Luka Jančič

THE IMPACT OF LAYERED TECHNOLOGIES ON ARCHITECTURAL MODEL PRODUCTION AND USE

AR
UDK 72.02
COBISS 1.02
prejeto 28.2.2013

VPLIV SLOJEVITIH TEHNOLOGIJ NA IZDELAVO IN RABO MAKET V ARHITEKTURI

izvleček

Članek je poročilo o raziskovalnem delu, ki nastaja v okviru doktorskega študija in se posveča uporabi slojevitih tehnologij za potrebe izdelave arhitekturnih maket. Uporaba maket je razširjena tudi v okviru računalniško podprtega oblikovanja in izdelave, kjer makete ostajajo prva materializacija abstraktnih zasnov. Uporabljajo se za predstavitev, iskanje, vrednotenje in razvoj novih zamisli. Čeprav so novi načini izdelave običajno vrednoteni predvsem s stališča stroškov ali tehničnih vprašanj, je članek namenjen predstavitvi raziskovalnega dela namenjenega določitvi osnovnih mehanizmov tradicionalne uporabe maket s ciljem določitve načinov delovanja, uprabe in nalog maket v arhitekturi. Lastnosti slojevitih tehnologij, ki so proces izdelave maket ločile od ročnega dela, želimo ovrednotiti skozi prizmo tradicionalnih nalog maket v arhitekturi. Ugotavljamo, da je uporabnost slojevitih tehnologij odvisna namena izdelane makete in se spreminja glede na njeno funkcijo.

abstract

The following paper is an in-progress report on the research conducted as part of PhD studies focusing on the use of layered technologies for the production of physical models in architecture. In the age of CAD/CAM (Computer-Aided-Manufacture), physical models remain widespread and are often the first materialization of abstract concepts, used not only as a way of presentation but also for the generation, evaluation and development of new design ideas. While latest modes of model production are often discussed in terms of costs and technical issues, the paper at hand focuses on a stage of our research where we aim to identify the basic mechanisms of traditional model use in order to determine the performance, use and implementation of physical models in the field of architecture. The characteristics of CAM tools and systems based on additive technologies, which have removed the model-making process from the hands of architects and model-makers, are examined through the scope of traditional physical model tasks in architecture. We find that the practicality of additive technologies is dependent on the type of physical models produced and varies according to their function.

ključne besede

arhitektura, slojevite tehnologije, makete, digitalno podprta izdelava

key words

architecture, layered technologies, physical models, digital fabrication

Introduction

"In a period of absolute digital obsession, it has become obvious that no single medium, tool, software, material or technique will suffice to achieve the kind of vigor and complexity that an innovative work of architecture necessitates." [Schork, 2009: 309]

The development of informational technologies and the omnipresent use of computers in the late 20th century have changed the world dramatically. In architecture, the revolution started with the emergence of CAD software that offered an alternative to the standard set of tools used to make architectural drawings. After 2000 years of service [Sheil, 2012: 137] compasses, dividers, rulers and squares were being replaced by a single tool. In the first period of CAD use, the shift from analogue to digital means of drawing brought little reflection of that fact in the shape of buildings [Iwamoto, 2009: 5].

In the few decades that followed the advent of CAD, computers became not only the principal tool for the production of architectural drawings, but also a powerful design tool that enabled radical changes in the way architects design and build architecture.

The first considerable shifts came with the introduction of three-dimensional computer modeling tools. These were soon recognized as much more than just a method for the rapid production of perspective drawings, and started being used in ways that began to expand the use of complex geometries in architecture. As architects ventured deeper into digital design, the tools at their disposal became more sophisticated. The early days of modeling software, when programs had to be individually written for a limited number of parts, are long gone. Today's computer modeling tools offer easy-to-understand interfaces and almost intuitive handling possibilities that allow for creations of unprecedented complexity.

The increasing complexity of creations, enabled by the use of use of three-dimensional computer modeling tools, has introduced CAD/CAM (Computer-Aided-Manufacture) into architecture. As the new free-form designs proved to be very challenging for traditional/analogue fabrication techniques architects turned to processes that have been used for decades in the development and fabrication of cars, airplanes and smaller consumer goods [Dunn, 2012: 20]. The new way of materializing ideas helped energize architectural design thinking, and expanded the limits of architectural form [Iwamoto, 2009: 5].

Today, design as well as construction, the two fundamental activities and concerns of the discipline, are redefined by an increasing proliferation of three-dimensional design tools and digital fabrication, enabling architects to conceive and produce designs that would be very difficult to develop using traditional methods [Dunn, 2010: 20].

Digital methodologies now allow architects to conceive architecture more fluidly in terms of information, and digital fabrication provides a way to produce such designs directly from digital data. The shift from analogue means to digital systems of conceptual design and material production enables a more profound interaction between data and matter [Kolarevic, 2005]. These profound changes have transformed the use of the entire array of traditional design and presentation tools. Some of them became redundant while others are experiencing a revival. Among the latter, physical models are one of the most obvious.

These objects that were initially strong candidates for extinction and replacement by their virtual counterparts [Dunn, 2010: 80] seem to be more popular than ever. It may be that their current popularity is rooted in the wide success of the very reason behind the initial speculations of their possible extinction - computer modeling software. Available software tools offer almost intuitive handling possibilities and can produce results that are very difficult to assess, evaluate and proof sufficiently based solely on a two-dimensional projection on the computer screen [Kern, 2008: 106]. CAM is often used to bring such designs into physical form as models, so that they can be examined and developed further. Among the most popular systems for such tasks are those based on layered technologies, generally known as rapid prototyping or 3D-printing machines.

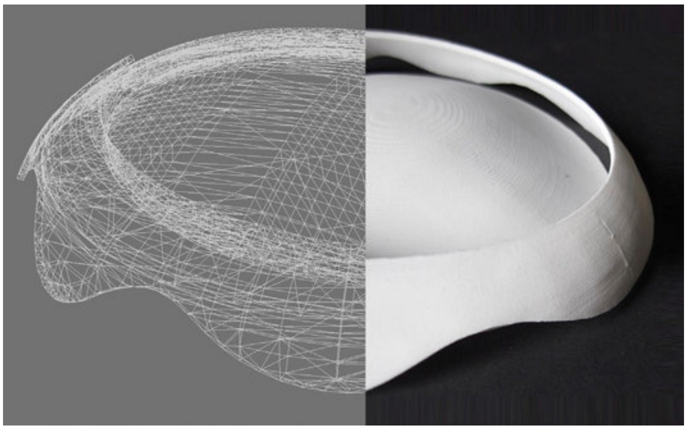

Figure 1: Layered technologies allow a rapid and accurate materialization (right) of digital 3D models (left). The process is fully automated and the final product is produced in a single production stage.
Slika 1: Slojevite tehnologije omogočajo hitro in natančno materializacijo (desno) digitalnih 3D modelov (levo). Izdelava makete poteka v enem koraku, postopek pa je popolnoma avtomatiziran.

Layered technologies are a group of additive manufacturing systems able to transform digital models into physical objects by depositing thin layers of material according to data automatically retrieved from the blueprint. This automated way of model-making allows for the rapid and accurate production of physical models during all stages of architectural conceptualization, demonstration and production and is a valuable way for establishing a continuous dialogue between the physical and digital concepts during design development.

The new relationship between data and matter enabled by digital additive technologies was first recognized as a promising way to produce architectural models over twenty years ago [Streich, 1991]. Since then, there has been a lot of discussion in the architectural community about the possibilities for transferring the means of modeling and prototyping from the mechanical engineering and manufacturing industry, where they were initially developed, to the architectural design process itself. The discussion is mostly focused on the issues of price, speed, detail and size of models produced with layered technologies in comparison with traditional and other digitally controlled ways of model production. This discourse has shown a certain tendency to separate the product from the process, and model-making is rarely regarded as an integral part of the architectural design process. Assessment of the final outcome is often performed according to production standards alone (finish, accuracy), while other non-technical (and often quite as important) qualities and aspects that influence the usability of the product are all too frequently ignored.

One could argue that an old segregation has reemerged in the context of digital fabrication of physical models, namely the division between intellectual and material aspects of architecture where, according to Starkey [2006], architectural drawings are often discussed in relation to ideas whilst architectural models are more likely to be discussed in relation to matter. The vivid discussion on models in relation to ideas characteristic for the last decades of the 20th century [Moon, 2005] has in the scope of layered technologies once again been replaced by the issues of matter and the relation to manual labor and craft, and has therefore dissociated itself from the intellectual.

At a time when it is becoming increasingly difficult to separate the physical from the digital, when the methods of design and production have converged to form part of the same process, we ought to take a closer look at the impact of new technologies not only on production but also on the use of physical models in the architectural design process itself.

Problem

The effect of technical changes affecting the design process (CAD) in combination with new manufacturing technologies (CAM, Computer Aided Manufacture) on the production and use of physical models in architecture is still largely unknown.

The industry is well informed on the comparison between traditional and layered manufacturing in the context of architectural scale models. In recent decades, the issues of price, size and speed have been meticulously researched and evaluated. Although these criteria are absolutely essential for the process of model-making, it should be noted that models are not only about economy [Morris, 2006: 9]. They are strongly connected to abstract ideas regarding the process and stages of design development that influence both their production and use. The implications of the production process are often an integral part of the model's performance and should not be judged by technical criteria alone.

Objective

"If designers do not understand the idiosyncrasies of the media and tools they employ, they will be forced to move their design in a direction that was not intended." [Schork, 2009: 309]

"Each of the traditional methods has its own individual intrinsic value, and each will retain a place in the architect's design and presentation arsenal long after rapid prototyping has been adopted by the industry." [Kirton & Lavoie, 2005]

Our research is aimed at identifying the basic similarities and differences in the production, use and performance of physical models created using traditional technologies compared to those made with layered manufacturing.

In this way, we wish to contribute to both theory and practice by shedding new light on the processes that often go unnoticed [Morris, 2006: 7]. We focus on the basic qualities of traditional physical models in order to determine how their removal from the process of model-making that occurs in automated production (and the rather predictable result of that process) is compatible with the traditional use of models in architecture. To achieve that objective we focus on the basic principles of layered technologies (which are more or less constant, not subject to continuous change like the size, price and speed of the machines) and the ways they differ from traditional means of model-making in order to determine how these principles fit into architectural design.

In our research we do not seek to establish rules, but rather examine meticulously the patterns of layered technology application in relation to traditional techniques, and the potential for new ways of physical model use in architecture. We wish to promote the critical use of these technologies by identifying the particular phases or aspect of design where they may show better results and hope that the study will contribute to an objective classification of correlations between traditional and digitally produced physical models.

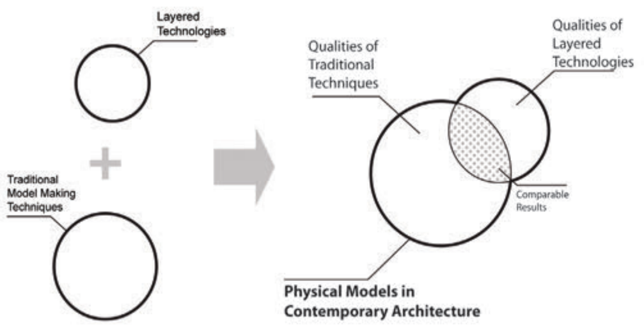

Figure 2: Research goal. We set out to establish the position and potential of additive technologies in the context of contemporary architectural model-making.

Slika 2: Cilj raziskovalnega dela je določitev vloge in potenciala uporabe slojevitih tehnologij za izdelavo maket v sodobni arhitekturni praksi.

Research questions

Initial research has shown that we should evaluate the impact of layered manufacturing on the production and use of architectural models by defining and examining the basic principles of physical model use and the possibilities of applying those principles to models made with layered technologies. To determine the effectiveness of new-technology models in performing the traditional tasks of physical models and define the potential new ways of physical model use, the following research questions were formed:

- Can layered technologies be used to produce physical models that fulfill traditional model tasks in the conceptualization and presentation of architecture?
- Is rapid prototyping enabling new ways of using physical models in spatial conceptualization?

Methodology

Research is being conducted in two stages. In the first stage we consider the practicality of layered technologies through the scope of traditional architectural model making. In the second stage we intend to determine if the shortcomings we detected during the first stage are replaced by some other qualities traditional techniques do not offer. The paper discuses the data and findings of the first stage where we focused on the specifics of the architectural design process and the use of physical objects in order to define the possibilities for the critical use of additive technologies in the process of designing architecture. The basic mechanisms, characteristics and reasons for different methods of model production were defined with the use of the comparative method. Comparative study provided us with the essential mechanisms for the successful use of physical models in architecture and the abilities of layered technologies in that context.

To determine the basic qualities, the following sub-questions were formed:

- How do models function?
- Why do architects build models?
- In which cases can the product and the process of architectural model-making be separated, and what are the consequences of such separation?

In order to answer these sub-questions, we compare a number of reports from the fields of architectural theory, model making, and the design process to determine the qualities that must be provided during the model-making procedure in order for models to be able to function in accordance with the demands of architecture.

Relations between layered technologies and digital models were established using the same method.

Abstraction

"Models are representations of objects, states, events. They are idealized in the sense that they are less complicated than reality and hence easier to use for research purposes. […] Models are easier to manipulate than the real thing, and there is a process of abstraction in which only the relevant properties are represented." [Healy, 2008: 7]

According to available sources, abstraction is the key for the successful use of models. Through the process of removing certain elements from something, the subject is reduced to a set of essential characteristics. Abstraction leads to ambiguity and requires a form of intuitive or common experience in order to be understood. Understanding the language of abstraction allows one to see more than what is actually there.

Abstraction in architecture

"Design does not operate exclusively on the basis of resemblance, but on the basis of abstract codes and a complex instrumentality. Architecture presumes a transformation of reality, but an architect attempting to work directly with that reality will be paralyzed. The detachment of architecture's representational codes allows the designer to experiment with relative freedom. But abstraction is more than an expedient. By working with the abstract material of number, proportion and interval, the architect can structure internal relationships and move smoothly between the visible and the invisible. Invention follows, and paradoxically, a more complex appearance is produced than if appearance were the starting point." [Allen, 2009: 75]

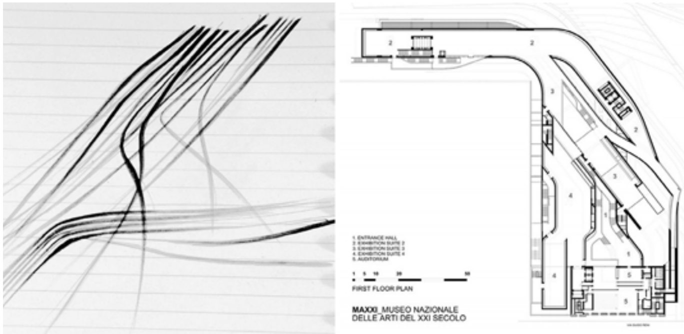

Figure 3: While a sketch and a plan are both abstract forms of display and can be equally confusing to an untrained eye, a technical drawing is a much less ambiguous form of abstraction.

Slika 3: Skica in načrt sta, kot abstrakta načina predstavitve, lahko laiku enako nerazumljiva, vendar je tehnična risba veliko manj dvoumen način abstrakcije.

In the renaissance, abstraction established itself as a principal way of architectural expression. Drawing as the primary form of two-dimensional abstraction allowed architects to influence the building process and construction indirectly, from a distance. During the centuries that followed, particularly during the period of domination of the École des Beaux-Arts, the profession became a world of two-dimensional representation [Morris, 2006: 17]. In this abstract world certain rules were established in order to avoid confusion and architectural drawing became a form of language fully understandable only to professionals.
However, the use of abstraction in architecture is not ambivalent. Two practices of use are evident. One is used in technical drawing, as a language governed by a set of strict rules that reduce the possibility of free interpretation to a minimum. A floor plan, for instance, should only be interpreted in a certain way, which makes it an unambiguous form of expression to anybody familiar with the rules. The other practice present in architecture is abstraction with no strict rules that allows for multiple interpretations and can lead to new and unexpected results and discoveries. This method is used more individually as a tool of exploration and generation of ideas. That is why freehand sketching is a popular way of development and evaluation of initial ideas [Edwards, 2008].

"The architectural model shares the mechanism of abstraction and scale reduction with the drawing. Beyond this it offers the three-dimensional quality of its representation, which gives it its particular vividness, and the possibility of freely choosing the materials for construction." [Gänshirt, 2007: 151]
Gänshirt does not specify the particular quality of three-dimensional presentation, but the statement suggests that abstraction presented in three-dimensional form is the source of the distinct functionality of physical models.

Functioning of physical models

"They (physical models) are representations of an object or architectural structure at a reduced scale; but they are also an object in their own right, full of expressive meaning." [Pascuali Miró et al., 2010:8]
It is this "object" that Healey (2008:53) refers to when he states that physical models are converting abstraction to reality and reality in this case is the object itself. On the other hand, Healey also states: "The physical model is an artifact such that its parts, their relations and its working are suitably analogous to some other system."
According to the above, models are useful for at least two reasons. As an artifact they are a materialization of an abstract idea that makes the idea more "real". As an analogy they can be used to represent future architectures, allowing architects to experiment freely well beyond the possibilities of a drawing [Gänshirt, 2007:152] and to provide laypeople with a presentation they can easily understand.
Although scale models may be important as artifacts, they are generally perceived as representations. The more generally recognizable features/qualities a form of presentation possesses, the easier it is for the observer to connect the abstraction to its referral. Models are often regarded as the most easily understood form of architectural presentation, but are as such still ambiguous.

Figure 4: Three-dimensional presentations in the form of the physical models are the easiest to understand, but can still be ambiguous.

Slika 4: Tri razsežnostne fizične predstavitve v obliki maket so najlažje razumljive, a so kot način prezentacije lahko vseeno dvoumne.

Morris [2006: 68] refers to Christian Norberg-Schulz who argues: "As the concretization, the totality is only present in the finished work, but it can be represented in different ways. Such representations are never satisfactory, as most people lack the ability to "read" drawings and models". Oswald [2008: 35] approaches the same problem from a different angle, through the specifics of modern age: "The diminishing ability of architects, clients and brokers to interpret an abstract model is a symptom of an education decline extending to perceptual skills, which atrophy trough exposure to computer images. As a result, architectural models are embellished with trees, figures and other accessories from toy land […], which tempt the decision-makers to assume a playful attitude toward understanding their own design. The art historian Walter Grasskamp coined the term "sentimental model" to describe this trend in model building. Sentimental models are open to the charge of aiming only to look pretty in themselves. Their message is misleading and misses the true purpose of an architectural model in the design process."

In that scope, it is possible that the power of conducting the basic design idea may be overpowered by the expressive meaning of the object itself; particularly when presented to laypeople.

Laypeople cannot be expected to perceive physical models in the same way as architects do because they do not share the same models of interpretation. "To share models of interpretation is to share tacit understandings, forestructures that are learned not by rules or formulae but by words accompanied by demonstration in concrete examples and by practice in specific situations. […] Evaluation never is or can be exclusively personal and private. On the contrary, evaluation is predominantly communal. These communal preconceptions are far stronger than the personal." [Snodgrass & Coyne, 2006: 121-122]

"But if the model is deemed to be as professionally encoded as drawings, why then are presentation models, for example, made in the first place? It may be that the model is not a universal object in terms of legibility, it may instead be deeply culturally determined, but that cultural filter is not a professional one." [Morris, 2006: 68]

Models function differently and are perceived different according to the "filters" applied, but because communal preconceptions are far stronger than personal ones, it is possible to manage their ambiguity.

Ambiguity

Ambiguity of the physical model is often neglected when it comes to the presentation of ideas, but it is well known for enabling creative shifts during the design process. Indeed, it is their very ambiguity that makes models such a useful design tool.

Goel [1992] argues that ill-structured, open-ended problems, like the preliminary phases of design problem solving, need "ill-structured" diagrammatic representations. Ambiguous media is said to enable lateral transformations. Further research on the subject in connection with the use of models in architecture conducted by Gürsoy [2009] found that ambiguity could be two-sided: the ambiguity of the design medium vs. the ambiguity of the design process. This study showed that the ambiguity of a design process with unambiguous media also makes way for lateral transformations. Therefore, lateral transformations are not solely the product of ill-defined representations, but can also be the product of ill-defined design processes.

Physical models in architecture

Models have always been a bit of a blind spot in architectural theory. They are often used but rarely considered [Morris, 2006: 17]. As early as renaissance, when Leon Battista Alberti pointed out the distinction between "plain and simple" and "loudly dressed" models [Elser, 2012: 16], a division has been made between the type of models used and made by architects for their own use, which are often plain and simple in their appearance, and their elaborate counterparts used to present architectural ideas to laymen.

Today, the duality between models used for the generation and evaluation of ideas, and the ones used for presentations of finished designs is as evident as ever. According to their function, those models that affect the design process are called working models, while presentation models is the designation used for those used to convey a vision of the final product – architecture. While models from the first group are generally recognized as an important design tool, the ones in the second group are often regarded as nothing more than stand-ins for the real thing [Schmal, Elser, 2012: 8], an advertising aid that is done post festum and does not affect design decisions in any way. The two groups may sometimes appear similar, but they function in very different ways.

Working model

"Investigative models, preliminary models- models used primarily for feedback or for the designer within the creative process." [Greenhalgh, 2009: 8]

For working models to be effective, they have to be available to architects at the time of decision-making, which is why working models are mostly constructed by architects themselves. As a highly ambiguous medium, they enable creative shifts to new alternatives [Gürsoy, 2009: 66] during the process of model-making, through examination of the final result, or both. In the case of working models, physical model-making is a form of sketching [Gürsoy, 2009: 66] where the process should not be separated from the product if one wishes to achieve optimal results. The power of working models to strengthen design through their production and evaluation makes them the most important group of models in architecture. [van Berkel, 2010: 757]

Before digital modeling enabled for advanced digital form-finding methodologies, experimental models were important tools in the development of structures capable of bearing loads with minimal material input. At the time when it was nearly impossible to draw the forms of such structures, scale models formed the base of spatial investigations and were used at all stages of design development [...]. To transfer the results of such tests into the form of technical drawings special methods of photogrammetry were developed [Janke, 1978: 88].

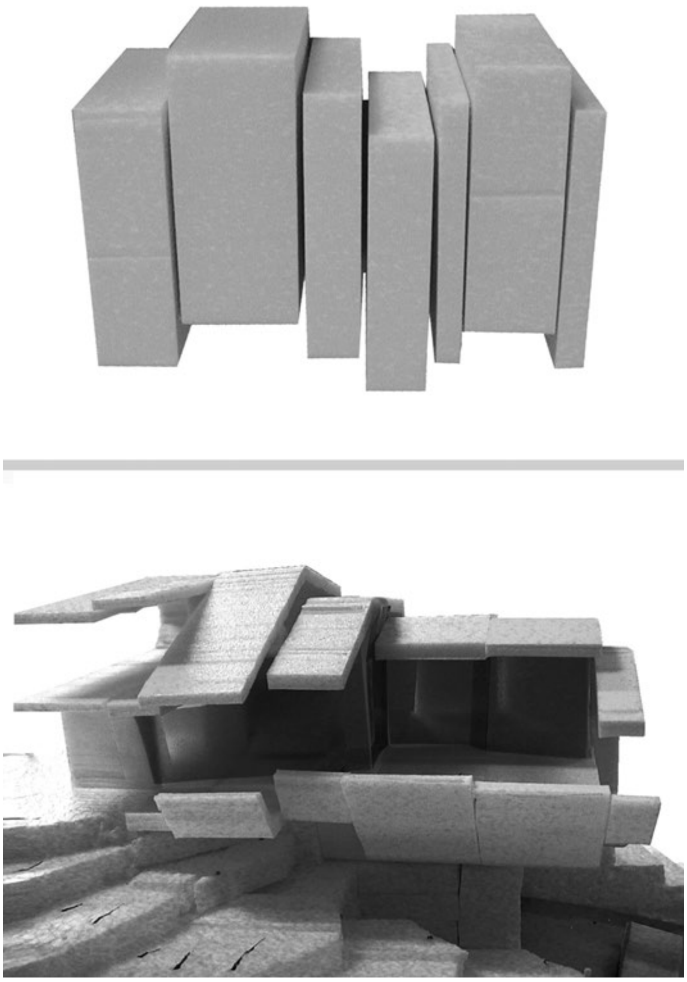

Figure 5: Highly ambiguous working models, used in initial design stages, become more defined during the design process, but can still facilitate design decisions and generate new ideas.
Slika 5: Zelo dvoumne delovne makete, ki se uporabljajo v začetnih fazah projekta, postajajo z razvojem zasnove veliko bolj določene, vendar še vedno prispevajo k sprejemanju odločitev in spodbujajo nove zamisli.

Figure 6: Colors, textures, and a whole array of other elements and effects are used in presentation models to facilitate the understanding of the finished design.
Slika 6: Razumevanje končne zasnove olajša ustrezna raba barve, teksture in ostalih elementov na predstavitveni maketi.

Presentation model

"It (presentation model) is truly an object in the world. Final models are rarely the designer's favorite models; compromises are inevitably made in the interest of legibility. Unlike sketch models, final models aggregate intention, reveal a totality." [Morris, 2006: 69]

Presentation models are produced after all the design decisions have been made in order to showcase them. They aim to represent a project or architectural idea holistically [Morris, 2006: 69], are therefore less ambiguous and often approach visual conventions of other media in an attempt to communicate more broadly.

Layered technologies

The majority of CAM systems in operation today are computerized versions of traditional tools used to process raw materials. In the shift from analogue to digital, human handlers are simply replaced by computers (CNC, Computer Numerical Control) that guide milling, routing or cutting (laser-beam, plasma-arc, water jet) heads according to a pre-planned path. The procedure is analogous to traditional processes. Results are achieved by cutting or subtraction of raw materials to create desired shapes. The fabricated parts are later assembled to form the final object.

Layered technologies represent the next stage of CAM development, where the production process is further removed from the hands of the maker. The term layered technologies is used to define a group of additive fabrication systems commonly known as rapid prototyping or 3D printing. The name derives from the principle of production that is common to all of them. They are used to produce physical objects automatically, by applying or solidifying thin layers of material according to data automatically retrieved from a digital 3D model. Most of the systems can only print one material at a time. The entire process of creating the final object is undertaken by the machine, which performs the complete job in a single production stage. The idea for this form of production may have come from NASA [Knaack, 2010: 9] as it was looking for a way to avoid the problem of carrying spare parts on long space journeys. The result was a system of production that enables the fabrication of any necessary parts on the spot when needed, from a single raw material, and creating no leftover waste.

Since the late 1980 when first such systems became commercially available, they have been adopted into a large number of industries (engineering, consumer goods, medicine, etc.). The ability to produce almost any conceivable physical shape in a relatively short time enabled massive shifts in the design processes, which affect the material culture (rapid manufacturing), enable new strategies (mass customization) and result in increased functionality that brings competitive advantages.

While architecture has never been regarded as a mass-industry, and product customization is intrinsic to the discipline, some advantages of layered technologies, such as production without the need for manual assembly from components by cutting, screwing, welding or gluing and fitting, appear promising in the context of manufacturing of actual architectural parts or even entire buildings. Adapting layered technologies for use in the construction industry could provide the possibility to produce architecture in one go. Currently, a lot of ongoing research is being conducted in this field [Knaack, 2010; Soar and Andreen, 2012], which may bring significant changes to the way architects design and build structures, but as of this time there is yet to appear a fast current of parallel development that can be seen in other industries present in architecture and the building industry. "To date, the most significant limitation of rapid processes has been the size of objects they are able to fabricate. This factor, further nuanced by the considerable expense of fabrication machines along with the relatively long time required to make objects, has led to a reasonably narrow use in architecture." [Dunn 2012: 104] The majority of that use is still limited to the production of physical scale models.

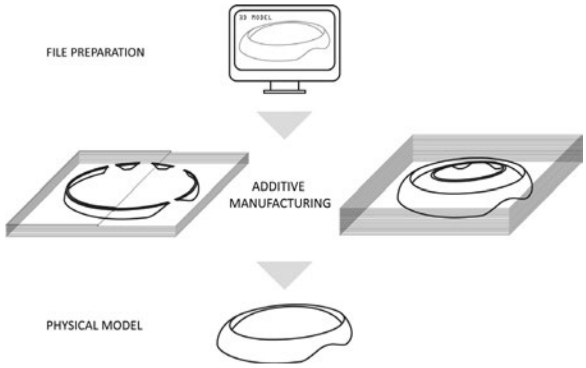

Figure 7: The layered fabrication process.
Slika 7: Proces slojevite izdelave.

Digital model
"The use of CAD has changed the design process, as many designers now think through the computer." [Greenhalgh, 2009: 9]
Thinking through the computer is taking a toll on abstraction. The traditional set of projections that was once used by architects to define objects is now being replaced by the virtual environment [Allen, 2009: 76]. Architects work directly on a virtual 3D object itself in an environment that operates in actual scale; objects are fully defined and capable of producing an endless numbers of projections of themselves. This drastic change affected both workflow and representation in architecture.

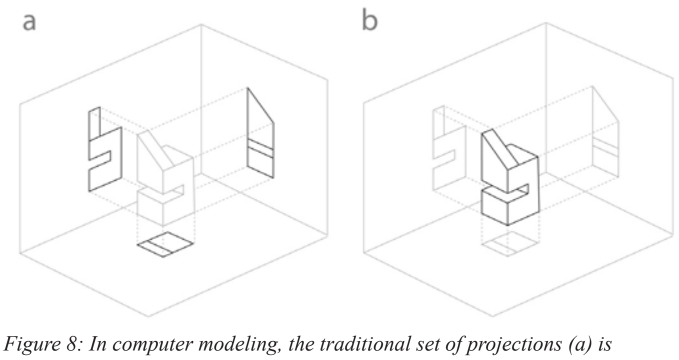

Figure 8: In computer modeling, the traditional set of projections (a) is substituted by the digital object itself (b).
Slika 8: V računalniškem okolju je osnova za delo virtualni objekt (b), ki nadomešča tradicionalne projekcije (a).

Paynter et al. [2002] state that haptic manipulation enabled by free-hand sketching and physical model-making in the early phases of the design process is disabled in the virtual environment because complex interfaces interrupt the creative process. Gürsoy [2009: 63] adds: "Independent of the complexity of the form, the objects in virtual space are always fully defined making them unable to provide appropriate support in the early stages of design where more ambiguous representations should be used. Compared to free-hand sketches and physical models, digital models are clear-cut representations. This sharpness evokes a feeling of completeness and causes the early crystallization of design ideas." Gürsoy [2009: 66-67] places digital models somewhere between working and presentation models. Design cannot benefit from their ambiguity, if they are ambiguous in some way, because they are so well defined.
Conversely, the virtual environment allows the creation of complex models and ideas and allows designers to experiment with forms without the use of the physical model. "A key advantage is the ability of software to allow the comparison of concepts without having to create additional models from the beginning." [Greenhalgh,2009: 9] As architects rely more and more on the computer's precision and unmatched potential to manage complex geometries, it is becoming increasingly evident that: "At first, computer software simplifies the production of complex forms and volumes. But it is impossible to fully understand, prove and evaluate such shapes based on a number of various viewpoints in form of 2D projections on a computer screen." [Kern, 2008: 106]
Virtual models also establish a new way of visualization. Allen states that computer renderings often presume that abstraction is a liability to be overcome, and tend to bring visualization closer and closer to reality. By doing so, they ignore the traditional distance interposed between the thing and its representation that gave architectural representation its particular power. [Allen, 2009:75]
Digital models are not affected by the abstraction and scale reduction typical for drawings and physical models. Though they appear small on the computer screen, they are created as full-sized digital representations in an environment that operates in actual scale. The potential of CAM systems can be used to materialize such designs in a number of different ways.
"In theoretical terms, the difference between printing a model and manufacturing actual elements for a construction site has been abolished. Model data is now equally suited to the production of model parts as it is to the production of parts for real buildings. […] As a result, the question of whether the digital image on the computer is still a model or the complete data set for reality is a purely academic, or rather a philosophical one." [Elser, 2012: 20]

Layered technologies in architectural model-making
The advantages of additive manufacturing, such as the ability to produce complex geometries and the absence of any need for manual, gluing, joining and fitting of the parts, appeal to architects in the context of model-making. Combined with high speed and relatively low costs of production they are the main

reason for the increasing proliferation of layered technologies within the architectural community.
Layered technologies were developed for the rapid and accurate materialization of digital models in the mechanical engineering and manufacturing industry. Their aim is to bring the physical model as close as possible to the one in the virtual environment in a fully automated manner. When used for the purpose of architectural model-making, some of their original qualities can also be viewed as drawbacks.
Architectural models produced this way include all the data from the digital model, are highly detailed and therefore provide a precise description of the design [Dunn, 2012: 20]. This is regarded as a disadvantage by some authors who caution [Oswald, 2008: 35] that a physical architectural model cannot and should not be a real life duplicate of 3D visualization; while others [Moon, 2005: 198] question the model-making process that has been completely removed from the model-maker's hands and see it as a dead end for the model as a medium, since models produced at the push of a button cannot offer the individuality and range of expression requisite for the task, nor can they adequately put to good use the creative imagination and lateral thinking of architects.
While one can agree that 3D data is today produced as part of routine project documentation, it is not objectively apparent whether it can be optimally employed directly for the production of physical models using layered technologies, as Kirton & Lavoie [2005: 23] imply. The limitations of additive systems such as minimal wall and detail thickness, which result from the technology and materials used, require a series of adjustments and modifications before physical models can be made and prevent a printed model from being an exact physical-scale duplicate of a 3D computer model of a project.

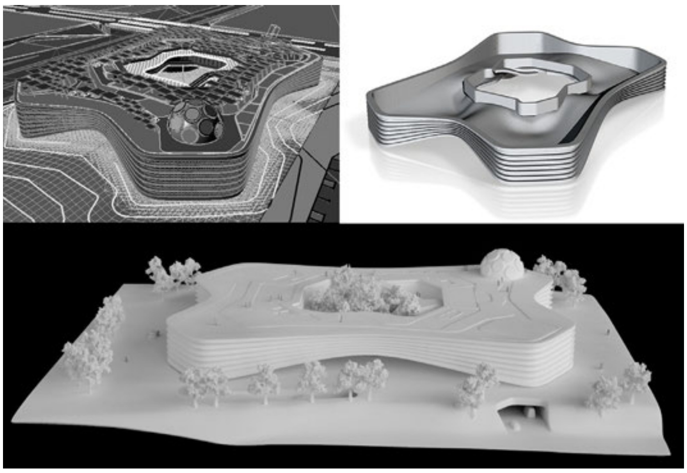

Figure 9: Digital models used to produce physical models are often heavily modified parts of the actual project model. Modifications have to be made to meet the requirements of layered production process in reduced scale. The final physical model is often a combination of the parts made using layered technologies and traditional techniques.
Slika 9: Digitalni modeli, ki so osnova za slojevito izdelavo, so pogosto močno predelane različice digitalnih modelov uporabljenih pri projektiranju in virtualnih predstavitvah. Prilagoditve omogočajo slojevito izdelavo v pomanjšanem merilu. Predstavitvene makete so pogosto kombinacija delov izdelanih s pomočjo slojevitih tehnologij in tradicionalnih postopkov.

Dramatic scale dissimilarities between the subjects being modeled in virtual environment (in 1:1) and those produced in the form of the physical model (in scale) also put some of the advantages of layered manufacturing shown in mechanical engineering and the manufacturing industry into new perspective. During the process of extensive scale reduction, which usually occurs, detail is lost - an automatic abstraction occurs. It is possible to use that fact in the advantage of the physical model and perform a conscious abstraction of the virtual model before the start of the production process. In such a manner certain qualities can be shown or emphasized, making the model comparable to those created using traditional techniques.
Another fact that has to be taken into account is that although layered technologies enable models to be fabricated in a single piece, such models are fairly rare. Most often, digital fabrication is combined with other techniques so that individual strong points of different mediums can be fully exploited.

Results

According to available reports and theory, our research has shown that models produced using layered technologies can fulfil traditional model tasks in the presentation of architecture while their practicality in conceptualization is rather limited.
We have established that abstraction is the key for the successful use of physical models. The level of abstraction is in close relation to the ambiguity of the model. Architects build models for two basic reasons; for generation and evaluation of ideas and for representation of finished design. As a consequence, two major groups of models exist:

- Working models take full advantage of ambiguity in order to advance design by allowing free interpretation of abstraction. The process of model making can be just as informative and helpful in the cognitive process and acquisition of new ideas as the end product itself.
- Presentation models are scale renditions of finished designs. Ambiguity and abstraction levels are low and used in accordance with culturally common visual convention able to provide clarity of the message and easy understanding.

We find that laboratory models do not fit in any of the groups above because they are governed by a different kind of abstraction and evaluated using scientific methods. As their use and production has little to do with visual conventions and evaluations, we feel that they should be classified as a separate group.
We also find that the lack of ambiguity associated with digital fabrication appears to be intrinsic to virtual environment as such. Layered technologies were developed to produce physical object as faithful to those in the virtual environment as possible. Consequently, physical materialization of digital designs cannot be expected to drastically change the level of abstraction or ambiguity.
Contrary to expectations, there are not many models that lead a double life, existing in both digital and physical form in architecture. In comparison to rapid prototyping in engineering

and industrial design, the process of digital model-making in architecture is quite different. One of the specifics of architectural model production is that it involves a drastic scale reduction that is in itself a form of abstraction. If the reduction of detail present in the digital model is not automatic but performed by the architect and devised in accordance with the future function of the scale model, it can have a beneficial effect on the operational power of the digitally produced physical model that should be comparable to traditional techniques.

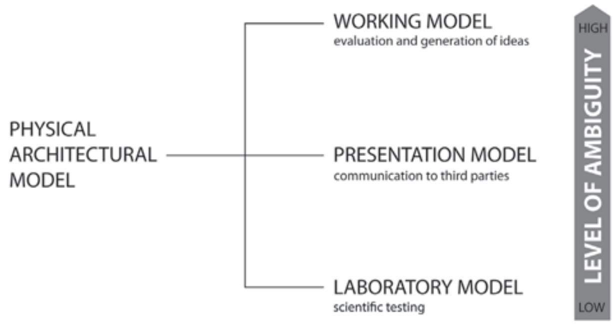

Figure 10: Different types of physical models used in architecture. General levels of ambiguity do not vary only according to the type and use of model but also according to the manner of its production.
Slika 10: Različne pojavne oblike arhitekturnih maket. Splošna raven dvoumnosti ni odvisna le od funkcije, ampak tudi od načina izdelave.

Discussion

In the part of our research discussed in this paper, we set out to define the most essential mechanisms that influence the use of physical models in architecture and determine if the same results can be achieved when layered technologies are used for the realization of architectural models.

Presentation models are materializations of a fully defined, finished design and are as such perfectly suited to be produced using layered technologies. In the case of working models, though, the process of model making is an integral part of the experience and often cannot be separated from the end product. This makes an automated process of production, such as layered technologies, less appropriate for the production of working models.

Another drawback is that the need to adapt virtual models for digital fabrication in reduced scale can interrupt the intuitive design processes and could, particularly in the early design stages, be considered as an unwelcome distraction.

One could argue that the preparation of digital data in accordance with physical model use is part of the model-making process, and can as such lead to new discoveries. But because this is done in the virtual environment, it remains subject to an unambiguous process that cannot be compared to hand manipulation.

Since our research was conducted using comparison to traditional techniques in order to determine the qualities of layered technologies, the gathered data is only relevant in the context of traditional architectural design strategies. Although the method used does not enable for the detection of potential novelties brought to the field of physical model-making by layered technologies, the results are an essential step towards the well informed and critical use of such technologies.

In order to determine the potential new uses of physical models enabled by layered technologies, a second stage of research will be carried out. Using a different method we will focus on some of the aspects we were forced to ignore during stage one.

The instrumental power of models within some of the contemporary design strategies such as those based on numerical data (parameters, algorithms, etc.) remains relatively unexplored. In stage two of our research we will focus on the possibilities for the implementation of physical models and layered technologies within the different design strategies specific to contemporary architectural practice.

Physical models remain popular because they can overcome the limitations of two-dimensional presentation of a virtual model on the computer screen. Layered technologies can produce complex geometries and delicate features much faster than traditional model-making ever could, thus forcing architects to re-evaluate the use of models. In the generative processes, certain characteristics of the virtual environment that might be perceived as an obstacle in the traditional design process now form the very base of design development. While the traditional process benefits from ambiguity, new design strategies rely only on known facts in order to produce an outcome that is the only unknown part of the process. In that context a question emerges: How can the architect benefit from a haptic experience during a "white box" design process where the only uncertainty is the result?

We intend to answer the question by studying a number of individual cases of model use in contemporary practice, focusing on the use of models in the realm of new strategies.

We believe that layered technologies are able to increase our ability to manage some more vague aspects of complex geometries that can only be assessed in physical space. We intend to show how relations in conceptualization, control and creation of architecture are affected by the integration of digital conceptualization tools with physical matter, and how they can contribute to the production of increasingly fluid architectural forms, flexible spaces, and transformative assemblies.

Further research

We would like to conclude this paper by introducing some additional research questions the study evoked. Answers to the following can be determined by future research:

- What impact does the choice of material, color and manufacturing principle (non tectonic process in the case of layered technologies) have on the use of physical models?
- Could layered technologies offer a way of reintroducing physical models to the younger generations who work exclusively in the digital environment?
- What is the connection between the production of physical models and full-scale digital fabrication in architecture?

References

Allen, S., (2009): Practice: Architecture, Technique + Representation. Routledge, Abingdon.
Dunn, N. (2010): Architectural Modelmaking. Laurence King Publishing, London.
Dunn, N. (2012): Digital Fabrication in Architecture. Laurence King Publishing, London.
Elsner, O. (2012): On the History of the architectural model in the 20th century. In: The architectural model: tool, fetish, small utopia [ed. Elser, O., Schmal, P.C.]: 11-22. Deutches Architecturmuseum, Frankfurt/Mein.
Gänshirt, C. (2007): Tools for Ideas: an introduction to architectural design Birkhäuser,Basel.
Goel, V. (1992): Ill-structured Representations for Ill-structured Problems, Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society, Hillsdale, NJ: Lawrence Erlbaum.
Greenhalgh, S. D. (2009): "Rapid Prototyping in Design Education: A Comparative Study of Rapid Prototyping and Traditional Model Construction" All Graduate Theses and Dissertations, Paper 248, Utah State University.
Gürsoy, B. (2010): The Cognitive Aspects of Model-making in Architectural Design (Master Thesis) The Graduate School of Natural and Applied Sciences, Middle East technical University, Turkey.
Healy, P. (2008): The Model and its Architecture, 010 Publishers, Rotterdam.
Janke, R.(1978): Architectural Models. Academy Editions, London.
Kern, C. (2008): Knowledge Transfer. in: Micro Architecture Studio + Projects [ed. Horden, R.], Institute for architecture and product design, Faculty for Architecture, Technical University, : 104-107, Munich.
Kirton, E.F.; Lavoie, S.D. (2005):Utilizing Rapid Prototyping for Architectural Modeling, "Engineering Design Graphics Journal", 70 (1): 23-28.
Kolarevic, B. (2005): Architecture in the digital age: designing and manufacturing, Taylor and Francis, New York / London.
Moon, K. (2005): Modeling Messages: The Architect and the Model, The Monacelli Press, New York.
Morris, M. (2006): Models: Architecture and the miniature, John Wiley & Sons Ltd., Chichester.
Oswald, A. (2008): Architectural models, DOM, cop. , Berlin.
Pascuali Miró, E.; Pedrero Carbonero, P.; Pedrero Coderch, R. (2010): Advanced Architectural Modelmaking, W. W. Norton & Company, London.
Paynter, K., Shillito, A. M., Wall, S. A., & Wright, M. (2002): How can Haptic Feedback allow an Applied Artist to externalise their ideas more intuitively during the Germinal Phase of the Creative Process?, Edinburgh College of Art & Edinburgh, Virtual Environment Centre, Edinburgh.
Schork, T., (2009): Modes of composition - a computational approach to design, Design Modeling Symposium Berlin 2009: Concepts Beyond Geometry, University of the Arts Berlin: pp. 300-311, Berlin.
Elsner, O., Schmal, P.C. (2012): The architectural model: tool, fetish, small utopia. Deutches Architecturmuseum, Frankfurt/Mein.
Sheil, B. (2012): Distinguishing Between the Drawn and the Made. In: AD Architectural Design, 2012, 2: 136 -141.
Snodgrass, A.; Coyne, R. (2006): Interpretation in Architecture: Design As a Way of Thinking, Taylor & Francis, New York.
Soar, R., Andreen, D. (2012): The Role of Additive Manufacturing + Physiomimetic Computational Design for Digital Construction. In: AD Architectural Design, 2012, 2: 127 -135.
Starkey, B. (2006): Models, architecture, levitation: design based research into post secular architecture. In: Journal of Architecture", 11,3: 323-328.
Streich, B. (1991): Creating Architecture Models by Computer-Aided Prototyping, Proceedings of the 21st ICAAD,1991
vanBerkel, B.(2010): UNStudio, interview in: Architectural model lead to design, [ed. Pyo Mi Young], DAMDI Publishing Co.: 756-757, Seoul.

Luka Jančič m.i.a.
mladi raziskovalec iz gospodarstva
Sadar + Vuga d.o.o.
Tivolska cesta 50, 1000 Ljubljana

Translation Jeremi Slak.

Naložba v vašo prihodnost
Operacijo delno financira Evropska unija
Evropski socialni sklad

iz recenzije / *reviewer notes*

The article presents an overview of recent model-building technologies and their place in the architectural design process. It discusses them in comparison with traditional modeling techniques, and quotes a wide range of references and opinions about their roles and effects in the architectural profession.
Missing:

- A clearer, more readable structure, hierarchical headings system.
- Some of the discussion seems to belong to the conclusion (e.g., that layered technologies are better applicable for presentation models than for working models).
- A clearer writing of the problem and conclusion sections.
- A clearer definition of the next research stage.
- Mentioning that the reason that layered technology is more for presentation is that its refinement process is too specific and removed from the design itself in order to be executed by the same person who actually does the design (i.e. an architect can make a model, but not clean-up a virtual model for printing).

doc. dr. Or Ettlinger
University of Ljubljana, Faculty of Architecture