolation characteristics and even the assembly of the design can be researched in detail. This means that a designer nowadays will get relatively more certainty about the characteristics of his design than he or she could have attained in earlier days.

In our opinion the virtual and material prototyping are complementary to each other and should be both part of a design process at the same time. Researching every aspect of a conceptual design will be very useful for the design process and will as a consequence speed up the process. The material prototype still has a smaller but convincing function of its own.

6 CONCLUSION

After eight years of experience the full-scale prototyping of building components as a part of the curriculum of the MSc BT is no longer in an experimental stage. Graduates have now a thorough knowledge of prototyping: from concept design to confrontation between materials and production methods right down to the making of shop drawings and full-scale material prototypes. Co-operation between the building industry and the MSc BT will certainly benefit both parties: our students are capable and willing to help the building industry complete their product development processes by making prototypes of new product ideas which have been developed by the industry's R&D departments. Virtual 3D modelling is an increasingly useful tool for component designers in the building industry as it is for almost every technical designer and it prevents too much costs to be spend on material prototyping. But material prototyping of component design remains a core necessity in product development. With this experience graduates of the MSc BT are fully able to materialize architectural design concepts with their digital skills and the use of material prototyping.


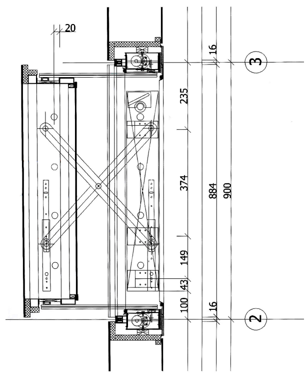

Figure 9-10. Prototype of a continuous double façade, even with opened windows

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