

Digital materialization for architecture: definitions and techniques

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Abstract. *The introduction of digital technologies for making models, prototypes, and buildings or building parts in the architectural research, teaching, and practice is a reality today. However, the process is sometimes jeopardized by the lack of clarity regarding the use of certain terms still found in the literature. The goal of this paper is to contribute for overcoming this flaw by providing such a clarification and a possible categorization of the available technologies. The term digital materialization is proposed as a general term to designate all the production technologies available for making physical artifacts.*

Keywords. *Rapid prototyping; digital fabrication; rapid manufacturing*

1. Introduction

The expressions “rapid prototyping”, “rapid manufacturing” and “rapid tooling” have their roots in the fields of mechanical engineering and product design. These techniques have been recently introduced into architecture and are becoming more and more common in the field. However, the meaning of certain words and expressions related to these techniques vary from one field to the other. For this reason, there is an urgent need to establish proper definitions to be used in architecture. The present paper aims at starting this discussion. Definitions of the most important words and expressions related to the field are presented below, from an architectural point of view, based on a literature review.

1.1. Models

In sciences, “to model” means to represent reality in a simplified, schematic, abstract way, showing just the elements that are strictly necessary to understand specific aspects of the phenomenon being studied. Real-life situations are often too complex to be studied, so a model can be seen as a tool that supports our cognitive process (Mc Millan, 1992). The higher the complexity of a phenomenon, the higher the need for modeling it.

There are different types of models and different modeling techniques. According to Mitchell (1975), the three modeling methods most used in architecture are the analogue, the symbolic and the iconic.

In analogue models “one set of properties (...) is used to represent another analogous set of properties of the item being designed” (Mitchell, 1975, p.130). The representation produced by Gaudi, with wires and sand bags, of the Sagrada Família, is a good example of an analogue model. In this representation the tension vectors are represented by the wires, whose shape and direction are analogue to the physical phenomenon they represent. As a result, the architect was able to find the (inverted) ideal shape for the vaulted structure.

Symbolic models use symbols, such as words, numbers and mathematical operators. In architecture, symbolic models are used for simulations and evaluations of structural, acoustical, lighting and

thermal performance. Symbols are typically displayed as mathematical formulae, tables and arrays. More recently, though, advances in computer graphics have allowed the three-dimensional display of quantitative information on top of geometric models, using gradients of colors. This type of visualization allows architects to make quick visual, qualitative evaluations (Kolarevic, 2007, p.197).

Iconic models are more literal. Typical examples of their use in architecture are plans, elevations and scale models. These models involve scale (enlargements and reductions) and projection (3D to 2D and 2D to 3D) transformations. In fact, architectural models are usually miniature representations of buildings. Mitchell (1975) emphasizes the role of this type of model in the generative process; according to him, in iconic models “a particular state of the system actually ‘looks like’ the potential solution which it represents” (p.130).

1.2. Prototypes

Prototypes are a special type of models. According to the Marrian-Webster dictionary, a prototype is “a first full-scale and usually functional form of a new type or design of a construction”. Prototypes are usually built during the design process in order to preview how the building or building part will look like and function. It is also used for planning the production process.

According to Liou (2008) “prototyping is an approximation of the product along one or more dimensions of interest (...) ranging from concept sketches to fully functional artifacts.” According to this definition, prototypes are not necessarily full-scale models. In architecture, it is often unfeasible to produce full-scale prototypes of entire buildings. For example, when Frank Gehry designed the Walt Disney Concert Hall, a 1:10 prototype of the main music hall was built to test its acoustics (Fig. 1A).

Usually, full-scale prototypes are used in architecture only when a building or a building part will be reproduced many times. For example, a small part of the façade system used in Gehry’s Guggenheim Museum in Bilbao was produced in full scale to test its performance (Fig. 1B).



Figure 1A. 1:10 Scale model for Disney Concert Hall



Figure 1B. 1:1 Model for Guggenheim Museum in Bilbao

Therefore, the concepts of prototype and scale model in architecture overlap, especially when we refer to working models. Working models are one of the three types of models defined by Hetchinger and Knoll (2008). The other two are conceptual and presentation models.

Since, as seen above, architectural scale models can sometimes be considered prototypes, the expression prototyping can also refer sometimes to making scale models.

1.3 Manufacture

To manufacture or to fabricate is to mechanically produce a final-use object, often in large numbers. More recently, the mechanical processes have become computer-controlled, i.e., they are controlled by digital information. The concept of fabrication is associated with the concept of mass-production.

1.4 Tooling

Tooling is the act of making tools. In mechanical engineering a tool is not just a hammer or a screwdriver – it can also be a mold for casting metal, extruding ceramic, or injecting plastic.

1.5 Virtual prototyping

According to Liou (2008) “a virtual prototype is an analytical model of some aspect of a design.” The advantage of virtual prototypes is that they are not as expensive and as inflexible as physical prototypes.

1.6 Rapid prototyping

The term rapid prototyping (RP) is used to describe technologies in which prototypes are produced specifically by the automated deposition of layers of material (Volpato et al, 2007), which vary from liquid to solid. For Geng (2004), “many have adopted this term for processes that are quick but not truly rapid prototyping. Everything from machining to molding is now described as a rapid prototyping process.” However, other authors agree with the use of the term for the quick production of prototypes with any automated technique, including CNC routing and laser cutting (Lennings, 1997).

To avoid this discussion, Pupo and Celani (2009) have proposed the use of the term digital prototyping. However, this expression can be mixed with virtual prototyping.

1.7. Rapid manufacturing

The definition of rapid manufacturing (RM) is similar to RP in terms of the production process, but it has a different objective. In the RM process an end-product – not a prototype - is produced. Technically, this term does not include the production of prototypes, but only end-products.

1.8. Rapid tooling

Rapid tooling is the use of CNC techniques for producing molds for manufacturing. According to Chua et al (1999) rapid tooling (RT) is the technology that adopts rapid prototyping (RP) techniques and applies them to tool and die making. Research into RT techniques has shown that it is gaining more importance and is starting to pose a serious threat to conventional machining. In this paper, several popular RT techniques are discussed and then classified. A comparison is also made on these techniques based on tool life, tool development time, and cost of tool development."

2. Proposed terminology for the architecture field

The table below shows the proposed terminology of digital techniques in the field of architecture. The left side of the table shows the terms used in the field of product development, while the right side presents the corresponding terms for architecture. The top part of the table is related to the initial phases of the design process whereas the bottom part refers to the final product or the finished building.

The term “digital materialization” is proposed to define the physical production of prototypes, scale models, and building parts.

Product Development		Architecture		
Virtual Prototyping	Functional Aspect	Gemometric Modeling/ Simulation	Virtual & Function Evaluation	DIGITAL PROTOTYPING
Rapid Prototyping	Additive/CNC	Rapid Prototyping	Additive/Subtractive/ Formative	
Rapid Tooling	CNC for Mold	CNC for final part or mold	DIGITAL FABRICATION	DIGITAL MATERIALIZATION
Rapid Manufacturing	CNC for product			

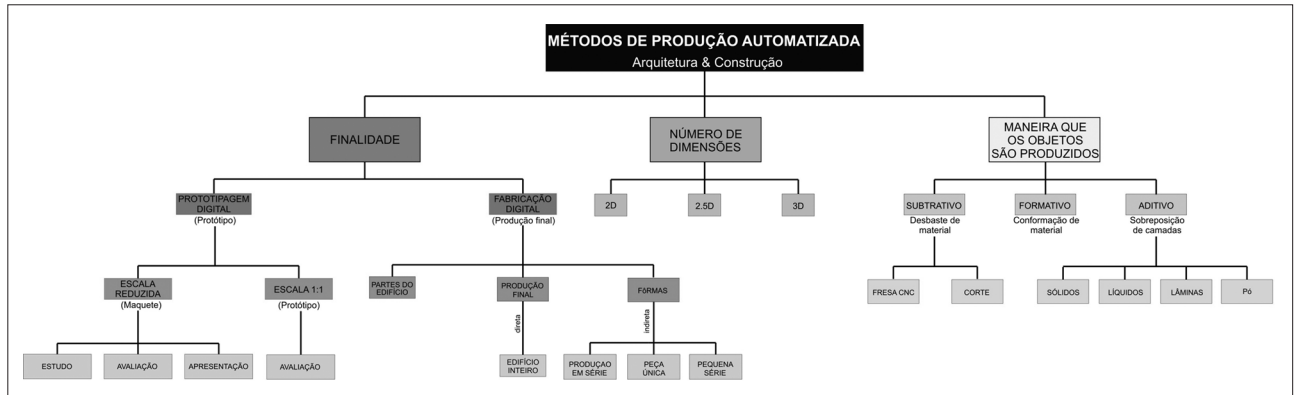


Figure 2. Digital materialization techniques

3. Possible categorizations

The digital materialization techniques can be subdivided according to different categorizations. The purpose of these categorizations is to help understand how they relate to each other. We herein propose three possible categorizations: according to purpose, number of dimensions, and the type of process by which objects are produced (Figure 2). In regards to purpose, digital materialization techniques can be subdivided in two: making models (digital prototyping) and producing building-parts or entire buildings (digital fabrication). In the first case, the techniques can also be subdivided according to the purpose of the prototype: for visual evaluation, functional evaluation, and presentation. In the second case, the techniques can also be subdivided according to purpose: they can be used to produce the building parts or buildings directly, or indirectly by means of molds. In the latter case, the term rapid tooling also might be used if the mold is produced layer by layer. Regarding the number of dimensions, the techniques can have 2, 2.5 or 3 dimensions. Regarding the process by which the objects are produced, the techniques can be categorized as subtractive (which includes routing and cutting), formative, and additive.

4. Example of technologies

In this section examples of additive, subtractive, and formative technologies frequently used in the field of architecture are presented. Additive technologies can be divided according to the state of the material used, which can be solid, liquid, powdered or layered, as indicated in Table 2.

Solid	Liquid	Powder	Layered
FDM (Fused Deposition Modeling)	SLA (Stereolithography)	SLS (Selective Laser Sintering)	LOM (Laminated Object Manufacturing)
MJM (Multi Jet Modeling)	PolyJet	3DP (3D Printer)	PLT (Paper Lamination Technology)
BenchTop		CAM-LEM (Computer Aided Manufacturing of Laminated Engineering Materials)	
		EBM (Electron Beam Melting)	

Subtractive technologies can be primarily classified according to whether the removed parts have three dimensions, in which case they are called machining or two dimensions in which case they are called cutting. In fact, the latter can be considered a special case of the former, in which the tool used to remove the parts cuts across the material.

Machining technologies are of two kinds, lathing and milling. In lathing, the parts spin and the tool moves in one direction, thereby creating objects with axial symmetry. In the simplest form of milling, the part is still and the tool moves in three directions, x, y, and z to remove material. In more complex forms of milling, the part or the tool can rotate to permit the removal of material in non-perpendicular directions or in other perpendicular planes of the part rather than the XY plane used in 3-axes milling machines.

Cutting technologies can be classified according to the specific type of technology used to cut the material: laser cutting, water-jet cutting, and hot wire cutting. The latter differs from the other two because it can be used to cut not only sheets of material but also blocks. By moving the endpoints of the wire in x, y, and z directions, it is possible to create blocks with ruled surfaces.

In forming technologies forces are applied to change the shape of the material, and so these technologies can be classified according to the type of forces applied, such as mechanical forces or electro-magnetic forces, the plasticity of the material when subjected to deformation, and the use of molds. Bending, extrusion, thermoforming, and molding are some examples of these types of technologies.

5. Conclusions

After looking at so many technologies, there is still an important question to ask: which is the best technology for making a scale model, a building part prototype or an entire building? Cost is still an important issue, as well as availability of equipment. But soon digital materialization machines will become more available and affordable, so issues such as color rendering and resolution will become more important.

However, just knowing about the available technologies is not enough. It is important to know how to design a model or a building part so that it can actually be produced by a machine. In other words, the whole process of model-making, prototyping and building will have to undergo a transformation in order to take full advantage of the new technologies.

The goal of this paper is expected to contribute for the teaching of digital materialization in architecture by clarifying the terms used to designate available technologies and by providing a possible categorization and a general overview of such technologies. The goal was not to cover all the existing technologies, a difficult task since there are many plenty of them and new ones are being developed every day.

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