Hypertext, Solid Modeling, and Hierarchical Structures in Formal Architectural Analysis

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The paper presents computer reconstructions of unbuilt projects relevant to the history of Italian rationalism together with the potential and limits of three CAAD environments. While an evaluation is provided for each one, a more detailed attention is devoted to hierarchical structures because of their capability to capture knowledge, to support further investigations, and to provide new insights into architecture. A model built in this environment allows simultaneously (1) the analysis and reconstruction even of a complex project at the size of a personal computer; (2) the simulation and test of different material, crucial in the case of restoration or in the case of incomplete and uncertain original project data; (3) the critical analysis (but also the co-presence of the different project alternatives of design phases) through the reading at the various level of the hierarchy; and (4) free investigation on the structure of data that can support new critical hypothesis and insights that were not anticipated at the moment of project creation.

Keywords: hypertext, solid modeling, hierarchical structures, Giuseppe Terragni, Italian modern architecture.

1 Introduction

The chapter discusses the potential strengths of computer-aided architectural design for the documentation and analysis of architecture using, as examples, three unbuilt projects that were reconstructed either by the author, as part of a research project on the architecture of Giuseppe Terragni (1904-1943) funded by the Graham Foundation for the Advanced Studies in the Fine Arts, or by his students at Carnegie Mellon University in Pittsburgh, PA USA (1984-1990) and ETH Zürich (1991-1993). The central part of the chapter is dedicated simultaneously to one project and to a specific computer environment. Information and critical interpretation about the “Officina del gas” (1927), the “Villa sul lago” (1936), and the “Danteum” (1938), are provided at the beginning of each section. The technical components of the use of computers in (a) hypertext and interactive teaching; (b) solid modeling and interpretation; and (c) hierarchical structures and simulation are subsequently addressed. An evaluation with trade-offs of each environment, in addition to a checklist, is provided at the end of each section. The new insights that the use of

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the three environments provide for architectural investigations concludes the chapter together with some suggestions to further develop hierarchically-structured software.

1.1 Background

The interest in using CAAD for documentation and analysis of modern architecture (DAA) began for the author almost a decade after his first studies on the history of Italian rationalism. Since the mid-eighties, he has started to develop and to teach university level courses on architectural theory which incorporate computers as an increasingly important tool.

The first course, which used the just-born Macintosh in the realm of DAA, was taught at Carnegie Mellon University in Spring, 1985. Students used an innovative program to relate information to graphic objects. Filevision™ [1], a graphic database, allowed the user to append text as properties to graphic entities. This environment allowed: (1) storage of large amounts of information in a structure meaningful for architectural scholars; (2) advantages of database search based on specified criteria to be applied not only to the text but also to the linked graphic elements; and (3) the possibility to disassemble and reassemble the drawing according to the database categories.

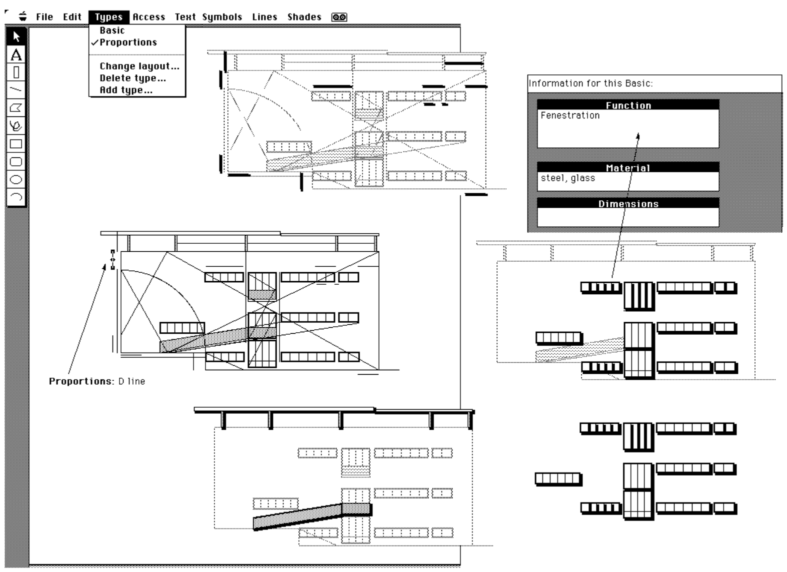

Figure 1. Each graphic element can be linked to a record containing related information. The information, normally hidden from the user, can be easily accessed by clicking on the various parts of the graphic. The drawing can be highlighted as a result of a user-defined search (Villa Bianca by G. Terragni, Seveso, 1936. Model by T. Sanders and S. Shaw, CMU, 1988).

The second course that used computers in the area of DAA was taught in Fall 1986, at Carnegie Mellon. Students selected a villa of the Modern Movement and analyzed it

[1]The original product was the result of a team composed by Howard Metcalfe, Matthew Jacobs and David Murray for Telos Software. The lastest release is called Filevision V™ and is distrubuted by Visual Information System, Inc.

with a set of different tools. Animation was used for the first time for teaching DAA at Carnegie Mellon. After several experiments, it became clear that the best use of computer-generated animation was to create a "design story". The use of animation techniques forced students to develop a deeper understanding of architectural issues and to present them in a chronological order with a "before" and an "after."

The most recent courses were taught at ETH Zürich during the winter semesters of 1992 and 1993. "Giuseppe Terragni Architecture: A Formal Analysis using CAAD" focused on a critical reconstruction of unbuilt projects by the most well-known architect among the Italian rationalists. The ETH courses, whose results will be partially discussed in the final section of this chapter, have shown the potentials of hierarchical structures in the realm of DAA.

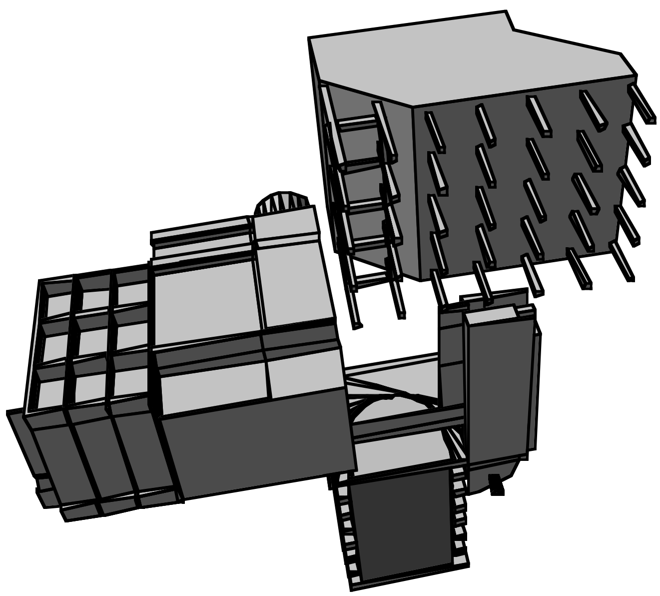

Figure 2. The project is located on the periphery of Como, commissioned by a real client, and based on a realistic functional and distribution program (Officina del gas by G.Terragni, Como, 1927. Model by A. Saggio, Rome, 1988).

In parallel to these experiences, the author developed his own research in architectural theory. Although the papers present the result of computer investigations, they do not specify the process, the problems and the potential of the tool. In this chapter, the critical result is condensed, but an evaluation of the use of computers in DAA is provided.

2 Interactive Architecture Documentation

For several years the author was interested in developing interactive tools to communicate and explore architecture, but the task was too complicated for a non-programmer specialist. Only in 1988 was he able to develop computer-based lectures for studies in architecture that provide effective interactive modes. These lectures include access to database sections with pictures and text, direct three-dimensional exploration of the building under analysis, animation insertions in addition to electronic sketching and note-taking. The most important aspect, however, does not concern the isolated materials present in these examples, but their level of integration and of interaction with the user which are provided through four different levels: to see, to explore, to study, and to interpret. In this section, an example of this interactive lesson of architecture is applied to the Officina del gas, the first important project by Terragni.[2]

2.1 *The Workshop for Gas Production, Como, 1927*

The project is articulated in four different bodies that through their separation reveal the different functions they serve. The first, with a clog shape, contains the coal deposit; the second, composed by several volumes among which the most characteristic is a tower with a tank on top, contains the ovens; the third, with a semi-cylinder section, contains the machines; and the fourth, two-stories high, the offices.

Terragni uses four design devices for the four objects. The ideation of the first body is related to the research of expressive emphasis on the volume. The design action which creates it is *hoisting*. The definition of the second body follows an operation of *assemblage*: the pieces, volumetrically distinct, are combined together creating three parts—two parallelepipeds for the ovens, and one composite for the tower. The development of the theme of the *joint*, which is present in a minor way in the tower, has a complete application in the definition of the third body containing the machines. The fourth body of the office appears to be the most simple one. The strongest aspect defining this building is the shape of the floors in their final stage. These floors describe a quarter of the circumference linking the building to the machine room. The gesture reveals that the generating force is not internal, as it happens in the other cases, but it is generated by a will of *connection*. Through its longitudinal shape, this building dynamically ties the machine room and the coal deposit. While *hoisting*, *assemblage*, *joint*, and *connection* are four different devices that the architect used for the different parts of the building, in the overall composition we are in front of an original system.[3] The syntax that guides the composition is the subtle relation between the autonomy of the pieces (the coal deposit, the tower, and the room of machines) and their assemblage or joint. The capability proven by Terragni is that of solving the implicit contradiction in the combination of the two approaches through a disposition of the shapes in the space in a calibrated asymmetrical way.

2.2 *Hypertext*

The thesis presented above is available in a computer file which provided, for the first time, an example of interactivity in the realm of formal architectural analysis. The

[2]One example of an interactive lesson has been presented at Ecaade 1989 conference in Aarhus, and in other seminars and conferences in Italy (Saggio, 1989; Saggio, 1990). To the issue of DAA with computers, the author has written three previous works (Saggio, 1990, 1993a, 1993b). While in some cases description and drawings are similar, this chapter represents a substantial new understanding of the application of CAAD in analysis of architecture.

[3]This is not a constructivist syntax, as the objects maintain a separation which is foreign to the 'unity in the diversity' of the constructivism. This is not an approach of Gropius because the buildings, although they invade the dimension of the perception in time, are too strong in themselves to hide the story of their autonomous existence. This is not a Corbusian approach because the existence of the volumes is subject to the two previous inspirations which result indissolubly merged with it.

program that has been used is Hypercard™ [4] which, thanks to its programming language Hypertalk™ , allows one to create with ease a personalized electronic environment. Using graphics, text and buttons, it is possible to create a structure to collect and display all kinds of information. While the stack provides the overall framework and a general metaphor to display the information, the end user can read and utilize it by just clicking the mouse.

This software was commercially available since Fall, 1987. The author used it the following year in the field of DAA in a first stack dedicated to the Donnelly Erdmann Dormitory of Louis Kahn at Bryn Mawr, and later, with the help of architecture student Massimo Cesaroni of *La Sapienza,* for the Workshop for Gas Production.

While in the first case a sketchpad metaphor was used, in the second, a different one was adopted. Each card is represented as a blackboard. In the central area images and text fields are contained. At the base, two buttons with an arrow shape allow the user to go from card to card, proceeding in the analysis at one's own pace. The lesson begins with the title and the basic information about the project. In the next card, the user finds a button with a movie icon. By clicking on it, an animation with a walkthrough of a reconstructed three-dimensional model of the workshop can be seen in order to have a general idea of the building. In the next card, together with new information, the user will find a new button with a book shape. Clicking on it, a database section can be accessed where all the existing materials about the project (site plan, general plan, perspectives views, pictures of the original model), are digitized, titled and referenced.

The lesson proceeds in two basic parts. The first part deals with the relevance of the thematic choice.[5] A field with the text of the author's article is provided which has few hypertext functions such as direct access to footnotes. The second part, devoted to the functional and architectural language of the project's themes, makes a full exploitation of Hypertext. Each one of the four bodies of the buildings has its own card which shares an identical structure:

- a title which summarizes the basic design device used in that part (hoisting,

[4] Developed by a team led by William Atkinson for Apple Computer, Inc. The basic entity of this environment is a card. The collection of cards, which comprise a computer file, is called a stack. Each card may contain a number of elements belonging to three categories: images (directly created or digitized), text fields, and buttons. Buttons are used to perform specific instructions (such as " go to a linked card," "search for a word," "show an animation," or "go to another program and then come back"). Using graphics, text, and buttons, it is possible to create a structure to collect and display all kinds of information.

[5] The room of "Gruppo 7"» at the first show of rational architecture, held in the Palace of Exhibition of Rome in the spring of 1928, exhibited a number of proposals similar to those presented the previous year at the III Biennale of Arti Figurative of Monza. Functional programs replaced the monumental ones and describe a different and modern city: the exposition of low income housing studies, public services, and industrial buildings. Terragni focuses on the last of these programs, deciding to give public importance to two of his first projects: the Workshop for Gas Production and the design for a Pipe Foundry. Terragni's insistence on the industrial theme is not accidental. The functional destination of the architecture is the tool for creating a direct connection with the short history of artistic vanguard on the one hand and with the affirmations of the contemporary European architectural culture. It is also evident that this project for a workshop—designed a little more than a decade later than the projects of Italian Futurists—creates a connection with Antonio Sant'Elia and with the drawings by Mario Chiattone and Ugo Nebbia. But the major difference from the Futurists that Terragni wants to make evident in the design as well as in the writings, is the capability of the modern architecture to give a concrete answer, and not a utopian one, to the demands present in the Italian society at the end of twenties (Saggio, 1988).

Figure 3. The formal analysis is subdivided in four cards characterized by buttons which allow 3D exploration, access to database, vision of animation, sight of the body in the overall building. (Officina del gas by G.Terragni, Como, 1927. Interactive lesson by A. Saggio with M. Cesaroni, Rome, 1989.)

- an axonometric view depicting the specific body;
- a text area that describes the architectural choices; and
- four buttons: the first brings one into a three-dimensional electronic environment where a direct exploration of the model can be made; the second, with a camera icon, allows one to watch an analytical animation that in few seconds depicts the fundamental design action; the third displays a picture from a key standpoint for studying the body under analysis in the overall context; and the fourth button brings one to a new database, where digitized titled and referenced images of comparable architecture, which almost surely Terragni used as source of inspiration, are collected.

2.3. *Evaluation*

This environment was presented officially in 1989 at European computer-aided architectural design conference (Ecaade) in Aarhus, and later in many other public occasions. Since then, many tests about its potential and limits were done that can be summarized as follows.

1. The interaction that a user can have with this product tailors it to a variety of uses: from a student for individual application to a teacher as a support for in-class lessons, to the scholar for in-depth documentation. The time

spent with this stack ranges from ten minutes (in order to have a basic understanding of its overall structure) to two hours to read the text, explore the three-dimensional model, study the comparable projects and to proceed back and fourth in the stack structure.

2. The different materials (text, digitized images, animated walkthrough, didactic animation, direct three-dimensional model exploration) are integrated in an environment that support and reinforce each other. For example, while in the architectural design analysis, a few seconds of animation are more effective than a full page of text; in the case of cultural and historic relevance of the project, the contrary is true.
3. The stack was designed to run on the simplest model of the Macintosh computer line (the Macintosh Plus). This implied that the stack and all the support files had to be contained on only two diskettes and provided ease of circulation and duplication (with the subsequent possibility for students and scholars to re-use parts of it thanks to electronic cut and paste). At the same time, the characteristic of the hardware (and of the software at the time) forced the use of black and white images to be displayed on a small screen size, although projection onto a large screen brought no degradation of image quality. By current standards, the stack appears a little crude in comparison to the extensive use of color and photorealistic pictures, and reveals the pioneer moment of its creation.

2.4 Checklist

From this and other experience, we can provide a checklist when creating hypertext.

- *Metaphor.* The first point is the use of a metaphor to collect and display information—in this case, the blackboard and the electronic special buttons located at the base of the blackboard. Hypercard™ itself has been defined as a *metaphor creator*, but too often we see Hypertext that is based on the pre-defined card metaphor.
- *Inserted animation.* Animation is provided through a special program (Videoworks Driver™ by Macromind, Inc., that directly displays movies from Hypercard™), but it is also possible with Hypercard™ commands. In the area of animation (together with voice annotation) exist the most important today's technical advancements, thanks to the possibility to bring in a stack video through Quicktime™ compression. This feature is stimulating for motion images captured from reality, but it is even more interesting if the data are originally digital. (Real time walkthrough can be recorded in analogue format from a powerful graphic computer and input back by Quicktime™ in a stack).
- *Database*. As will be discussed again in conclusion, to exploit the database possibility of the Hypertext may bring new and unexpected results.
- *User participation.* The user must have an active behavior and not simply explore it passively.[6]

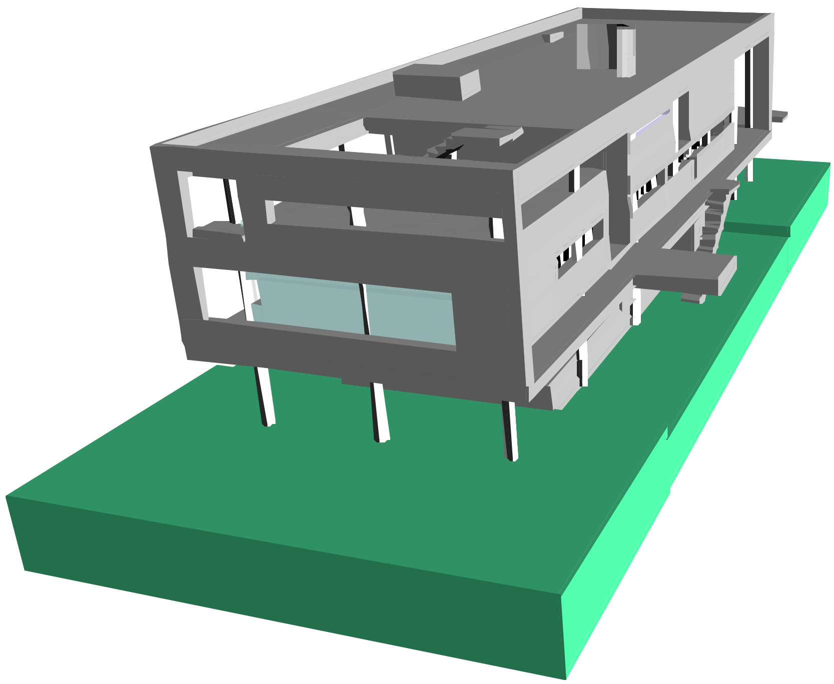

Figure 4. The structure is exposed along the length of the building, but it is elevated figuratively in a variety of ways. While the street front is an asymmetrically-carved solid wall, the lake facade is organized around the transparency of a large, expansive window. In any case, despite the different ways with which the walls of the house are treated, they are never directly revealed to the outside; rather they vibrate because of the contrast against the large scale frame that defines the whole volume. (Villa sul lago by G. Terragni, 1936. Street facade. Model by A. Saggio, 1990.)

3 Formal Analysis and Reconstruction

Solid Modeling (SM) is useful for architectural analysis for at least two reasons. First, its application forces an understanding of the basic components and spaces of the building. Second, as with other three-dimensional environments, it provides scholars with views and information about a project which may be essential if the building has been de-

[6] In the stack of the Officina del gas, active behaviour is provided at a very basic level (direct 3D exploration of the building); but in the mentioned stack on Kahn's building, the user has to find an interpretation of the building by sketching and by collecting information provided in the stack. A very interesting application of active behavior, together with use of a metaphor, it has been demonstrated for product design (Lentz, 1992), where the prototype of a juke box allows the user to test the different actions (turn the machine on/off, select a disk, play it) by clicking in the expected button. The author of the Jukebox proyotype, Helmer Håbløs, exploited the Hypertext capability of Macromind Director™ .

stroyed or never built. In the next section, SM is applied to an unbuilt but crucial project by Terragni, the Villa sul lago, designed in 1936 for an unknown client.

3.1 Villa sul lago, 1936[7]

The project combines the syntax of Purism and Neoplasticism, and not merely the appearance of architectural elements coming from those examples. From one side, the volumetric organization is that of the pure prism raised from the ground. But while in Purist planning, wall defines volume, here the architect reintroduces in the modern vocabulary the late renaissance *giant order*. Terragni creates a large scale frame that gathers together the variations of the elements that define the inhabited spaces of the house. This frame, supported by the setback pilasters on the ground level, is an empty, carved box. Formally unifying the variations of the panels, it allows their free arrangement: with forward and backward shifts, with different shapes of windows, and with loggias of various depths.

It is in the contrast between the monolithic raised prism marked by the frame, and the variations of the exterior surfaces of inside spaces, the syntax of this work is affirmed. Terragni synthesizes here the elements that inspire his poetics: the pure volume comes from Le Corbusier, while the free composition of the planes come from Mies and Rietveld. But in the Villa sul lago, one device lives within the other; one creates the order for the variation of the other in a new manipulation of the formal grammar.

3.2 Solid Modeling

The Villa sul lago was reconstructed using Pro3D™ [8] a computer program which belongs to the category of SM. What is crucial in a SM environment is that a complete model is achieved not only by adding the various pieces created with extrusion and revolution,[9] but also using what are known as “Boolean operations.”[10] The reconstruction of the Villa sul lago started from two basic objects. The ground and a solid prism raised on

[7] The Villa sul lago, very probably located on the lake of Como, creates a pure solid of about 12 meters wide and 35 meters long. In layout and organization, it shares the same basic organization of the contemporary Villa per un floricoltore. Along the elongated rectangle of the plan, bedrooms are distributed on one side, with the dining room and living room on the other side. The kitchen, service area and stair are located in the center. The interior is enriched by curvilinear elements, and by numerous spatial events such as: the living room double height (which allows the master bedroom above to be opened below) the second floor gallery that overlooks the entrance zone of almost seven meters of height, a terrace patio which carves the second floor volume and gives access to the terrace roof.

In his main designs of single family houses, Terragni puts into action a series of elements derived from the modern language of architecture and explores their expressive character. He experiments in Casa per vacanze of 1932 with pilotis and the double height loggia. For the first time in his domestic architecture, he adopts the frame as definition of the construction in Casa sul lago per l’artista of 1933. While these are timid experiments of the international rationalist architectural language, in Villa per un floricoltore, Terragni employs a new original element: a large scale frame that gathers the variations of the outside panels. This scheme is brought to completion with the project of a Villa sul lago of 1936, creating the possibility of a syntactic connection between container and content—between the large scale frame that unifies the building and the panels that define the inhabitable spaces. The Villa sul lago of 1936 marks, therefore, a crucial passage in the architect’s linguistic search. The formal grammar applied here, which has been little known before the first publication of the project in *L’Architettura cronache e storia* in 1968, it could have had a significant impact on Italian architecture if the project were built. Information and analysis of this building are summarized in an article by the author (Saggio, 1992).

[8] This product was developed by a team led by Steven Wiley for Enabling Technologies.

top of it. With Boolean operations, the box (+) was carved with a series of volumes (-). The largest (-) volume transformed the solid prism in a large frame structure, while other smaller (-) volumes created the openings in the end walls and the patio on the roof. Afterwards, the pilotis grid was created as an independent system(+) and merged to the frame(+). The solid modeling capability allowed the intersection of the two parts to be resolved automatically. The system of the inhabitable spaces defined by the outside panel was therefore created and merged with the rest. Finally, all the free elements (outside stairs, gangplank,and roof structures) were created and merged to achieve the complete model (Figure 5).

3.3 Evaluation

The final model achieved several objectives:

1. It creates an electronic environment that allows the study of the unbuilt project. In a fashion similar to a traditional one, it provides with some extra knowledge scholars of Italian rationalism. At the same time the simulation is contained in a diskette that can be easily distributed and studied individually. The end user can see directly the final result in a very simple environment (Clip3D™) that freezes all the possibility of accidental manipulation.
2. Solid Modeling puts an interpretative lens to architecture. This environment forces the user to interpret and analyze architectural masses and language: a strategy to create the various pieces of the building and to assemble them with Boolean operations must be developed beforehand or during the model construction. The reconstruction process becomes a test of the design interpretation.
3. A series of views, which can be mounted together to create a continuous animation, can be taken from the model. Although this is possible also in a traditional one, in an electronic environment the production of such movies is easier and more practical.[11]
4. If the in-progress versions of the model are stored as separate files, the Boolean phases of model construction can be used for didactic support. They show simultaneously the progress of construction and the architectural interpretation that has been adopted, as it forces one to analyze and interpret architecture.

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[9]The three-dimensional volumes of the project are created applying two basic operations to two dimensional polygons : “extrusion,” the linear duplication of the profile, and “revolution,” the rotation along an axis of the profile. In very schematic terms, it can be said that with extrusion the family of parallelepipeds is created, while with revolution the cylindrical volumes are created. (This is technically incorrect because a pyramid or a cone can be created in both ways: either manipulating the distortion of the basic profile along the extrusion or the number of rotations while revolving).

[10] Boolean operations in Pro3D™ can be applied only to two volumes at the time. Each volume must be characterized by a “+” or a “-” sign. If both are pluses the resulting object comes from the merging of the two. If they have opposite signs, the volume with a minus sign will carve the other. Finally, if both are minuses the resulting object will represent only the intersection part of the two original ones.

[11]The model was used to develop a computer-generated movie that has been shown in the “Lineamenta - CAAD” Exhibition 1991-1992 (G.Schmitt and W. Oechslin, 1991) for CAAD Futures ’91, and in the “New Realities” exibition at the Museum of Gestaltung of Zürich, organized by A. Schönberger, T. Bernold, and A.M. Müller.

5. The model may became part of a larger Hypertext environment as previously described. In fact, the model of Officina del gas was also produced using Pro3D™.

3.4 Checklist

On the basis of this and other experiences, the following checklist is provided for working with solid modeling:

- *Design and volumes.* The first point is the detailed investigation of the architectural object to reconstruct. This analysis has to be clearly depicted in a series of sketches which can be organized as a storyboard. On one side it is important to plan the way to create the various elements and spaces, while on the other, the articulation of the various Boolean operations should be forecasted.
- *Constructive alternatives.* A first test of these ideas within the modeling environment is necessary. It is not rare to develop more than one hypothesis before finding a meaningful and appropriate strategy to reconstruct the project.
- *Reconstruction history*. Since the Boolean operations are not undoable in Pro3D™, it is necessary to keep an incremental version of the file. These versions will permit depiction of the construction and interpretation process that has been followed.

4 Simulation, Interpretation, and Interactive Analysis

Hierarchical structures (HS) in a three-dimensional environment offer different kinds of possibilities for DAA. Aldus Super3D,[12] which belongs in this category, is very different from the SM approach of Pro3D™. Although Boolean operations are not possible in this environment, it provides an extremely important tool to reconstruct architecture. This environment was utilized in a recent course at ETH Zürich. Students analyzed and reconstructed the Accademia of Brera, two different versions of Villa of the floricoltore, the Competition project for Palazzo dei congressi at E'42, the House for an artist, the Villa con Darsena, the Cathedral project of 1932, and the Danteum. The following section is devoted to this last building and, as in the previous cases, to an explanation of the technical aspects and their evaluation.

4.1 The Danteum, Rome, 1938

The Danteum was promoted by Rino Valdameri, director of the Brera Academy in Milan, to celebrate Dante Alighieri with a building-foundation that in a metaphorical way follows the Divine Comedy. Through the emphasis put to the imperial ideas contained in the poem by Dante, the other intention of the proposed building was to pay homage to the colonial adventures of the fascist regime. This aspect was particularly strong because of the foundation of Mussolini's empire two years before, and because of the proposed location of the Danteum in the via dell'Impero, the new axis that goes from the Colosseo to piazza Venezia cutting in two the archaeological area of the Fori imperiali.

The building is structured as a tripartite temple with its major parts (Hall of 100 Columns, Inferno, Purgatory, Library, Paradise, and Imperio) connected by an ascending

[12] Developed by a team led by Michael Martin for Silicon Beach Software, Inc.

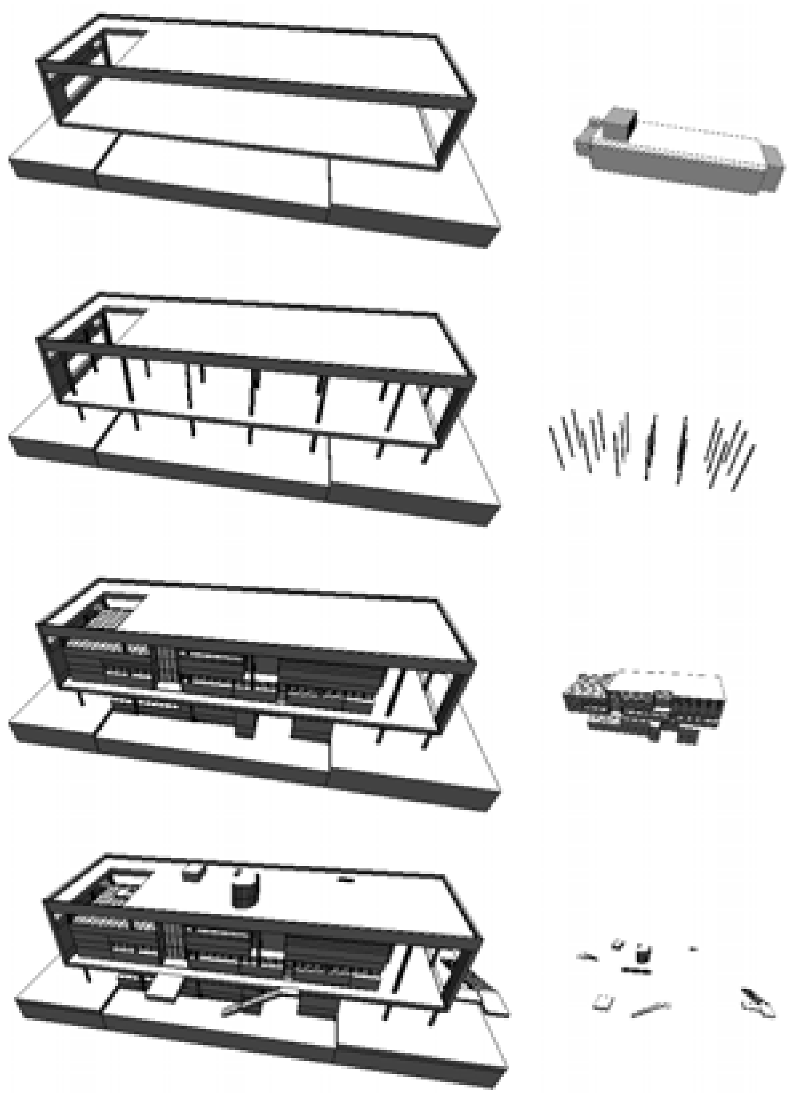

Figure 5. Animation sequence with Boolean operations. (Villa sul lago by G. Terragni,1936. Model by A. Saggio, 1990.)

path. The architectural promenade starts from the Hall of the 100 Columns, a metaphor of the forest in which the poet starts his voyage. The visitor encounters then the chamber of the Inferno, closed to the sky except for the strips of lights coming from the juxtaposition of the various independent parts of the upper floor. The path proceeds to the next level and encounters the Purgatory–its ceiling open to the outside with a series of progressive smaller squares. The Paradise is located at the top level, and is characterized by a grid of glass columns and a system of trellises creating the transition to the open sky. At the intermediate level is a library, which can be accessed directly from the outside, while at the end of the promenade is the room dedicated to the Imperio. The visitor exits from the building along a narrow stairwell on the opposite side of the entrance.

Many of Terragni's architectural motives are present in the building: the golden section used to proportion the relationships of the various parts (and the different elements of each chamber); the circular promenade with opposite locations of entry and egress; the shifted rectangle composition creating a gap for the circulation systems. The reconstruction of this building was done by a student of the special course "Giuseppe Terragni Architecture: A Formal Analysis using CAAD" offered by the author at ETH Zürich.

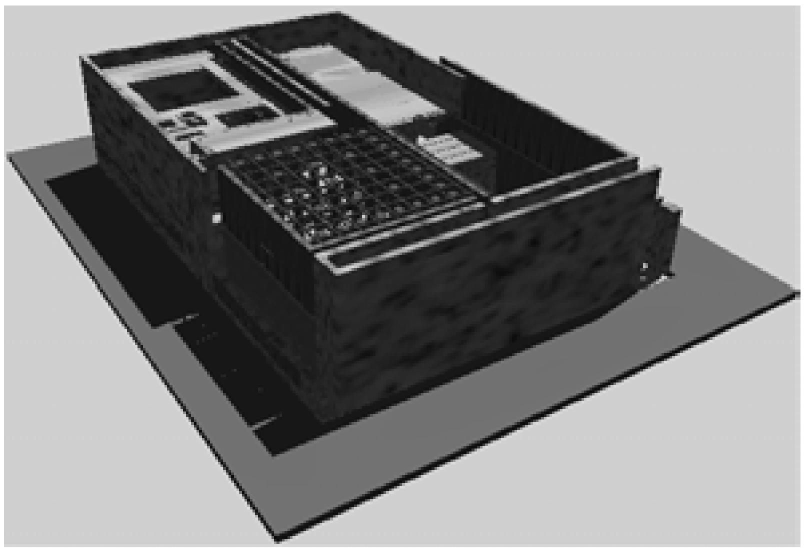

Figure 6. The project is situated in the ancient part of Rome in a site located in front of the Basilica of Massenzio. It was promoted to celebrate Dante Alighieri with a building foundation. (Danteum by G. Terragni and P. Lingeri, Rome, 1938. Model by C. Zimmermann, ETH, 1992.)

4.2 Hierarchical Structures

We refer to Hierarchical Structures (HS) for the construct known in different software as "symbols," "dynamic libraries," "type and instances," and "object based modeling (OBM)."[13] HS are based on "vertical" organization of data. Although they share some results with the horizontal layer structure of traditional and electronic drawing, HS are peculiar and unique to electronic manipulation of data.

[13]In a previous paper (Saggio, 1992b), the author adopted the definition of OBM proposed by C. Eastman (1991). In this paper are mentioned the pioneer works in OBM by Eastman and Borkin et al. (1981). The notation of "Object Based Modeling" points out the attention on the mechanism (the named objects) more than to the overall model structure. At the same time, OBM is not used by all authors. For example, the implementation in AutoLISP™ that Gerhard Schmitt has done (Cfr. *Principi CAAD*, ETH Zurich 1993) uses the definition of "type and instances," while in the recent work of Mitchell (1991) the attention to hierarchical structures is related to "knowledge-based computer-aided design systems." HS appears to this author to be a notation that is better able to capture the essence of environment.

Hierarchical structures require the representation of a model through the decomposition of its parts. When working in this environment, it is necessary to perceive the difference among *primitive object*, *instance*, *compound object*, and *class*. The primitive objects are nothing more than points, lines, surfaces, volumes that are normally modeled[14] in a 3D program. They correspond, in a structure that is not hierarchical, to the entire model. Let's imagine, that in a HS, we create six primitive objects and we want them to correspond to the construction material used in the building. In this case, each primitive is a three-dimensional volume and it is named as "Glass, Concrete, Steel, etc."

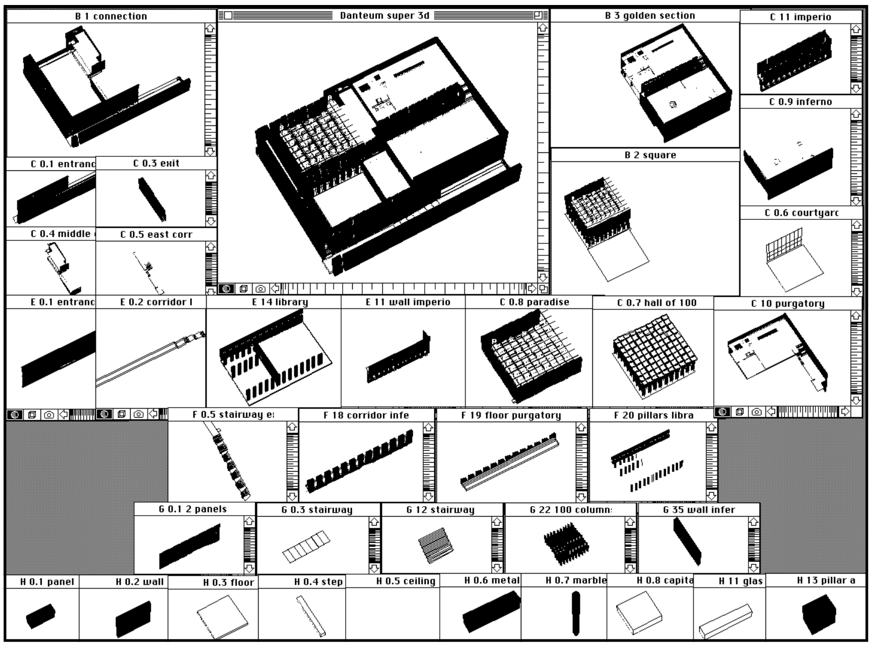

Figure 7. Hierarchical Structures. (Danteum by G. Terragni and P. Lingeri, Rome, 1938. Model by C. Zimmermann, ETH, 1992.)

In HS, the primitive objects must be combined one with another to create design elements or, technically speaking, "compound objects." For example, the primitives glass and steel are inserted in a higher level of the hierarchy to create the "window" element. This operation represents the first of a series of subsequent combinations. The window can be inserted in another compound object that represents, for example, the entire ground floor of a project. Naturally, at this level other elements that had a similar story may arrive (doors, partitions, exterior panels, etc.).

To understand the potential of this structure, the difference between "primitive object," "instance," and "compound object" is required. Coming back to the example of the window, this compound object is created by insertion of glass and steel. When the two primitives are inserted in the window, they become "instances;" that is, symbols or examples of the original objects. While each instance can be parametrically distorted, rotated,

[14]In Aldus Super3D™, a surface modeler, the creation of primitives can be the result of Boolean operations as well.

duplicated and freely located in space, the change of its geometrical structure can be done only at the level of original creation. Not only when the element “window” is inserted at a higher level of the model structure (in this case, in the ground floor) it is treated at its turn as instance–-the reciprocal relationships between steel and glass can be manipulated only at the level of their original combination. While this appears a severe limitation, it hides the strength of HS.

The model of the Danteum is an example of HS[15] produced as the final assignment in the course. The scope of the course was not only to exploit the HS organization to produce a technically efficient model, but also to create a model that supports an understanding of formal and compositional issues present in the project. Students created different kinds of hierarchical organizations that coincided with their interpretation of the building. Some students used a dichotomy between container and content; some used a distinction between structure and infill, while others articulated the various functional parts of the project.

In all cases, at the bottom level of the hierarchy are the different materials that make up the project. The real design analysis of the building was developed with a rich articulation of elements and spatial configurations that filled the gap between the primitive objects and the complete model. The hierarchical organization of Danteum’s model, in particular, was based on the functional difference between the various rooms of the temple. The model had more than fifty different elements, organized in different “classes” (the primitive elements, the subcomponents, the different functional parts, the overall model) which dramatically increased the possible number of thematic views. In particular, this hierarchical structure allowed the clear depiction of the different chambers (Inferno, Purgatory, Paradise, etc.) located along the ascending path that connects them.

4.3 Evaluation

The following are the most relevant advantages of HS:

1. It allows the construction of a complex architectural model at the scale of a personal computer. Because of the separation between primitive objects, compound objects and instance, the file size is minimized (every time the program finds an instance it goes to the primitive object to read its properties that are therefore stored only once).
2. Design and manipulation of the different parts of the hierarchy that create the entire model are controlled through “hide” and “show” commands. On one side this increases speed of rendering operations; on the other, it allows the user to show at any time its interpretation of the building by activating or deactivating elements.
3. Interactive architectural analysis is possible in this environment directly in the final model without returning to previous versions of the model’s file as in SM. The user can easily produce a series of didactic frames that later can be incorporated in a computer movie or in critical drawings.
4. It is possible to export the model from the Macintosh platform (through AutoCAD™ DXF) to the Silicon Graphics workstations that are tailored for real-time walkthrough and fast high-quality renderings. One of the several

[15]Students interpreted the projects by Giuseppe Terragni through readings, sketching, the instructor’s lecture, and group discussions. They used seven different software programs during the 15-week course to experiment with painting, digitizing, vector drawing, a graphic database, solid modeling, surface modeling, animation, and rendering.

types of products that were coming out of the Danteum model was a computer-generated movie that, in virtual reality, makes the promenade inside the building that Terragni had planned but could not test.

5. The articulation of HS, when exported to a dedicated rendering program such as Stratavision3D™,[16] allows a realistic simulation and the detailed

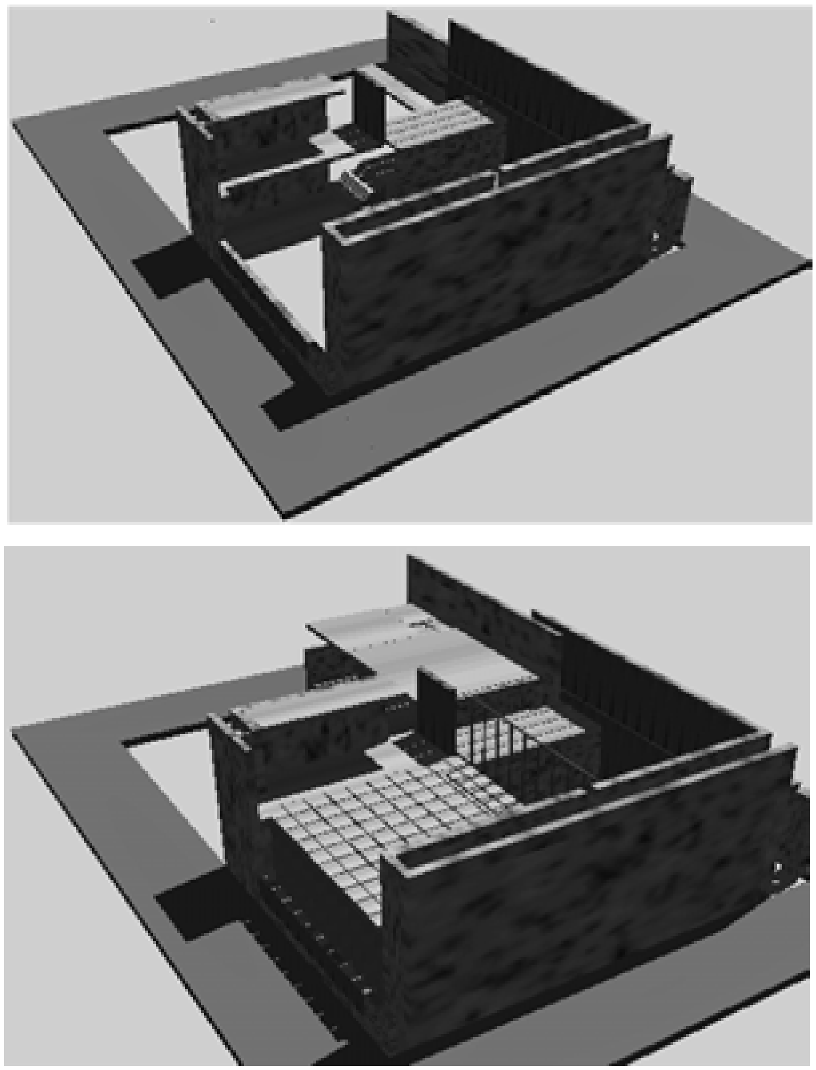

Figure 8. Selective views. Above, only connections among rooms. Below, Hall of 100 Columns, Inferno, and Imperio; Paradise and Purgatory are hidden. (Danteum by G. Terragni and P. Lingeri, Rome, 1938. Model by C. Zimmermann, ETH, 1992.)

[16]The product is developed by a team led by Kenneth and Gary Bringhurst for Strata, Inc.

study of materials. This is achieved through the HS capability known as an *instantiation*. Since the transformation of color, maps and material properties (gloss, transparency, refraction, etc.) of the original object is automatically updated, or instantiated, to all its occurrences, it is possible to make many different hypotheses about those aspects of the building's materials that were not exactly known from the original drawings.

4.3 Checklist

When approaching reconstruction of architecture in HS, it is important to check several aspects:

- *Critical understanding of design.* While SM demands that the user have an interpretation of the project, a HS does not require it *per se*. At the same time, as we discussed above, the structure of HS allows to have an interpretation to a much higher level of complexity than is possible in SM. A clear understanding of the project is required *before* starting a HS reconstruction. It is difficult to reorganize the data once input in a wrong way.
- *Project in the project.* The complexity and richness of HS requires a detailed "project in the project." The help of the outline functions of word processor or of dedicated software such as More™, in addition to storyboard techniques, can be of great help because of the hierarchical structure they use to manipulate information.
- *Duality of analysis and construction.* To exploit the potential of HS, one has to remember that two kinds of analysis should be present simultaneously. The first follows a constructive approach, from the primitive objects to the entire model, in a bottom-up fashion. The second follows the opposite approach, from the whole to the various parts to the detail, in a top-down fashion. While the first approach is quite easy to understand and implement, the semantic aspect of the second is open to different contents (functional, formal, geometrical) and it requires a deeper understanding both of the architectural design and of the potential of a HS. A useful technique to implement this semantic structure is to think in advance of some features of the final model and to use these expected results as ideas to articulate the model hierarchy.
- *Basic materials.* If export to a rendering package is anticipated, it is extremely useful to build the whole project with a limited number of primitive objects (i.e., construction materials); this becomes crucial to efficiently export to the Silicon Graphic workstations–separate files should be created for each material.
- *Documentation.* It is also useful to store (as a special object in the model) a description of its basic hierarchical organization. While these instructions are necessary when the model is used by another person, they can useful for the creator as well.

5 Innovative Representations for New Insights into Architecture

This paper summarizes eight years of work with computers in DAA. The basic question that must be answered in conclusion is: "Has this experience brought new insights into architecture?" To answer, it is necessary to address two distinct levels.

To investigate into reality we need a model that simulates a limited number of its features. A plan drawing of a building is a “model,” represented in an orthogonal view, at the level of “abstraction” of the chosen drawing scale. The model allows a “simulation” tailored to solve (or investigate) a subset of problems. The drawing of the plan does not produce *per se* new insights. The creator gains insights by *doing it* and *by using* the simulation supported by that specific representation. Simulation and insights are results of representation. The first is not possible without the second.

To work with computers allows different insights than working with traditional tools for two reasons, both of which have to do with this understanding of representation:

- *Displacement.* An electronic environment stimulates types of representations that are not common in the activity of an architect. It is the category of “displacement” (a well-established technique to gain new insights by approaching problems with new representation).
- *Innovative representations*. There are representations that are possible only with computers. These “innovative representations” produce insights into architecture that are not possible to be achieved otherwise.

To understand these two aspects in action, it is useful to recap the experiences described in the paper.

5.1 Animation and Solid Modeling, Database, and Hypertext

In the experiences described in the paper, SM and animation provide a type of representation that stimulated the study of the inner structure of a design. For this author the extensive use of these tools developed an attitude to describe a project as a sequence of subsequent design decisions. The insights that are gained by this analytical and sequential process influenced this author’s way of dealing with architectural theory. In fact, the short summary of the project analysis in the paper is the result of a process of investigation that could not be achieved without the type of representation allowed by animation and SM.

To represent graphical data within an organization of family of records-record-field obliges one to create a structure that ties together the physical element (graphic) with its semantic, functional, or constructive aspect. This is a particularly useful representation in the beginning of the education process when students very rarely perceive the complexity hidden in a design. In this environment, it is also possible to gain some new insights from a semi-automatic process. The simultaneous search on graphic and textual data may allow one to find some unpredictable correspondence among the information contained in the model.

The presentation aspect of Hypertext, which was stressed earlier, does not provide new insights to the person that creates the stack. At the same time, the characteristics of fluid organization of information and the new access to data may become *for the end user* a way to think, to explore, and to support personal investigations. At least partially, some of the consideration of graphical database can be applied to hypertext, but the most important insights that this environment can provide rely on the potential of programming (cf. Mortola, 1989).

5.2 Hierarchical Structures

HS provide an environment to represent (therefore to investigate and to simulate architecture) that does not have a traditional counterpart. While innovative representations allowed, for example, by spreadsheets have a minor role in architecture, HS are very appropriate and consistent with the discipline. They allow, *simultaneously,* a constructive (bottom-up) structure and a semantic (top-down) one.

It should be pointed out that the difference between traditional ways of analyzing architecture and the HS approach is that the process of deconstruction and reconstruction necessary to create analysis is not delegated to a set of different drawings. The critical ideas about how the project is interpreted are contained in the way the model is built. Therefore, critical understanding of the project and hierarchical construction coincide.

New insights this environment produces not only rely on representation unique to computers, but also on this environment's "multi-representational" inner nature (since we understand that representation-simulation-investigation is connected by a common string, "multi-representation" of data also means multiplicity of insights into architecture). In particular, the multi-representational aspect of HS brings up the possibility that after a model is built it can support further investigation on data. This aspect has been verified in our experience modeling the Danteum.[17]

A project reconstructed in HS is a completely different product than a traditional maquette. It is a live, dynamic and interactive model of reality that allows simultaneously a realistic, testing, critical, and open structure.

These four characteristics coexist in the same computer model that begins to approach the dream of "an intelligent model," because it can display and represent more knowledge than apparent in the original object.

6 Conclusions

As a final paragraph, it may be useful to indicate some desirable features future software implementations of hierarchical structures *in personal computer*s may have:

- *Buttons*. HS must be able to support programming buttons connected to specific three-dimensional objects.
- *Database.* The database structure of HS should be more strongly implemented because it appears obvious that a hierarchical model organized through named objects has to support the characteristics of a user defined search.
- *Outline.* The outline metaphor from word processing usage should be adapted to three-dimensional data display and organization in order to implement technically and logically sound hierarchical structures.

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[17]The student who originally created the model in the author's course has later written a report (Zimmerman, 1992) that presents many analytical drawings that illustrate design concepts of the building that were not clear at the time of model construction.

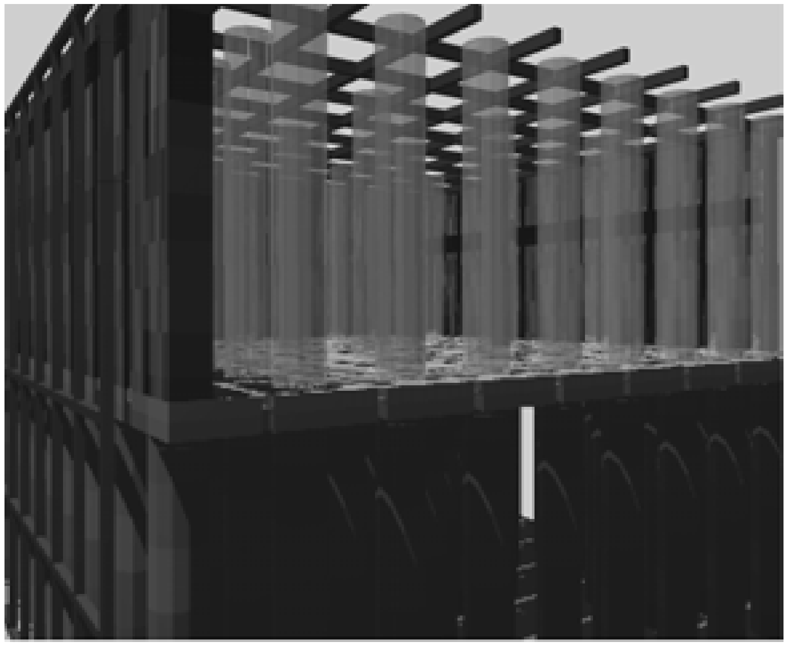

Figure 9. Section of Hall of 100 Columns and Paradise. (Danteum by G. Terragni and P. Lingeri, Rome, 1938. Model by C. Zimmermann, ETH, 1992.)

suggested appropriate keywords in the checklists. The readers provided substantial suggestions regarding the first draft, and challenging new insights brought about by this work.

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