Virtual Modeling for Architecture: teaching today digital representation techniques to tomorrow's professional designers.

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Abstract

Three-dimensional digital modeling is mostly a skill that needs to be consolidated in students' careers, to allow them an adequate preparation to the post-graduation professional world. Just like the traditional disciplines of drawing and representation, computer graphics techniques evolved over the years, introducing several fascinating possibilities in architectural visualization. What this paper is mainly concerned with is the analysis of issues and advantages as results of teaching a few of those methodologies establishing an original teachers/students collaborative learning environment. Some experiences gained during the "*Virtual Modeling for Architecture*" lectures, mainly held in the School of Engineering and Architecture in Bologna, will be introduced featuring many students, who were involved in digital representation of buildings related to an important Cultural Heritage landmark in the Italian city of Bologna: its *porticoes*.

Keywords

3D modeling, Cultural Heritage, Existing architecture, Digital representation, Architectural visualization.

1. Introduction

Drawings are often considered as the first level of understanding in architecture: designers have used them in many different ways, as a record for existing spaces or a tool for new projects and buildings.

When computers began to deal with graphic representation interactively, probably with the introduction of *Sketchpad* by Ivan E. Sutherland in 1964, drawing and drafting gradually started to proficiently take advantage of the Information Technology. As soon as digital tools became sufficiently mature, user friendly, and capable to assist with ease designers and architects without bearing unwanted constraints, they walked into everyday practice with strides (Gaiani, 2011).

Like those early kind of electronic drawings, also the contemporary digital representation allows the world to be better understood, since it dramatically evolved in its potential application. Just like the traditional drafting, computer technical drawing is ruled by conventions, based upon a degree of abstraction and analysis, which focuses the mind upon aesthetic values developed through the medium of graphic expressions (Edwards, 2008). For many architects in fact, today there is not a clear distinction between
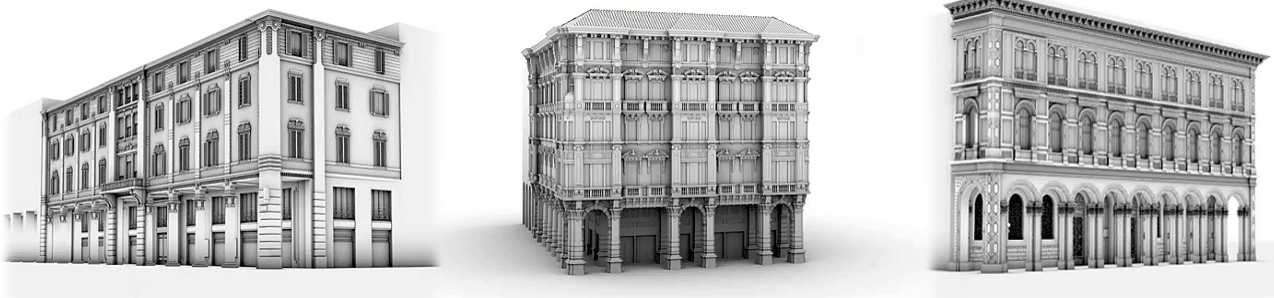

Fig. 1: Digital models of some historical buildings with *porticoes* in Bologna. To the left, a model by VMA students Michela Saracino and Simone Viani; in the center a model by Davide De Cecco, Leonardo Di Chiara, Francesca Di Nocco and Giulia Fratoni; to the right a model by Daniele Ballardini, Federica Farroni and Giulia Manzelli.

graphic representation, words and symbols as the are different expressions of the same language (Lawson, 1980).

1.1 Digital models as representation of knowledge

Due to existing computer frameworks, which are capable of a deep integration of geometries, materials and functions, digital models are the numerical result of a sharp work of interpretation, where the reproduction is not a copy, a matching duplicate of what does exist, but on the contrary a mimic tool to understand relationships and mechanisms embedded in architectural organisms. That is why drawing first, and then drafting and modeling, still keep their role of fundamental disciplines in architecture and engineering (Docci, Gaiani and Maestri, 2011).

In fact, the most recent trends in architectural representation are no more bound to visualization only but they are oriented towards collaborative strategies merging into knowledge databases, sort of heterogeneous collectors of information that describe how the actual world really works (Gaiani, Benedetti, & Apollonio, 2009). This relatively new concept, meant to organize in models data required all along the design, construction and operation phases of facilities from their inception onward, is deeply connected to the idea of digital knowledge repository generally referred today as *Building Information Modeling* (BIM).

Even if BIM is not the main theme of this paper, it has to be highlighted how computer models considered as coordinated, consistent and always up to date graphical datasets are paramount into its culture in order to reach higher quality, reliability, optimized scheduling, errors and costs reduction together with avoidance of any possible misinterpretation by different actors involved in the design process.

When a computer-generated model, in fact, embeds precise geometry and relevant data needed to support the construction, fabrication, and procurement activities, it is supposed to be a *BIM model* and the interactions with it by various figures determine a *BIM process* (Eastman, Teicholz, Sacks and Liston, 2008).

These digital extended representations rely on a specific feature, which is represented by *smart objects*, parametric architectural components self-aware of their identity and conscious of their interactions with each other.
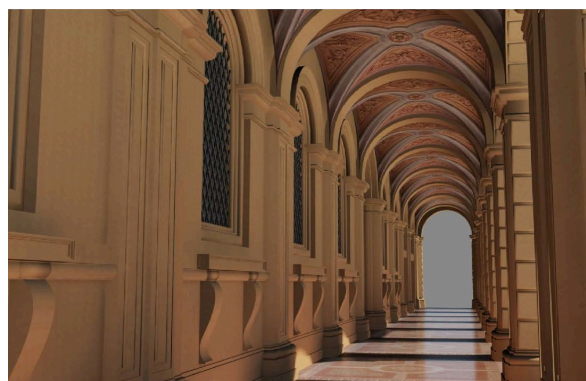

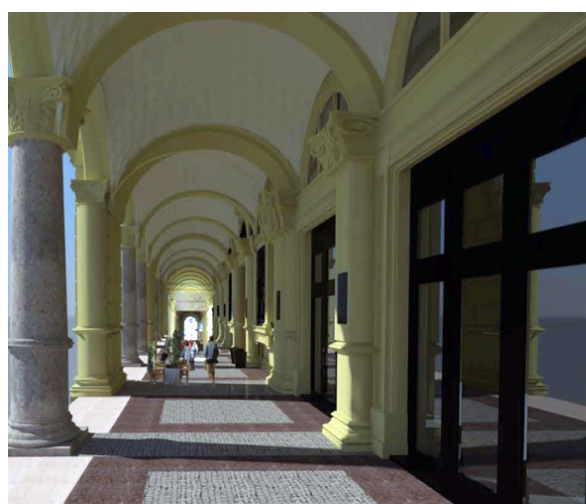**Fig. 2:** 3D modeled porticoes with decorated vaults by students Luca Cenacchi and Silvio Terribile.

Fig. 3: 3D digital porticoes and natural daylight, by VMA students Alice Cancilla and Micaela Manderioli.

Fig. 4: 3D porticoes and natural light simulation, by VMA students Guido Maria Amorati, Chiara Ricciardi and Cesare Zilio.

Fig. 5: Some accurate *texture baked* models in which high Level of Detail (hi LoD) is activated, by students Ilaria Braghiroli, Alessia Frescura and Giulia Meloni.

Fig. 6: 3D meshing of complex geometries: decorations generated with box modeling techniques by Jasmine Chiarelli, Anna Golinelli and Martina Servadei.

They are often hard coded in 3D modeling software and they include not only a morphological definition, usually ruled by numerical values, but routines capable of interaction as well (e.g., floor slabs are perpendicular to walls, doors and windows belongs to walls, etc...).

Digital models produced using this *object-oriented* framework are valuable because properties and relationships within their components enable useful information to be derived directly or by simulations and calculations. More specifically, it is a consolidated viewpoint in the scientific literature that the understanding of architecture and its grammar can be compared to the linguistic (Stiny and Gips, 1972). In fact, while syntax is the study of the combinations, semantics is the study of meanings: both are part of the grammar, which establishes all the rules to govern the composition. Similarly to letters that follow the grammar to form correct words, words form sentences following the syntax but, to have logical sense, they must respect semantics (De Luca et al., 2011). In the same way, architectural elements (words combined with correct syntax) have to follow semantic rules to combine themselves properly (floors are sustained by walls, foundations keep walls erected and so forth), just like in BIM models.

Since this complex and coordinated process seems to be very promising and it will probably mark the future operations of practitioners and designers, it is important having it considered in a much wider *scenario*, in which current students must correctly understand fundamentals of digital representation from a lower point of view, beginning from geometric modeling and basic visualization, being prepared however to the much more sophisticated multidisciplinary modeling approach once they will be professionals.

1.2 Learning how to model the architecture

The first step to author digital representation of buildings, whether they are new interventions or existing ones, is the geometric modeling: from a topological point of view, building elements are made of related vertexes, edges, surfaces and volumes that globally describe their shape. This way, an accurate reproduction of components' morphology leads to a successful final assembly to generate the whole digital *replica*.

Just like still-life hand drawing, geometric entities have to be recognized and digitally reproduced by users; even if the real world is a complicated collection of continuous elements, in the computer domain they have to be translated into discrete entities, following a precise binary logic. So designers have to be sharp in estimating dimensions and boundaries of architectural components, recognizing their seams or when different materials suggest various elements.

Evidently, using digital modeling as a multidimensional representation of architectural reality requires certain instrumental preparation as well; in fact, computers are ultimately numeric machines whose output results have to be understood and prearranged by users through

Fig. 7: Several urban contexts were modeled during the VMA course, producing nearly 3 Km. of digital porticoes. 3D model by Riccardo Raimondi and Nicola Di Biase.

Fig. 8: Materials and colors were accurately taken into account when producing realistic views. 3D model and render by Martina Anelli and Federica Fuligni.

visual forms much more comprehensible than numbers. It is not only a matter of graphic reproduction, such as for example photography could be. Modeling in three dimensions an object, a building or a townscape into a digital form entails a more direct engagement than mere photography; the investigation to acquire shape, proportion and colour requires greater efforts and more skilled observation than that needed simply taking pictures.

As already pointed out, in the real world the elements of the Euclidean geometry (lines, edges, polygons, etc...) fade in a *continuum* of matter in which they are nearly unrecognizable, so hardly measurable: even statistic, which deals with probability, is far from this concept being able to arrange events with numbers as well. In scientific literature the estimation of space discontinuities is much closer to the *fuzzy logic* domain (Kosko and Isaka, 1993), which suggests curious ways to estimate proportions leaving to the operator the responsibility to justify his choices.

So, a primary skill to improve when learning to model architecture is the correct understanding of shapes and how they can be represented into abstracted discrete digital primitives, in order to combine them and gain the whole. This is not a trivial task for students used to study buildings in their entirety, delving into details only as a last resort.

Many educational specialists over the years have turned their attention to the *constructivist*

Fig. 9: Huge buildings often have modular elements that repeat themselves along façades. Procedural modeling and geometric instances were explored by students during their training: 3D model by Alice Hecker and Valeria Lenzi.

learning models (Taxén, 2003), emphasizing students' active construction of their own subjective understanding (Twomey Fosnot, 1996). Constructivist pedagogies have been successfully used in learning situations where the acquiring of a deep comprehension of a subject is required, even if they seem to be less suitable for memorization (Von Glasersfeld, 2001).

Thus, the easiest way to encourage reflections is by having the learners talk with their teachers about what they are thinking, joining a problem solving conversation that emphasizes the so called *joint productive activity* (Stoll Dalton and Tharp, 2002), in which educators and learners produce together.

In order to describe a teaching approach similar to this one, results of an academic course in computer graphics applied to the architectural modeling are below presented.

2. The "Virtual Modeling for Architecture" course

The "*Virtual Modeling for Architecture*" course was established in 2008 as an option for students attending the last of the five years long single cycle degree (combined Bachelor and Master) in Architecture and Building Engineering, at the School of Engineering/Architecture Alma Mater University of Bologna. During the academic year 2013 - 2014 it was held with the partnership of Bologna's Municipality, in order to deepen the theme of historical *porticoes*, as part of a much wider research work still in progress and carried out to a higher level by a selected team of Alma Mater's researchers.

A detailed plan with specific historical buildings to be studied and reproduced in the digital domain was proposed to 120 students, who chose this theme and course as complementary part of their individual study programme.

Fig. 10: Historical buildings with porticoes in Bologna are made of peculiar materials: pictures considering their state of conservation were useful when preparing aged shaders aimed at final visualizations. 3D model and rendering by Carlo Bergonzini and Mattia Santi.

Fig. 11: 3D porticoes: digital model by students Danilo Calza and Corrado Cecconi.

Fig. 12: 3D porticoes: digital model by students Luca Bignami and Matilde Dalmonte.

Fig. 13: 3D porticoes: digital model by students Alice Spaggiari and Lorena Vecchio.

Lectures and trainings were shaped with the aim to introduce them to the methodologies and techniques of digital three-dimensional modeling, as a means of virtual prototyping and knowledge system, similar, homologous and isomorphic to the real world. The life span of the whole course was four months with overall 130 hours of frontal lectures: during this time students were trained on many techniques that were presented by two teachers and a tutor, at first following a theoretical approach, then letting them explore practical results in a specific 3D modelling environment.

2.1 The VMA syllabus

The course was originally divided into two sections according to the classical authoring scheme of a digital image: a first part in which issues related to geometric modeling were explored and a second one in which aspects pertaining to rendering and visualization were examined. Some references to the hardware graphic pipelines were introduced, together with full description of raster and vector based imaging. Those themes were preparatory to several training hours on 3D modelling software, where graphical transformations, editing of formally correct mathematics (curves, Beziér splines, Nurbs parametric surfaces, subdivision surfaces, etc...) were properly authored. During laboratory training sessions, several exercises were assigned to students individually at first, then constituting working teams as difficulties increased. Theoretical arguments were simultaneously experienced by means of step by step exercises proposed in form of tutorials, which had to be accomplished in classroom in a reasonable time and submitted when finished on a dedicated web server, in order to receive personal evaluation. Since the *porticoes* and their buildings were almost complex and most of participants had a few or not experience at all in accurate geometric modelling different from CAD drafting, first exercises were basic tests performed by students in order to acquire fundamentals on parametric object generation, box modelling and polygonal editing.

Fig. 14: 3D porticoes: some other details related to the digital model by VMA students Luca Braglia, Beatrice Lucchese, Michela Mancini and Maria Silvia Reggiani.

The second part of the course was aimed at the illustration of specific software and theoretical arguments fundamental to the understanding of the physical processes that govern the perception of images, from the human physiology to the computer simulation. In detail topics covered were: principles of color theory, the human visual perception and the tristimulus theory, some basics of photometry and the behavior of physical light. Lighting design was illustrated with accuracy, delving into the nature of lighting sources, the appearance of materials, the meaning of reflectance and color (*texturing* and *draping*), the use of shaders in rendering and the flat, Gouraud, Lambert and Phong lighting models. Some specific exercises were proposed on the propagation of light using global lighting models (lighting objects modeled and rendered into a *Cornell box* for example), making use of *ray tracing* and *radiosity* techniques, *photon mapping* and *final gathering.* Tools for quantitative and qualitative evaluation of the light were introduced too.

3. Final considerations and results

The educational goal of the VMA course was to help the students acquire the understanding of the digital graphics software pipeline and the fundamental concepts of three-dimensional modeling for complex architectures in a reasonable amount of time.

There was enthusiasm all over the course duration even if the workload was intense with a very tight schedule. Students initially complained about it but once they reached a satisfactory skill level in 3D modeling they started to be very productive and respectful of every deadline for their partial work submissions. Most of them gained a very good evaluation at the final examination, which was formally organized as a presentation session where all the teams introduced their work using slide shows about graphic renderings, animations and movies, or whatever they considered useful in presenting their efforts. Almost every student was able to discuss the final presentation, without further delays. As previously stated, the strong collaboration between instructors and students was meant to solve problems in a collaborative way, and it ultimately reached this goal. After the formal ending of the academic calendar, a final presentation was held at the School of Engineering/Architecture in Bologna, in front of the Municipality, the Dean and the President of the School. The complete work of 120 students, ten of them coming from International exchange programmes, consisted in about three thousand metres of *porticoes* digitally created, with about two hundreds desktop computers and laptops reserved for nearly five hundred thousand animation frames rendered in short movies and clips (Tab. 1).

Fig. 15: Rendering and visualization of complex 3D models with huge number of polygons were some of the major issues along the modeling pipeline. 3D model by Davide De Cecco, Leonardo Di Chiara, Francesca Di Nocco and Giulia Fratoni.

Fig. 16: Some photorealistic renderings of a complex building with porticoes in the historic center of Bologna, with digital model placed into a photographic real context. 3D model and visualization by Andrea Carecci and Domenico De Salvio.

As teachers, this experience was draining but outstanding at the same time: in-class training and theoretical lectures were pulled alongside with two web server systems (one for students' submissions and another officially dedicated to the download of tutorials, lecture notes, and software scripts) and a reserved VMA channel on social networks, in order to help students in each and every difficulty. This can be considered as the original approach of this experience, if compared to similar training courses documented in scientific literature: the deep connection between students and teachers during the course, by means of frontal discussion during the official lectures' scheduling and social networks, dedicated web pages, net forums and so forth over the remaining time was the focus of the whole learning system.

The future exists as an imaginative idea within the mind of the architect: it is strong hope that participants to the *Virtual Modeling for Architecture* course had successfully acquired basics and strategies to express their ideas with new consciousness, creativity and fun.

Tab. 1: The VMA course in numbers.

No. of enrolled students	120
No. of students from foreign programmes	10
No. of auditor students	29
Hours of frontal lectures	130
Duration in months	4
Teachers	2
Tutors	1
Desktops PCs & laptops used (estimated)	200
Official in-class exercises	10
Students who successfully passed the first examination	100
Total amount of modeled polygons	300 million
Animation frames rendered	500.000
Total amount of rendering hours	10.000
Amount of *porticoes* reproduced	3.000 mt.

Fig. 17: The top image is the official symbol of the *Virtual Modeling for Architecture* course (MVA in Italian) while at the bottom are represented graphics by Bologna City Brand, a visual translation of words into iconic symbols related to the city.

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