Materials in Architectural Design Education Software: A Case Study

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Most CAAD software in use for architectural education relies heavily on abstract geometry manipulation to create architectural form. Building materials are usually applied as finishing textures to complement the visual effect of the geometry. This paper investigates the limitations of commonly used CAAD software in terms of encouraging an intuitive thinking about the physical characteristics of building materials in the context of the educational design studio. The importance of the link between representation and creativity is noted. In order to sample the current functionality of typical software used in architectural education a case study involving 80 first year architecture students is presented. These outcomes are discussed and the possibility for new or extended software features are suggested. The paper concludes with an argument for design software that redresses the balance between geometry and materials in architectural design education.

1. Introduction

It is generally accepted that representational media has an impact on the making of design concepts. In relation to drawing, Daniel Herbert maintains that the uncertainty of the design process – the search for the 'inspired solution' to design problems via sketching – is a primary reason for the influence of media on conceptual design decisions [1]. For architectural education the reflective conversation young designers have with ideas and representation is a key activity during the crucial early stages of concept exploration. One of the objectives of most design foundation programs is to introduce students to a range of media in order to demonstrate the relative strengths and limitations of each to explore design options. Students learn to "recognize these limitations" and how to utilize different media to capture different design aspects [2].

One study from research on mental creativity and its relationship with human memory suggests the influence of representations of ideas via media is crucial.

> "The links between representations, thought processes, and behavior are so deep that even eye movements are partly governed by representations. Choice of representations can affect limited cognitive resources like attention and short-term memory by forcing a person to try to utilize poorly organized information or perform translations from one representation to another" [3].

Johnson maintains that in order to be able to deal with the multitude of variables inherent in architecture, designers develop personal "libraries of partial solutions." Those libraries include potential design assemblies such as "overhead plans, domes, walls, columns," as well as more generalized approaches such as building typologies. These libraries are designers' internal representations and the proposition is that poor external representations of these can adversely affect design performance [3].

The recent introduction of the computer into the design studio has added to the range of media available for "internal representations" and "libraries of partial solutions" during the early stages of design. Much has been made of the potential for these new tools to enable better representations particularly in relation to forms of geometry difficult to represent using drawings or physical models. (See for example [4]). Simultaneous with this energetic exploration of 'difficult' geometry has been the widespread use of images mapped on to surface to allude to material properties. Often these surfaces are abstract and while the best are seductive 'eye candy' there is little reference to the physical properties of materials (such as mass, weight, ductility and resonance) or the constraints of fabrication.

The preoccupation of most CAD software would appear to be with geometry as opposed to materials. This should come as no surprise given the architecture's historical pre-occupation with geometry; Robin Evans is one who has clearly exposed the history of architecture as a series of explicit or implicit references to developments in projective geometry [5]. We would argue that the use of the computer in the design studio potentially offers much more than the ability to accurately describe geometry. This paper raises one possible avenue of research: the potential to integrate a consideration of the physical properties of materials and the constraints of fabrication during the early stages of design. We present the outcomes of a case study undertaken at the University of Auckland School of Architecture, which examined the use of software made by first year students in relation to the representation of materials.

2. CASE STUDY

2.1. The status quo: building materials and CAAD modeling software

CAAD software has simulated various properties of materials through disparate packages that specialize in certain aspects of building materials such as structure, thermal, acoustics, and light. This is specialized software that tests the performance of building materials in the context of the design. Results of these tests are communicated in graphical and or numerical form. One example is the calculations related to light reflection and diffusion from a surface of a defined material. The result is, in most cases, numerical data related to lighting levels supplemented by diagrams. Other calculations can relate to acoustic, thermal and structural performance of building materials and these are also usually communicated in diagrammatic or numerical forms.

There have been some attempts to simulate the chemical response of materials [6] and some virtual reality applications have enabled the simulation of gravity to indicate mass [7]. Such specialized design support software tends to work best on the detailed design level rather than at the early stages of design and is seldom in evidence in architectural design studios, being more often found in specialist postgraduate laboratories. The software commonly found in architectural design studios represents materials by either the use of 'texture maps' or what we term a 'component-based approach' which references typical building assemblies such as walls and slabs. In the first approach images can be 'mapped' onto the surfaces of geometry and then surface characteristics such as brightness, transparency and other parameters can be manipulated. Users can choose one material from a library of images and develop synthetic alternatives through manipulating such parameters.

Alongside the use of texture maps is a second approach that uses assemblies of building parts such as walls, windows and floors. This component-based software is an implicit way of representing building materials and composite assemblies via the geometry of building parts. The 'wall' geometrical tool in ArchiCAD for example embeds structure, scale, and materials of typical wall materials, which can be represented in plan or section views.

2.2. Design Context

This case study examines the use that first year design students made of the material representation capacity of two standard CAAD applications (ArchiCAD 5.0 and 3D Studio Max 3.1) at the Auckland School of Architecture, New Zealand. The studio pedagogy was modeled on an experiment-test methodology as opposed to an analysis-synthesis approach [8]. Materiality was included as one of a number of design considerations that students were required to include in their designs. The use of a first year design class for this study allowed a large sample (80 students) that had yet to settle into habitual working approaches. The class was required to complete a two-week computer module as part of a semester design paper. The module required the students design two projects: the first was to design an exhibition space for chairs using ArchiCAD 5.0; the second was to design a chair using 3D Studio Max 3.1.

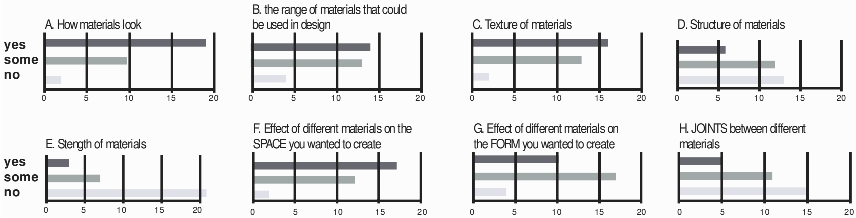
With the first design task students were given a file that contained a plinth on which five classic chair designs were placed. The design focus of this project was to explore and create interior architectural spaces that they considered appropriate for each chair exhibit. Students were asked to consider the surface and visual mass of materials as part of the exhibition design. In the second project, the focus was shifted from the design of space to that of form: students were asked to design a chair using 3D Studio Max software. They were asked to conceive their designs in terms of a functional and/or symbolic context of their choosing and were required to include a consideration of materials and the means by which the chair might be constructed. Most students had no previous experience with modeling software. The first two days of each week were used to give students a working knowledge. Instruction was focused only on the modeling tools and interface elements required to complete the design tasks. Material palettes and application methods were emphasized in these workshops.

2.3. Outcomes

A mix of observation, informal discussion, and survey determined the outcomes. The survey was completed by only 38% of the students and hence reliable statistical analysis was not possible. However the results give an indication of student thinking on the use of software in relation to materials. The most pertinent results to this study are reported in bar graph format in Figure 1. The question underlying the survey is as follows. Question: Do you think that modeling software has encouraged you to think about and include in your design:

A. How materials look.
B. The range of materials that could be used in the design.
C. Texture of materials.
D. Structure of materials.
E. Strength of materials.

F. Effect of different materials on the space you wanted to create.
G. Effect of different materials on the form you wanted to create.
H. Joints between different materials.



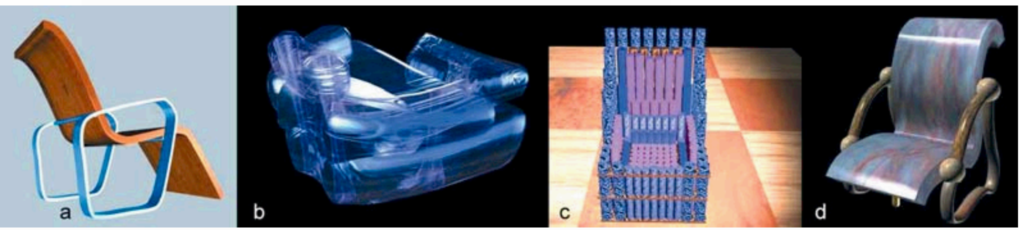
▲ Figure 1: Survey results.

When these survey results were compared with the outcomes (rendered images) from all the students, three groups were identified in terms of how the class dealt with the representation of building materials in their designs. These groups were approximately equal in distribution throughout the class although there were individuals who exhibited two or more tendencies.

2.3.1. Group 1

The first group had clear intentions about what materials they wanted to use for their designs. They tended to model the geometry in a way that responded to the nature and quality of the materials. For example one student who wanted to model a steel pipe used the 'loft' tool to create appropriate geometry and then decided upon the tone of the metal (Figure 2a). In another case a student wanted to model a stone chair and attempted to consider the cutting difficulties of the material and used simple geometry for the purpose (Figure 2d). Another student tried to model an elastic rubber material that could take the shape of the body – an attempt to model a feature of material that goes far beyond geometry or surface texture (Figure 2c). The student tried to imagine the behavior of the modeled material in order to develop the design but it was extremely difficult to model the rubber elasticity and distortion under body weight.

▼ Figure 2: Group1 decided about materials early in the design process.



This group tended to do the following:

- They worked with rendered views early in the process.
- The selection of materials from materials library was carefully considered.
- They created geometry relevant to the perceived geometry of actual materials.

2.3.2. Group 2

Students in the second group were less concerned about materials. They started by creating the geometry of their chairs and in developing the design they chose appropriate materials that suited the geometry.

▲ Figure 3: Group 2 considered materials after geometry.

This group tended to do the following:

- Minimal use of the rendering capabilities, especially at early cycles of their design concepts.
- Ideas about possible materials were vague and subject to change. However this vague materiality was implicitly included in the created geometry.
- Adding textures was a critical stage. This involved deciding appropriate materials for the geometry created. They tried to link the geometry of a vague materiality with textures of real materials. Images provided by the software in the materials library were used as tools for clarifying, crystallizing and maturing students' intentions.

2.3.3. Group 3

The third group focused on geometry and the visual composition without any consideration of materials especially in the early stages of concept formation.

The use of materials in designs were:

- Either decided at the end in a random manner, or was presented in their designs as neutral visual effect in order to not disturb their design focus on geometry.

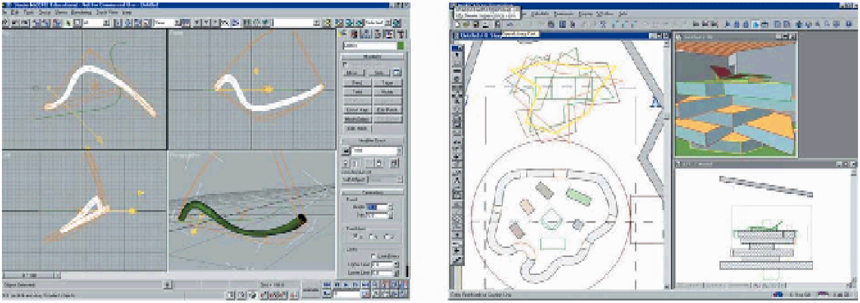
◀ Figure 4: Group 3 focused on geometry.

3. Discussion

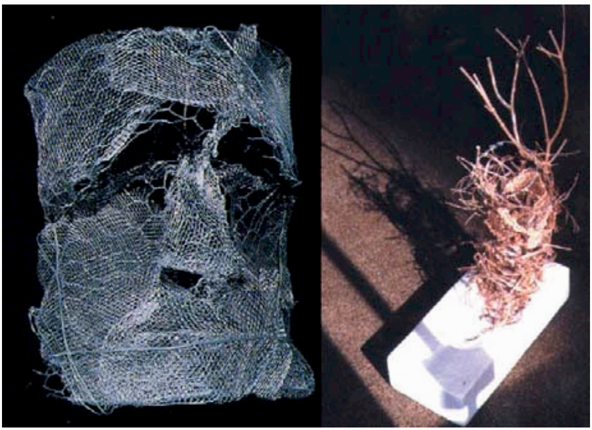
Despite the differing individual design concepts (given that there were 80 individual designers), geometry and materiality were strongly associated with one another in two of the three groups identified above (accounting for approximately 70 % of the class). This happened despite the obvious separation between geometry and texture in the software. Following this close observation of the computer design module we continued the case study by looking at samples of work from the other semester modules which utilized drawing and physical models as the primary design media. We itemize below our observations on the difficulties and potentials of the use of the software utilized in the case study to explore materials and, where appropriate, we compare the drawing and physical model outcomes. These are categorized in terms of perceived difficulties and advantages.

3.1. Difficulty: forced to perform particular translations

In order to model building materials the user typically needs to perform translations of internal representations. For example in 3D Studio, there is a need to abstract materials into an appropriate geometrical construction first, then find appropriate colors and images to represent intended textures. In the case of ArchiCAD, combinations of materials are already attached to the geometry – the user chooses geometry in relation to common building components. This can ease the modeling of these particular combinations, but it is difficult to use the libraries for non-standard assemblies. For example, one student wanted to model a steel grid. This required an abstract use of the 'window' tool to a produce steel bars, which were then duplicated and arranged in a way that represented the original intention. In both types of software students were forced to separate the geometric considerations from material considerations. As we have seen earlier, Johnson's work [3] suggests that if the external representation medium involves translation of the internal representation, this negatively affects the creativity of the designer.



▲ Figure 5: 3D Studio (left) – Abstracting a steel pipe to its geometrical construction. ArchiCAD (right) – building forms in a 2D environment.



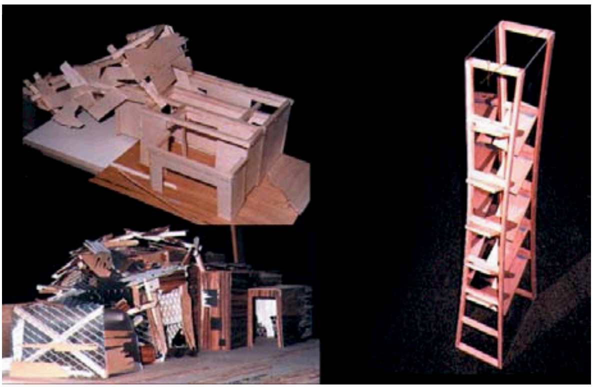
► Figure 6: Physical models and the creation of natural forms.

3.2. Difficulty: modeling of natural materials

It is notable that materials that are formed using tools or machines are easier to model with computer software than more organic materials or non-planar 'organic' geometries. Apart from the technical difficulties of using the software, students need to have sufficient experience and sensitivity towards the materials they are modeling so as to be able to produce convincing models. For these purposes the chosen software is a slow, rigid, time consuming and ineffective medium. Hand drawings, photography and physical models seem to be more effective in alluding to, or recording natural textures and forms. While we are interested in the potential of extending the use of computers there must inevitably also be a recognition of the limits of one media and the relative strength of others [9].

3.3. Difficulty: feedback about the response of materials to the physical forces

Materials modeled on computer generally do not respond to forces (internal or external) whereas in physical models forces such as gravity and load are inherent in the chosen modeling material. A student could, if the modeling material was a close match to the intended material, develop a good understanding of how materials perform structurally or intuitively experiment with surface deformations (Figure 7). This observation corresponds with those made by others who recognize the value of supplementing computer models with physical models in the undergraduate design studio [10]. The problem in the use of physical models in this regard is their very physicality; the process of testing to failure results in the destruction of the model. As noted by McCullogh, one of the inherent properties of digital media is the ease of duplication; "every copy is an original" [11]. If software could be developed for the intuitive examination of physical forces this would encourage speculative design testing without destroying the model in the process.



◀ Figure 7: Physical models give feedback about internal and external physical forces.

3.4. Potential: good feedback on impact of color and surface texture

The realistic representation of material texture and color are not easily achieved through any other media than the computer (especially in the case of the work of students at the first year level). Students were more inclined to explore the visual properties of materials when using the modeling software, compared to drawing and physical modeling that oblige students to develop particular craft skills. The uniqueness of computers is revealed when attempting to experiment on a range of materials to evaluate the impact of such change on the space and form of design. Students felt that modeling software encouraged them to think about the effect of chosen materials on the designed space and also, to a certain degree, on the form of the design in the case of the chair project. This would seem to be the most encouraging use of the software by foundation year students. The mere fact that they appreciated that visual perception of architectural space can be fundamentally changed by experimenting with a range of materials represented as colors and surface effects. The ease with which relatively complex combinations of materials could be explored resulted, in most cases, with a development of spatial perception in relation to color and surface texture.

▲ Figure 8: Explorations of color and texture on spatial perception.

3.5. Potential: facilitates good control in various scales

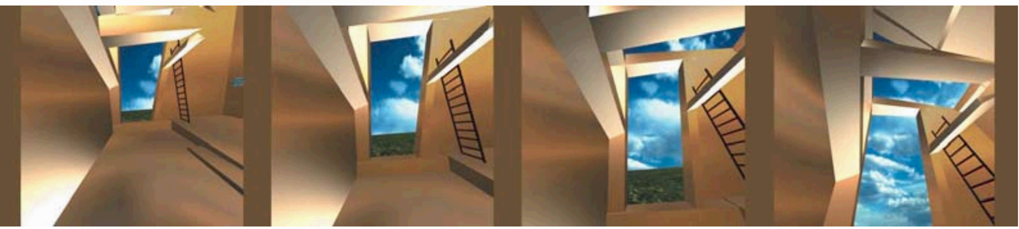
Modeling with computers does not require students to translate their design representations in terms of scale. Students have the option to model with full-scale dimensions and zoom in and out to visualize and work on details without having to produce new representations. One of the advantages of computer models is the ease with which scale shifts and viewpoints can be manipulated and hence students could examine the visual perception of materials and assemblies of materials from a variety of viewpoints. In addition the need for a decision about the full-scale dimensions early on can stimulate thinking about full-scale issues. Some students considered the constructional details of their designs despite the short period allowed for the exercise and their inexperience as designers.

Textures are automatically adjusted, giving direct feedback on the active scale, although one drawback is the distortion in bitmap resolution when taking a close render of a material textures. In this aspect developers of CAD software can potentially adapt approaches taken in computer game graphics. Typically these real time graphics engines store textures in a range of resolutions that are swapped in and out dependent on proximity. This allows a large number of textures to be calculated within the same view while retaining high-resolution versions for surfaces close to the camera.

3.6. Potential: exploration of the time dimension

Although in the case study little time was allowed for exploring the animation features of the software, the feedback experienced when changing position and viewpoints was addressed by most of students (Figure 9). The built-in capacity for ArchiCAD to generate sun studies that animate the movement of the sun allowed some to examine the effect of screens or translucent panels over time. However a lot more can be potentially achieved with software in regard to simulating perception of color and surface perception in a range of light conditions. Too often computer models are set in unrealistic or optimistic lighting conditions that do not relate to the local context. Again lessons can be learned from the computer games industry where the motivation to produce a range of graphic atmospheres has led to fog, precipitation and 'dirt' being applied to augment specific lighting conditions and context. Extending the exploration of the temporal dimension it may be appropriate in some cases to consider how materials age over time as some researchers have with computer representations of stone [6]. If a computer model can be used to generate 'age lapse' animations without substituting materials the consideration of the time dimension in relation to materials would be greatly enhanced.

▼ Figure 9: Exploring different view points through animation.



4. CONCLUSION

The case study has highlighted the general inadequacy of software typically used in the architectural design studio (in this case ArchiCAD and 3D Studio Max) to consider the physical characteristics and typical fabrication geometry of materials. At the same time, compared to drawing or physical models, there are inherent advantages in terms of imaging visually complex materials and dealing with issues such as scale and accurate visual reproduction. There is potential to build on these strengths by considering how physical properties and geometric constraints of different materials can be used as the basis for modeling architectural form in the design studio. The aim would be to attempt to bridge the gap between the physical properties of real world materials and their representation in computer models.

Poor design performance as a result of the mismatch between internal and external representations as explored by Johnson [3] has been evidenced in relation to materials, by some examples in this case study. In general the majority of the students started modeling their designs using primitive or complicated geometry that has no particular consideration of the physical properties or geometry constraints of materials. We propose that students should be able to 'build' their designs with an understanding of the physical properties of materials, recognize typical manufacturing geometry such as extruded sections, and also modify form using tools that are specific to the chosen material.

We have also raised the issue of a temporal dimension being explored in relation to the ageing of materials. The modeling of materials in this manner and its integration with design studio teaching can potentially contribute to a bridging of the gap between the computer simulation and the actual behavior of materials. More research is required to identify ways of incorporating these issues into a software interface.

The increasing use of library parts of building components specific to local industry is now becoming widespread. While this brings issues of scale and availability to the fore we would prefer a more abstract approach that deals with the inherent physical qualities of materials. How might we communicate tactile qualities such as surface and mass – can material sound libraries, which evoke tactile qualities, be included for example? Given new advances in 3D generative textures is there a possibility to imbue a sense of 'depth' to the often-sterile computer generated surfaces that are output from industry standard software.

While we have focused on material properties this paper does not necessarily indicate a return to modernist dogma in terms of 'truth to materials' as propagated by early modernists such as Kahn [12] or Wright [13]. Experiments with design software may, in fact, lead to materials being used in ways that differ from construction norms or result in proposals for the development of new hybrids and composites. We maintain however, some redressing of the dominance of geometry over materials implicit in most software can be achieved, perhaps to the point where Scarpa's definition of architectural space in relation to physical phenomena can be explored with digital representation:

"What I want to say is that the sense of space is not communicated by a pictorial order but always by physical phenomena, that is by matter, by the sense of mass, the weight of the wall" [13, p. 282].

References

1. Herbert, D.M., Graphic Process in Architectural Study Drawings, *Journal of Architectural Education*, 1992, Vol. 46, No. 1, pp. 28-39.
2. Schon, D., *Educating The Reflective Practitioner*, Jossey Bass, San Francisco, 1987.
3. Johnson, S., What is Representation, Why do We Care, and What Does it Mean? Examining the Evidence from Psychology, in: Jordan, J.P., Mehnet, B. and Harfmann, A., eds., *ACADIA '97 Representation and Design*, Association of Computer Aided Design in Architecture, 1997, pp. 5-15.
4. Lynn, G., From Body to Blob, in: Davidson, C.C., ed., *Anybody*, MIT Press, London, 1997.
5. Evans, R. *The Projective Cast: Architecture and its Three Geometries*, MIT Press, London, 1995.
6. Dorsey, J., Modeling and Rendering of Weathered Stone, in: *Proceedings of ACM SIGGRAPH 99*, 1999, pp. 225-234.
7. Kurmann, D., Sculptor – A Tool for Intuitive Architectural Design, in: Tan, M. and Teh, R., eds., *CAAD Futures '95 – The Global Design Studio*, 1995, pp. 323-330.
8. Ledewitz, S., Models of Design in Studio Teaching, *Journal of Architectural Education*, 1985, Vol. 38, No. 2, pp. 2-8.
9. Flemming, U., Get With the Program: Common Fallacies in Critiques of Computer-Aided Architectural Design, *Environment and Planning B: Planning and Design*, 1994, Vol. 21, pp. 109.
10. Cheng, N.Y-W., Linking the Virtual to Reality: CAD and Physical Modeling, in: Tan, M. and Teh, R., eds., *CAAD Futures '95 – The Global Design Studio*, 1995.
11. McCullogh, M., *Abstracting Craft: The Practiced Digital Hand*, MIT Press, Cambridge Massachusetts, 2000.
12. Friedman, D.S., The Life of the Wall: Material and Virtue in the Writings of Alberti and Kahn, in: Architecture: Back… to… Life, *Proceedings of the Seventy-ninth Annual Meeting of the Association of Collegiate Schools of Architecture*, ACSA Press, 1991, pp. 171-175.
13. Wright, F.L., The Natures of Materials, in: *Frank Lloyd Wright: Writings and Buildings*, World Publishing Co., Cleveland, Ohio, 1960.
14. Scarpa, C., Furnishings, in: Co, F.D. and Mazzariol, G., eds., Carlo Scarpa: *The Complete Works*, The Architectural Press, London, 1986.

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