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The roles of a model

As funções de uma maquete

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Abstract

The paper initially discusses the different applications of physical models in architecture. It then gives some examples of architectural scale models produced with digital fabrication techniques, with different purposes. Finally, a case study about the production of a model for an arts museum is presented. The objective of this model was to help the museum curators to plan an exhibition. The process involved many issues, such as drafting architectural details in CAD software, 3D-scanning of objects and using a laser cutter and a 3D-printer.

Key words: architectural scale model, rapid prototyping, 3D-scanning.

Resumo

Neste artigo são discutidas as diferentes aplicações dos modelos físicos em arquitetura. Em seguida, são apresentados alguns exemplos de maquetes arquitetônicas produzidas com técnicas de fabricação digital, com diferentes finalidades. Finalmente, como estudo de caso, é descrita a produção de uma maquete para um museu. O objetivo da maquete era ajudar a equipe de curadores do museu a planejar um exposição. Esse processo envolveu diferentes questões, como o desenho de detalhes arquitetônicos em um aplicativo CAD, a digitalização 3D de objetos e o uso de uma cortadora a laser e de uma impressora 3D.

Palavras-chave: maquete arquitetônica, prototipagem rápida, digitalização 3D.

Introduction

In sciences, "modeling" 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 understood, so a model can be seen as a tool that supports our cognitive process (McMillan, 1992). The higher the complexity of a phenomenon, the higher the need for modeling it.

In architecture, models are usually produced for presentation purposes. They can also be used for analytical purposes; for example, to run tests on wind tunnels or sun motion simulators. Models can also be used to support the process of design; for example, to help plan interventions on existing spaces.

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 Familia (Figure 1) 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.

Figure 1. Gaudi's analogue model (photograph by Gabriela Celani).

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) (Figure 2).

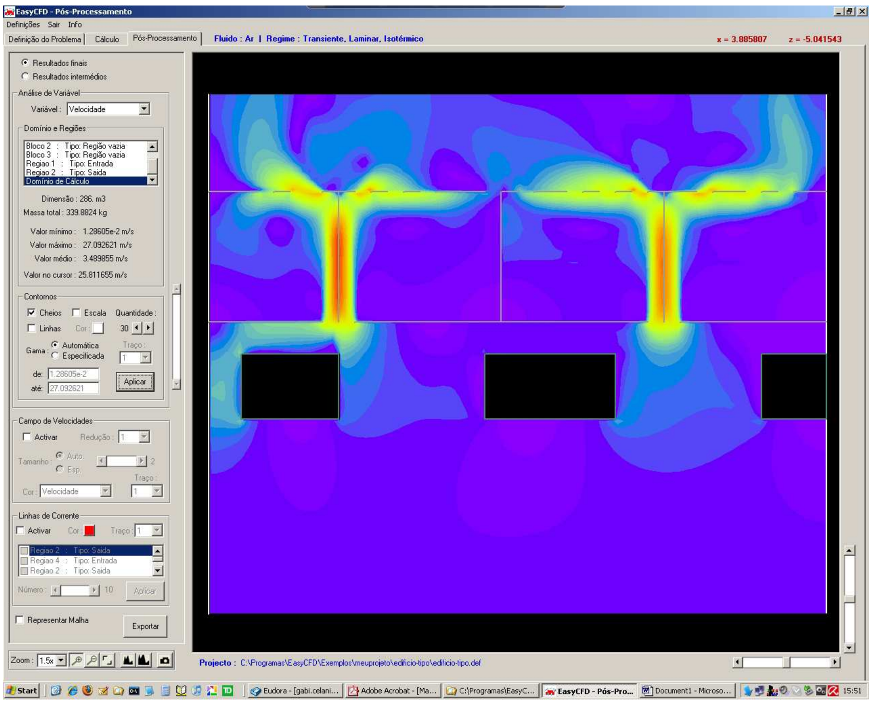


Figure 2. A geometric model displaying symbolic data: each color corresponds to a different air flow speed (printscreen of Easy CFD software).

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) transformations. Mitchell (1975, p. 130) 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".

In the past decades, while digital geometric models have become a tool in the design process, physical scale models progressively became used almost exclusively for final presentation. This was due to the difficulties in changing their physical state, especially when they are made of materials that need to be glued, nailed and fixed in a permanent way. Computer models, on the other hand, can be easily changed, at no cost.

However, more recently, computer-controlled machines, originally conceived for product design prototyping, started being used to produce architectural scale models. This technology made it possible to materialize models straight from the computer, thus increasing the production of physical models by architects.

There is some dispute on the terminology used to refer to these techniques. While some authors refer to both additive (such as 3D printing) and subtractive (such as cutting and routing) techniques as "rapid prototyping" (Lennings, 1997), because they allow making prototypes in a fast manner, others argue that this expression should only refer to layered object construction, based on the "historical" use of the term (Volpato, 2007). To avoid this discussion, some authors employ the expressions "digital fabrication", "digital prototyping" or even "digital materialization" (Pupo, 2009).

Figure 3 shows the steps in the automated process of producing a scale model (Celani, 2009). In this process, "construction documents" of the model must be carefully prepared in CAD software. These files are then sent to machines that cut, sculpt or construct the model's parts automatically. There is still the need to carefully plan the model, according to the machines and materials used, and the assembling and finishing must be done by hand. However, rapid prototyping techniques allow making models in a faster, safer and more precise way, allowing the representation of even the most complex, topological shapes (Sass, 2004).

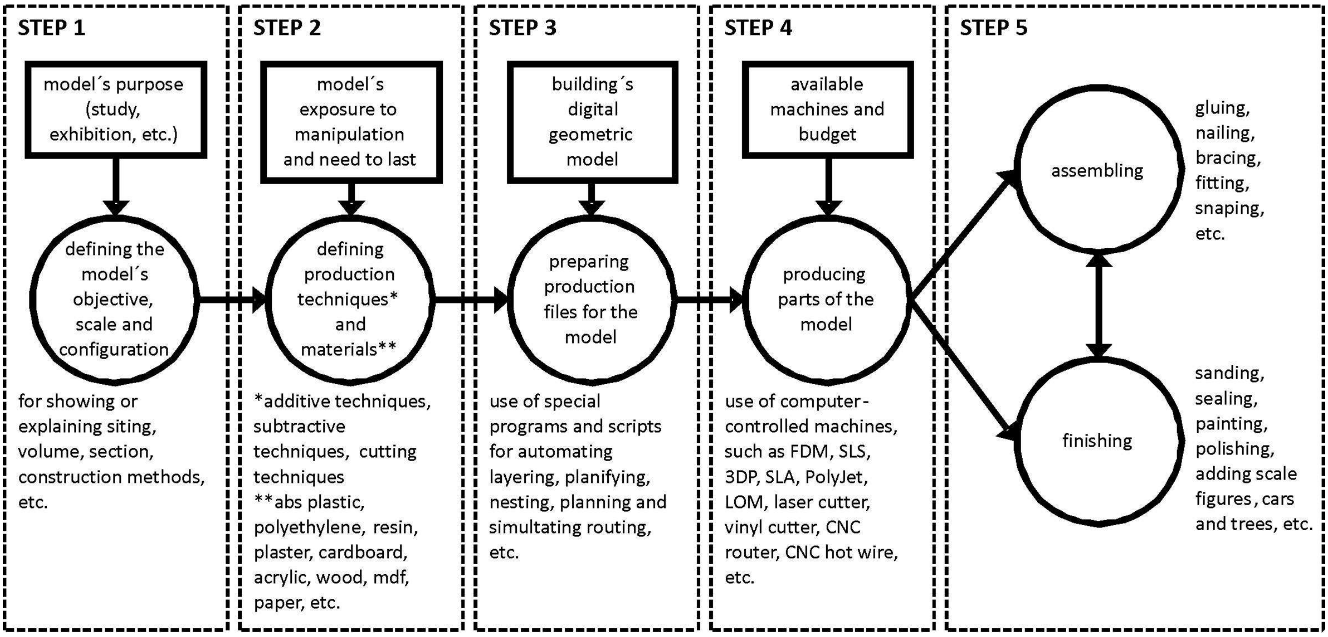


Figure 3. The five steps in the production of a scale model with rapid-prototyping techniques (Celani, 2009).

Examples of applications

The models presented in this section were developed at the Laboratory for Automation and Prototyping for Architecture and Construction (LAPAC), at the State University of Campinas, Brazil. This laboratory aims at developing research and methods for the use of rapid prototyping equipment in the production of architectural scale models, for applications in education and practice.

Since 2007 many research projects have been developed at the laboratory by undergraduate and graduate students, with scholarships from FAPESP, from the Brazilian Ministry of Education (CAPES), from the Brazilian Ministry of Science and Technology (CNPq) and from Unicamp's social service (SAE). Besides, the laboratory has offered training to students and faculty from other Brazilian state and federal universities, such as UFMT, UFRGS, UFRN, USP, UFC and USP-SC, serving as a model for the establishment of similar laboratories.

LAPAC is used by Unicamp's architecture students both for research and for studio work. In regards to studio work, the lab has been used mainly for the production of study and presentation models, especially by final year students (Figure 4). The introduction of rapid prototyping techniques in the model shop resulted in a larger number of models produced by students. Besides, the models now start being produced earlier in the design process and display a higher level of detail if compared to hand-made models. In special, the production of topographic models has been facilitated by the use of the laser cutter. Some professors have remarked that students stopped avoiding steep sites to develop their projects.

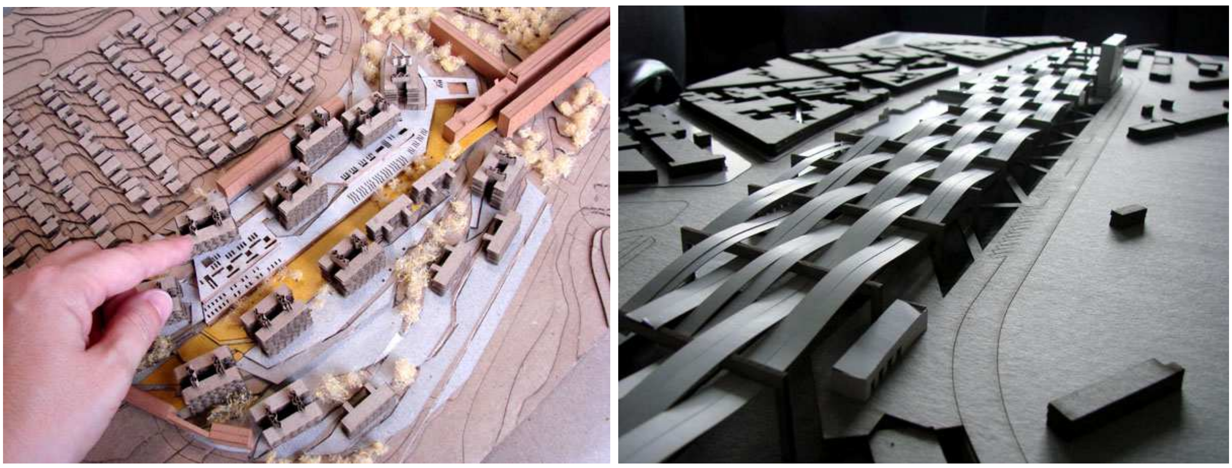


Figure 4. Study model for understanding topography and sitting; presentation model (photographs by Regiane Pupo and Gabriela Celani).

In regards to research, students have produced models mainly for evaluation and analytical purposes. In the first case, models are tested in the wind tunnel and the Heliodom, a sun path simulator (Figure 5). Figure 6 shows some examples of analytical applications of rapid prototyped models. In this case the models were automatically generated by a script that implemented Palladio's proportion rules. In some cases, models are for both evaluation and design purposes in a combined way.

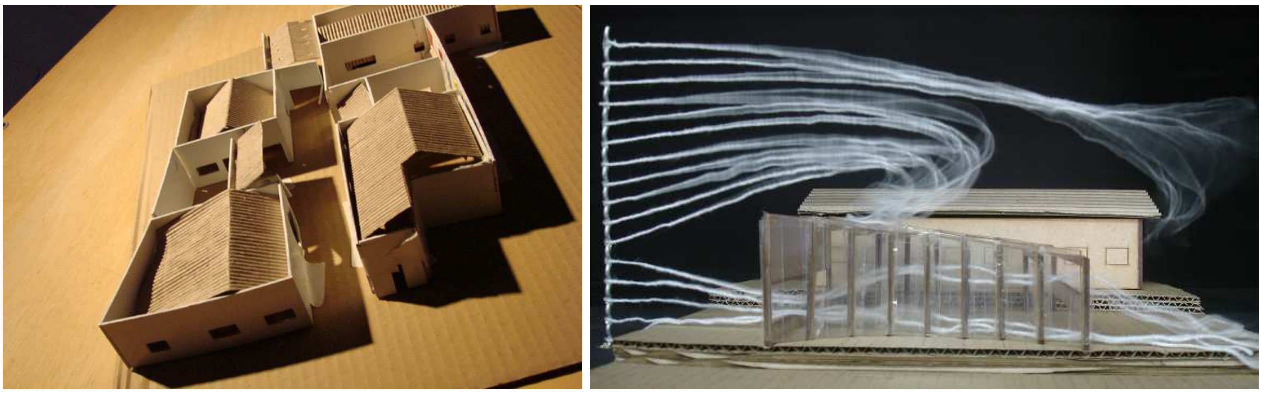
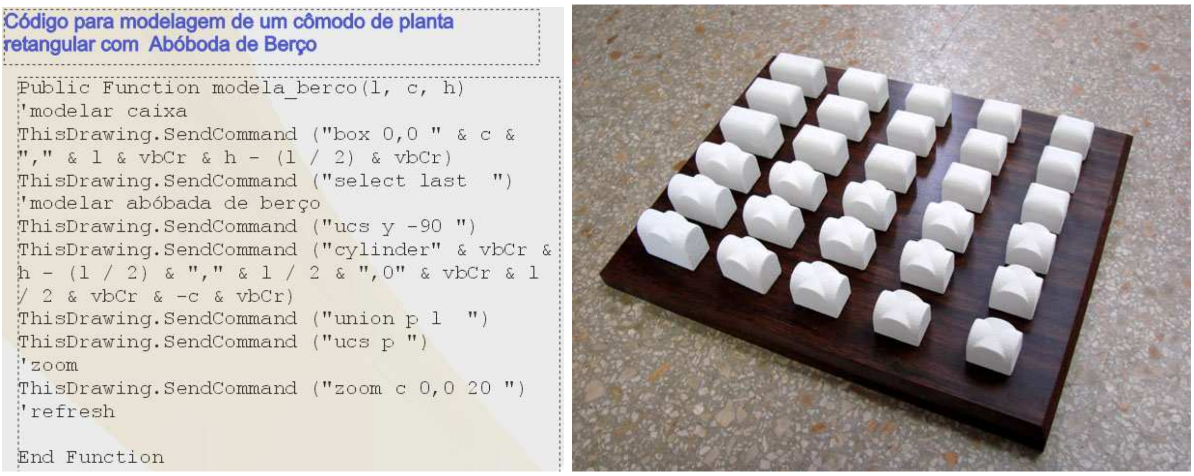


Figure 5. Evaluation models for testing wind performance and natural lighting (photographs by Fernanda Souza Cruz and Regiane Pupo).

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Public Function modela_berco(l, c, h)
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ThisDrawing.SendCommand ("box 0,0 " & c &
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h - (l / 2) & "," & l / 2 & ",0" & vbCr & l
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Figure 6. Analytical models for understanding Palladian proportions and the script used to parametrically generate the models (photograph by Gabriela Celani).

Case study: A model for an arts museum

The present section describes the production process of a scale model for Pinacoteca do Estado, São Paulo's largest arts museum. The model was produced with the objective of helping the museum's curators plan the new arrangement of the permanent collection's exhibition.

The production process of this model was used as a case study for three different issues: (i) the use of rapid prototyping techniques for making architectural models; (ii) the use of 3D-scanning techniques for the production 3D-printed scale models; and (iii) the use of architectural scale models for purposes other than simple representation.

The team that developed the present research was formed by Regiane Pupo, FEC's Ph.D. student; Ana Emilia Claudino and Joyce Carvalho, LAPAC's interns and Unicamp's undergraduate students; Laura Cancherini, FEC's undergraduate student; Gabriela Celani, LAPAC's coordinator; and LAPAC's technical staff. The team also had the support of Valéria Piccoli, a curator and researcher at Pinacoteca do Estado, and of Dr. Jorge Lopes da Silva and M.Sc. Marcelo Oliveira, from Renato Archer Information Technology Center (CTI). The work was structured in such a way that each researcher's topic was interconnected with the overall work.

Pinacoteca do Estado is one of the largest museums in Brazil, with a collection of 6,000 works from 19th and 20th century Brazilian art. Pinacoteca is installed in a historical building located in São Paulo's downtown. The three-story, classical style building has more than 20 exhibition rooms and was designed by Ramos de Azevedo, a famous Brazilian architect, at the end of the 19th century. In the '1990s, the building was completely remodeled by Pritzker-winner architect Paulo Mendes da Rocha. Technical areas are located on the ground floor, temporary exhibitions are displayed on the first floor, and the permanent collection is shown on the upper floor (Celani *et al.*, 2008).

The permanent exhibition has been set up more than 10 years ago and needs to be replanned not only in terms of the works on display, but also regarding layout and communication issues. In order to make the design process more effective, the curators of Pinacoteca initially asked LAPAC to develop computer renderings of the new arrangement of pictures and sculptures in the galleries. A research was conducted to find out about digital exhibition planning tools. Although digital databases are used for exhibition management (Moon and Kim, 2008) and virtual reality is often used for online exhibitions or interactive exhibitions inside the museums (Sparacino *et al*., 1999; Hirose, 2006), not much was found about the simulation of exhibition spaces with digital means.

The next hypothesis was to build a scale model of the museum, which would be more interactive and easier to manipulate by multiple designers simultaneously. During the research, nothing was found about the use of physical models as a planning aid for museum curators, even in journals such as Curator, Archives and museum informatics, Museum international and Museum management and curatorship.

The curators liked the idea, but the model would have to be carefully planned, in order to meet the following requirements: (i) portability and storability; (ii) the possibility of displaying the room all together or separately; (iii) the possibility of previewing room views at eye level; (iv) the possibility of changing the model's floor and wall colors when needed; (v) the possibility of easily "hanging" pictures on the model's walls; (vi) the reproduction not only of the paintings, but also of the museum's sculptures.

Just like in any kind of construction or product development, a scale model of a building needs to be carefully planned. The objectives and requirements of the model need to be defined, and materials need to be specified in detail. In this case, the availability of digital fabrication tools at LAPAC determined the production techniques to be used: laser cutting and 3D-printing. The design process started with sketches and practical experiments in the laboratory (Figure 7).

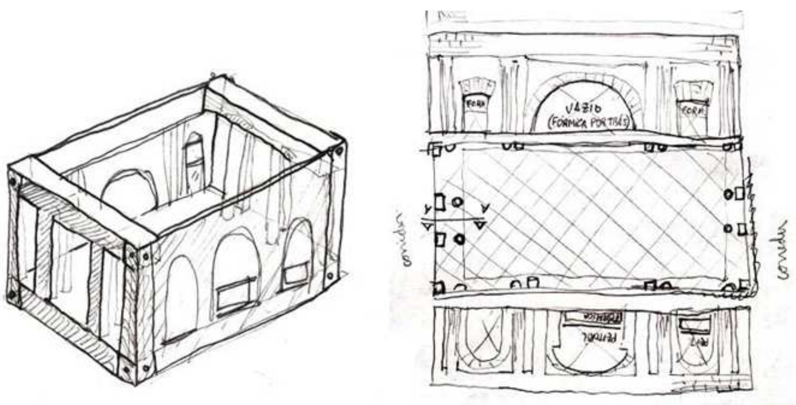

Figure 7. Initial sketches for the museum's scale model (sketches by Gabriela Celani).

In order to decide which would be the best scale for the models, mockups of the larger and the smaller exhibitions spaces were produced in corrugated cardboard at 1:50 and 1:25 scales, along with samples of paintings and sculptures (Figure 8). Photographs of these mockups were taken through their door openings, in order to show the curators the type of image that they would be able to obtain once the model was ready (Figure 9).

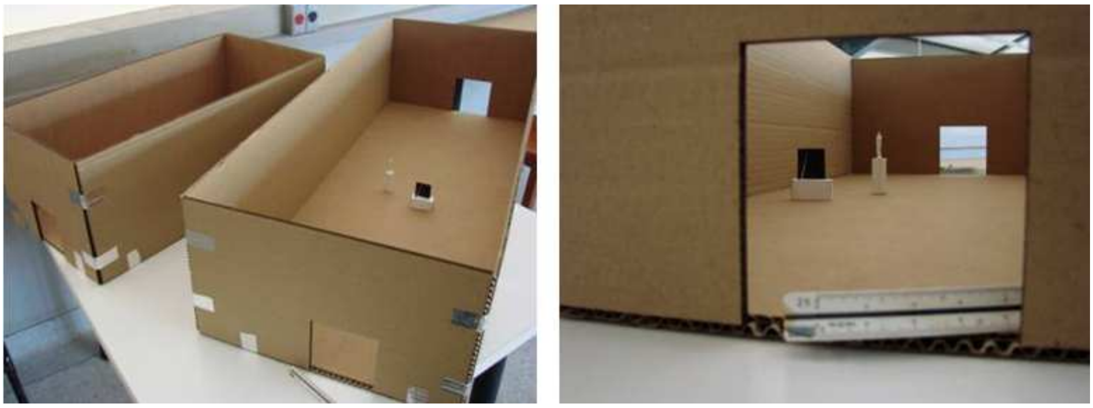

Figure 8. Mockup scale comparison: 1:50 and 1:25 (photographs by Gabriela Celani).

Figure 9. The 1:25 mockup furnished and a view through an opening (photographs by Gabriela Celani).

In the 1:50 mockup the smaller paintings and sculptures were too small to handle and displayed a very low level of detail. The 1:25 scale was chosen by the museum's curators, despite the resulting larger size of the model (approximately 2x3m overall), which would make it more difficult to store.

Since the new exhibition has primarily to deal with the best of the museum's collection, displaying pieces from early 19th century until contemporary art, the project will be developed by different teams, which will work according to their area of expertise. One important requirement for the making of the model was the possibility to work with it in separate parts – in a way that each team could be able to study and make propositions for its section – still keeping the connection to a master plan. Therefore, the model needed to be split in separate parts, so that each team can bring part of it to its own department. At certain times, however, they will need to put the connecting rooms together in order to see the exhibition as a whole.

For this reason, instead of making one large model, the LAPAC team decided to build separate boxes for each room. The curators will be able to connect the boxes, when necessary, by placing them on top of a

1:25 scale plan of the museum, printed on a foldable canvas, which is easy to store (Figure 10). This strategy allows the model to be easily transported and stored.

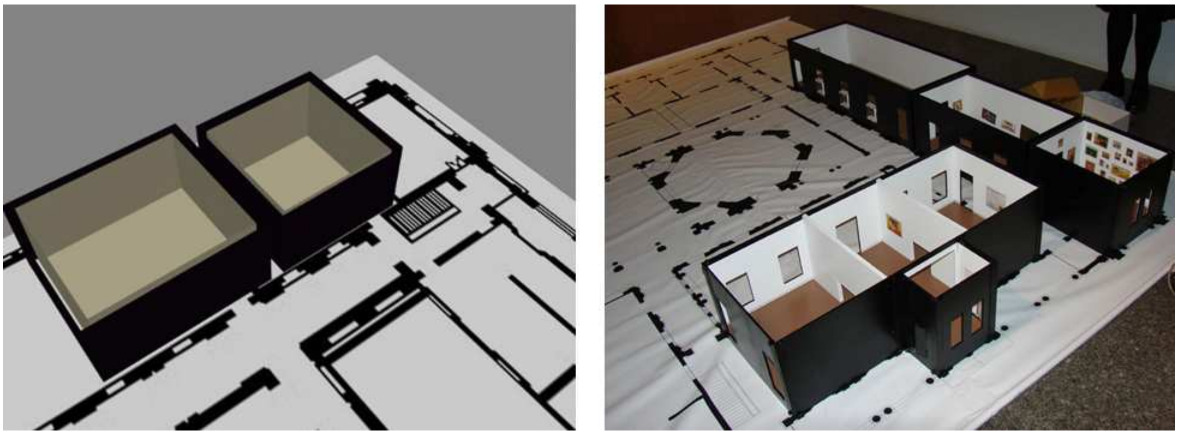

Figure 10. Models of exhibition rooms over the canvas base (rendering and photograph by Gabriela Celani).

Six mm-thick MDF was chosen for making the models, due to the possibility of easily cutting this material in LAPAC's 60 watt Universal Laser Systems machine. Three mm-thick MDF was also used for applying extra volume in places where the walls are not flush (Figure 11). To avoid gluing the parts of the boxes, L-shaped aluminum brackets were used to connect them, with large bolts on the bottom and the top of the models (Figure 12). A floating floor system was developed, in such a way that the lower bolts would not be seen in the inside of the boxes (Figure 13). The floor boards lay on top of invisible aluminum brackets. This strategy allows to easily disassemble the models for storage or in order to change the colors of the floor or the walls. 0.4 mm-thick Formica was used for making details such as skirting boards and door moldings (Figure 14). This material can be easily cut and scored by laser. 2D digital drawings were prepared in CAD software to be sent to the laser cutter to cut the walls in MDF sheets (Figure 15).

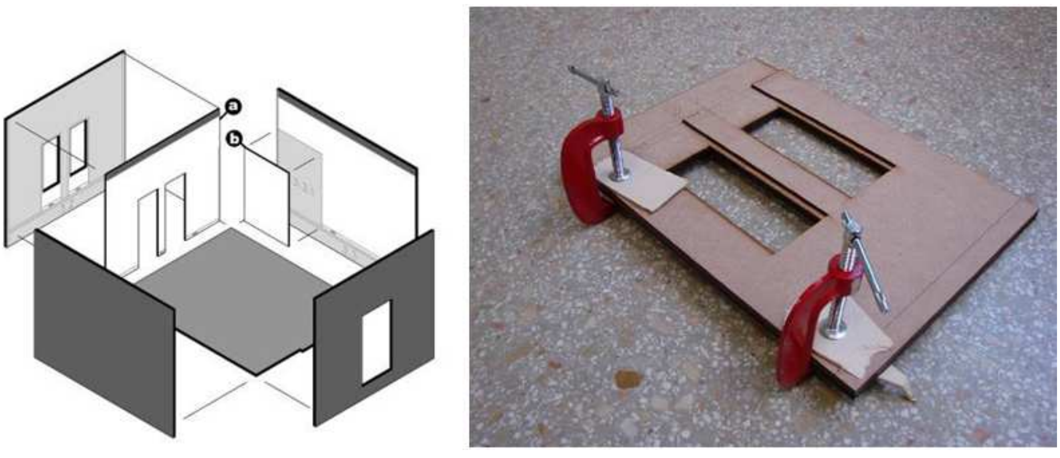

Figure 11. Applying add-ons where the walls are not flush (rendering and photograph by Gabriela Celani).

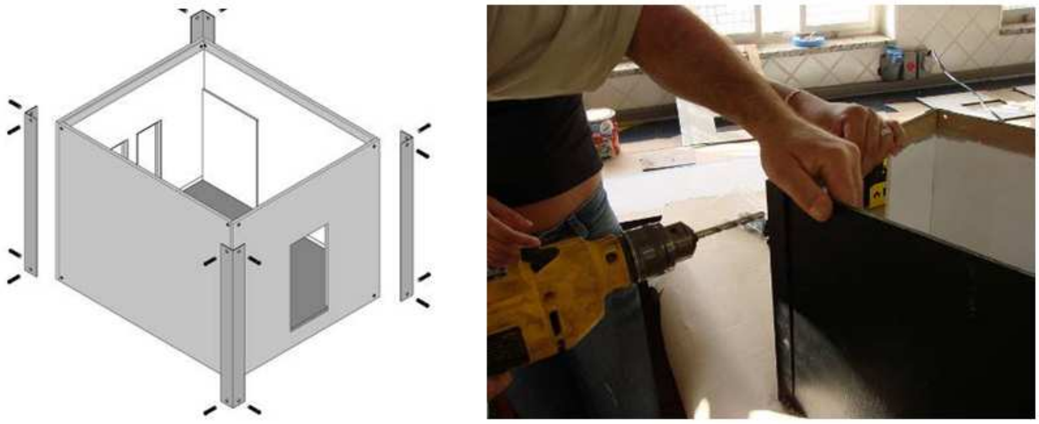

Figure 12: Aluminum brackets and bolts for connecting the walls (rendering and photograph by Gabriela Celani).

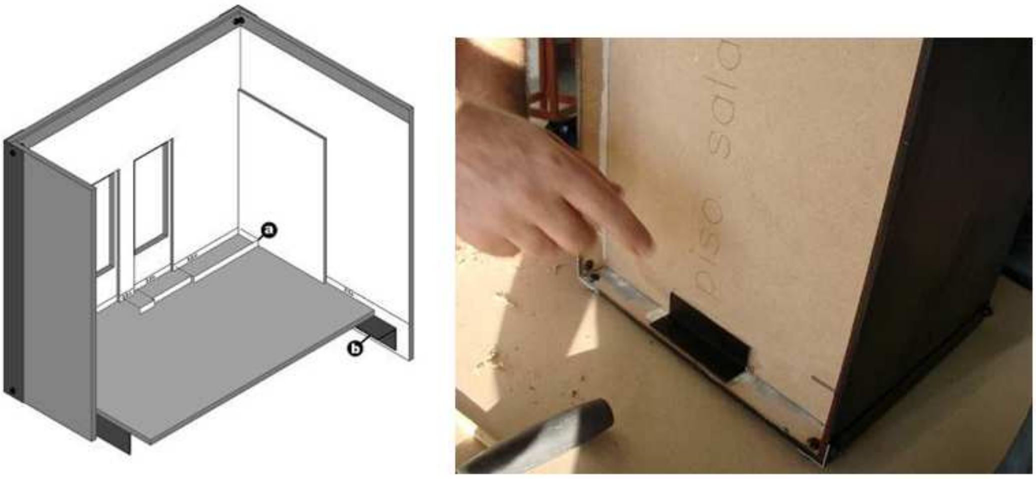

Figure 13: Floating floor laying on an aluminum bracket (b), and the application of the Formica skirting board (a) (rendering and photograph by Gabriela Celani).

Figure 14: Door moldings made up of 0.4 mm Formica, cut and scored by laser (photograph by Regiane Pupo).

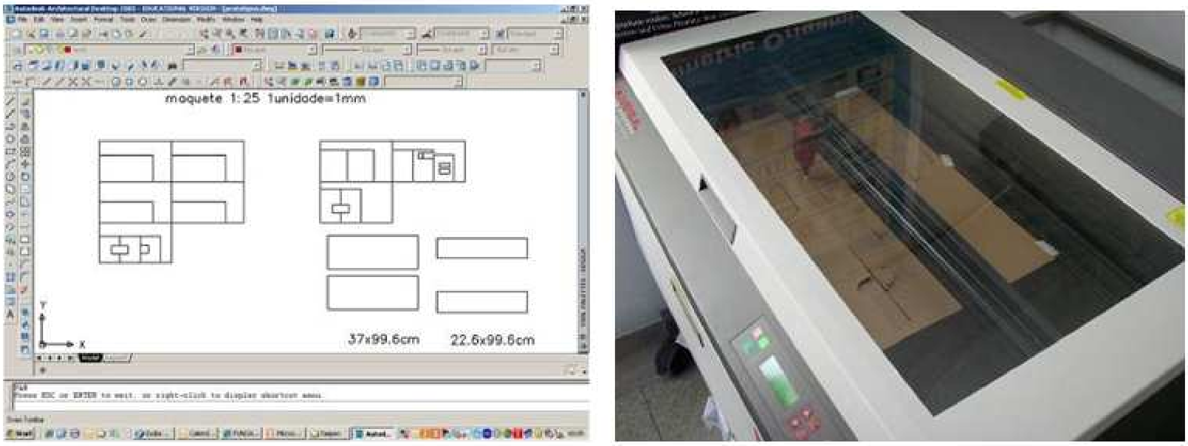

Figure 15. Laser-cutting the CAD drawings (printscreen and photograph by Gabriela Celani).

In order to allow the curators to freely play around with paintings on the models' walls, magnets were used. Tests were carried out in order to decide whether the walls would receive a coat of magnetic paint or metal stripes. The initial tests with the magnetic paint showed its efficiency with the application of three coats of painting. A final coat of white paint had to be applied, because the magnetic paint is grey (Figure 16). The museum's equipment, such as display boxes and benches, were also CAD-drawn and laser-cut (Figure 17).

Figure 16. Application of magnetic painting (photograph by Gabriela Celani).

Figure 17. Benches and display boxes (photographs by Regiane Pupo).

The museum's paintings were printed with a high resolution color laser printer, and mounted on magnetic sheet bases, with laser-cut frames made of 1 mm bass wood (Figure 18). The miniatures were organized in pocket file sheets by the museum's curators, for easiness of use.

Figure 18. Magnetic paintings placed on the model's walls (photographs by Regiane Pupo).

The museum's sculpture collection was very heterogeneous in terms of materials, geometry and sizes. Larger sculptures made of light color materials, such as marble, were digitized with photogrammetry software and 3D-printed. Although this system was not the most accurate or easy-to-use, it was relatively inexpensive and did not require bringing heavy, bulky equipment inside the museum. The resulting 3D models were 3D-printed in LAPAC (Figure 19). However, it did not work for shiny, dark materials such as bronze and other metals. Most authors, such as Iuliano and Minetola (2005), acknowledge the difficulties in the digitations of shiny and dark objects. More tests still need to be carried out in order to define the best digitation techniques for the sculptures made of these materials.

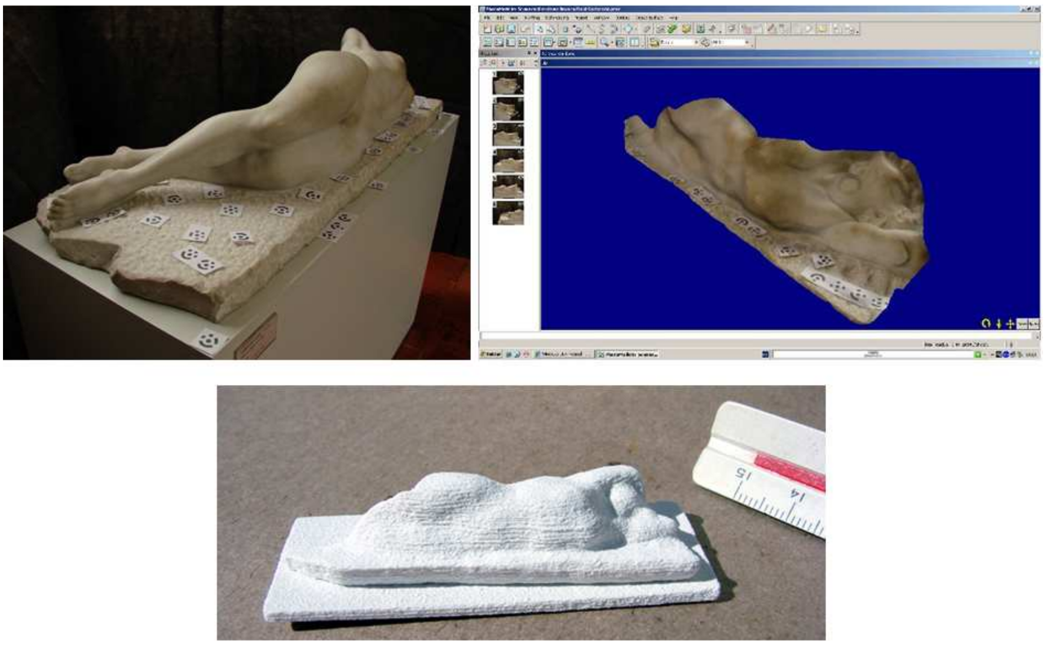

Figure 19: A marble sculpture at the museum, the processed model in the software, and the resulting 3D-printed 1:25 scale model (photograph, digital model and 3d-printed model by Laura Cancherini).

The model produced is currently being used by the museum's team of curators for the planning process of the permanent collection's new layout. All the team's meetings now happen around the model (Figure 20). According to the team's leaders, the model has allowed them to plan the exhibition keeping the overall space in mind. This is very important, considering that the permanent exhibition space occupies 10 different sized halls plus a patio for sculptures. The scale of the museum is too complex to be kept on one's mind without a 3D planning tool, such as this model.

Figure 20. A meeting of the museum's curators around the model (photograph by Gabriela Celani).

Discussion

This paper examined the different types of architectural models and their applications, within the framework of new automated methods. It presented a number of applications for study, presentation, evaluation and analytical models, and a case study that included the use of different technologies, from 3D scanning to rapid prototyping. The examples presented show the inclusion of rapid prototyping technologies at Unicamp's architecture course both at the studio and for research projects. They also have emphasized the role of analogue models.

The case study presented also showed the opportunity of including different research interests in the production of a larger model. Very frequently students develop research on related topics in the same laboratory but in a completely independent way. The project described here was important because it gave students and graduate researchers the opportunity to develop different studies in an integrated way. Besides, it allowed the integration between students from different levels and backgrounds, which is one of the objectives of the university environment.

On top of producing a model that is very useful for the museum's curators, the project resulted in a method for making scale models with rapid prototyping technique and in specifications for a future acquisition of a 3D-digitation system for the laboratory.

In regard to the introduction of digital model-making in the architectural curriculum, the laboratory proved to be an efficient way to encourage students to experiment with the new technologies. The next step in the incorporation of digital technologies in the design process consists of using parametric and programmable CAD software in the earlier design phases, for automatically generating shape, using paradigms such as rule-based systems and evolutionary computation.

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