An Inquiry into Computers in Design Education

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Introduction

We are living in an increasingly computerized world. It's often been said that computers have triggered a second industrial revolution, to characterize their impact on our lives. Driven by the notion that computer literacy is mandatory for success, computer has now become a standard tool in architectural offices across the US and around the world. Academic institutions in US are actively integrating computers into the curricula and some are even requiring their students to purchase computers. This affects all schools of architecture. Educational theorists, recognizing that computers are here to stay, caution more computerizing may not necessarily result in more learning [AHERN, 2001]. While computers' potential for enhancing innovative exploration in the design studio is widely reported in literature, many design educators see a pressing need to establish a critical appreciation of the ways in which computer affects the student learning, teaching practices, and studio culture [BALFOUR, 2001].

Consequences for design education

Dorsey & McMilan [1998] note that computers lack the fluidity and flexibility necessary for recording and exploring ideas during conceptual stages of design[1]. Similarly, Yessios [1986] from a heuristic[2] and Turk [2001] from a phenomenological perspective argue that while computers replaced the drawing boards for design representation, they do not yet solve conceptual design and most of the hard design problems. The notion that computer does not adequately support design without restricting the artist's creative process has been echoed elsewhere in design research literature [for example: HANNA & BARBER, 2001: P 261]. Greg Lynn, an avid proponent of computers in architectural design,

[1] They do note that computer revolutionized drafting by enabling rapid entry and modification of design, visualization by allowing designers to walkthrough their designs with photorealistic imagery, and engineering by improving the analysis and construction of buildings. However, they consider these tasks to occur near the conclusion of a larger design process once the major artistic and design challenges are solved.
[2] Yessios observes that the internal representation and operational behavior of available CAD software has not really been geared for architectural problem solving.

concedes[3] that, "at this point, the design ideas are subordinate to computer" [CRAMER AND GUINEY, 2000]. Senagala [2001] presents an interesting argument[4] on how software tectonics affect the imagination, definition and construction stages of architectural design process. Even given all of the above limitations imposed by computer of design some of us see a value in their use in design education. Perhaps Neuckermans [1999: p10] captures this sentiment better by reading into Einstein's quote[5]: "it is a system which makes the good more easy and the bad more difficult". Computers' potential for enhancing innovative exploration in the design studio is widely reported in literature.

Computer as design tool: inadequacies make it inappropriate?

From an educational point of view, do computers improve or inhibit architectural design process? What are the consequences to student's learning and studio culture? Computer as a design implement creates an interesting paradox of enhancing the possibilities for innovation and at the same time impeding the design process due to its inadequacies. Given this, what is the best way to prepare our students to deal with this paradox, particularly in studio setting? Herbert Simon of Carnegie Melon University, one of the world's leading authorities on human decision-making and a Nobel laureate, made the following remarks fifteen years ago, which are just as valuable and relevant today in understanding that computers' inadequacies do not necessarily make it a inapt tool for inquiry.

> "Surely, the second industrial revolution is just as unpredictable as the first one was—and the second has barely begun. We are closer in time to the first computer than James Watt[6] was to Thomas Newcomen[7]. There is a lot of solemn talk about what computers can't do—there's even a book by that name — but that's not a very interesting subject. **Computers today are doing a lot of things they were "known" to be unable to do a while ago, and what they can't do today they may very well be doing tomorrow.** (The author of that book has already had to get out several revised editions.) Besides, our task is not to decide what computers can't do but to **look ahead for the very short distance that we are capable of and to think about what we can get computers to do, what we would like them to do that they can't do right now**." [SIMON H, 1987]
> (Footnotes, emphasis added by author)

Cuff [2001] explains both the opportunities and limitations created by the increasing use of 3D CAD and visualization programs in teaching studio and suggests "these tools are vehicles for creating not only new forms of architecture, but also new teaching methods and enhanced design capabilities". In a recent thoughtful and informative article, Balfour [2001: p268], Topaz Laureate, notes how computer changes the studio culture and calls

[3] As implied in his statement, "at this point, I would have to say it is the software making the calls".
[4] He sees solids (B-Rep), surfaces (polynomial), blobs (isomorphic polysurfaces) as three *softerials* (materials) that have begun to transform the way we imagine, define and build our world.
[5] In answer, when Le Corbusier asked Einstein to judge Le Modular.
[6] James Watt made some important improvements on the engine in 1769, in the course of trying to repair one of Newcomen's engines.
[7] The invention that started it was Thomas Newcomen's "atmospheric" steam engine, which appeared in about 1711.

for critical teaching practices that aim for developing sensibilities about technology and about the conceptualization of its role in methods of design.

A Hybrid Approach

Layering computers over the traditional tools of architects as an effective strategy to make the best of both worlds has been suggested in literature. For example, Clayton makes a case that both digital and tactile design are necessary components of contemporary design teaching [CUFF, 2001: p202]. Architects that are successful in their use of CAD tools are distinguished by their ability to change modes rapidly between traditional and digital domains [DORSEY & MCMILAN, 1998]. Hanna & Barber contend that "Eisenman and Gehry are very experienced designers, and with their great knowledge and experience, they may find it not so challenging to adapt their working methods to fit CAAD and at the same time create buildings of elegant form and design. Novice designers might find it extremely difficult to adapt their design methods in relation to CAAD and at the same time produce 'good' designs." Yet Bermudez and King [1998: p9] note that there is little or no instruction of procedures or concepts about how to negotiate the interface between digital and traditional media. They also present a set of 19 hypotheses[8] on the impacts of analog-digital conversations in the design process by bringing together reported experiences from diverse researchers over the past decade. Calling for further systematic inquiry into the matter, Neuckrman [1999: p9] portrays a spectrum of approaches schools take across the world ranging from *computerless* to *paperless*[9] studios, and use of computer *to mimic traditional*[10] to *new ways of designing*.

Instruction of Digital skills

Although the issue of how the student acquires computer skills for digital representation appears to be tangential at first, it has significant bearings on the nature and the depth of studio activities. Student's ability to draw and apply it for design is not a genetic gift but an acquired skill [LOCKARD, 2000]. Welch et al [2000] demonstrated that novice designers do not use sketching (freehand) as way to generate, develop and communicate design proposals, but as a means to build 3D models. Further, they (novice designers) learn to express their ideas through instruction that helps them organize their thoughts through discussion and contextualizing. This already happens in all architecture schools in foundation graphics media courses that teach how to use graphics for design. If students are expected to use computers for design, computer skills need to be part of the instruction in the foundation courses. This is not without controversy. Vasquez de Velasco and Clayton [1999] see an introductory CAAD course as a necessary prerequisite for participation in design studios that employ computer methods. On the other hand, some worry that the addition of such a course into already crowded curricula may come at the expense of displacing traditional subjects and call for integrating computer instruction within the existing courses. Several ideas on balancing this have been discussed at a special session titled Ideal Digital Curriculum, in a recent ECAADE conference, in Helsinki [PENTILLA, 2001: 165-199]. Digital skills bearing on

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[8] Some of these have been tested as reported in subsequent sections in this paper.
[9] A movement started by Columbia University's architecture faculty in the mid-nineties.
[10] What is traditionally done by hand

admissions[11] process and inclusion of computers in the graphics media foundation courses[12] will be an important subject of discourse among the schools in the near future.

Experiences in *Computer* Design Studio Instruction

To provide a context, for the past 4 years, the author has been teaching a studio focused on using computers for design as an elective. The class typically consists of a total of twelve students (a mixture of Juniors, Seniors, and Graduate students) with a range of expertise with computer graphics media. All the undergraduate students in our program get a 7-week introductory exposure to digital media in their freshmen graphics media class. Some of them further their skills on their own through work experience and self-teaching. The majority of students lack experience in designing with computers, especially using 3D modeling. Self-assessment of each student's computer skill levels and attitudes towards role played by computers in design were recorded on the first[13] and the last[14] days of the class. This information was used in continuously developing the course. The objective of the course is to provide the student an experience that helps gain an understanding of "what we can and should do with computers and what computers might do to and for us" [SIMON, 1987]. This is accomplished through two successive projects. The first, normally four to five weeks in duration, focuses on "what we can do with computers and what computers might do to us" portion; the second, lasting for the rest of the semester (about 10 weeks) addresses "what we should do with computers and what computers might do for us". The project[15] described in this paper provides an example of the effectiveness of the first project.

The Project

The design challenge was to design and build a small inspirational object to be placed on their desks (for the duration of the semester) based on a character that they liked as a child. This object was to be built from a single 18"X24" piece of cardboard, and it must be portable, monolithic, no larger than 6"X6"X6" and be able to sustain a fall of 4'. The expectation was that this project would lead to the subsequent major project: the design of a childcare center. This project was thought be a good lead-in to a childcare center in the following ways:

- Rational (e.g.: Object had to be constructed to withstand a fall, with a given type and quantity of material) and irrational (Childlike composition) processes were simultaneously at work in this project. Working with computer could suppress rational process sometimes, and allowing irrational to take over[16].
- This project was fun and playful for the students allowing them to refresh their memories of what it was to be a child. Topics having recreational component enhance the learning of digital media [CHENG, 1999].

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[11] Traditionally, during admissions process, architectural schools expect the desirable applicants to have prior proficiency in traditional representational media such as pencil, watercolor, pen and ink, photography, sculpture etc. Most schools use a portfolio review to help assess these skills.
[12] At author's institution the curriculum has been recently revised and expanded the foundation courses length and scope to strengthen computer media skills.
[13] By filling a write-in survey form.
[14] Through a descriptive reflective essay.
[15] Conducted during Fall 2000, is based on author's four years of experiences in teaching design studios focused on using digital media.
[16] Hanna and Barber [2001: p 258] describe how these processes were at work in Alvar Aalto's design methodology and that for him major ideas emerged after restraining the rational. They also concede that the choice of 'which' mode of thinking to suppress depends on the architect himself and his design approach (functional/aesthetic).

The Process

Stage 1: Design Manifesto; One-half week;

Each student researched and prepared a 300 word summary of the traits and attributes of the character they chose and a specific design manifesto including the intended object's topology and characteristics.

Stage 2: Cardboard Interpretation; 1 week;

Students were given a week to interpret their design manifesto with cardboard.

Stage 3: Computer Interpretation; 1 week;

at this stage, students were asked to interpret their design manifesto[17] in digital realm using computer. Learning objective, as Greg Lynn says,[18] was to take an inventory of what the machine wanted to do, so that the students may then begin to ask what they desire from the machines in subsequent phase.

Stage 4: Cardboard Reinterpretation; 1 week;

The students were then asked to build a cardboard model of the solution they had generated in computer, to distinguish what the computer wanted to do that cardboard could not.

Stage 5: Design documentation, presentation, and discussion; 1 week;

the students prepared and presented a 24"X36" poster (Plate III represents an example of this) comparing their cardboard and computer generated design solutions along with critical self-reflections on the effect of process on the outcome.

Analysis of the Outcome

The student projects are summarized in plates I and II. Each row (numbered 1–12), represents an individual students work and consists of four columns (labeled A–D). Column A shows the character student drew inspiration from, the subsequent columns B, C, D show an image from stage 2 (cardboard exploration), Stage 3 (computer interpretation), and Stage 4 (cardboard interpretation of digital solution) respectively. Column E records the influencing factors as noted by the student reflections using a conceptual framework listed below.

- Discovery: How fresh was the digital interpretation compared to the original cardboard solution? (Restrictive or supportive role?)
    - *High*: Digital solution represented a new discovery.
    - *Moderate*: Digital solution represented a little deviation from that of cardboard.
    - *Low*: Nothing much changed during digital phase.

- Usefulness: Did *transformation imposed by digital media* contribute to the final design?
    - *Yes*: They found them desirable and incorporated in to the final design
    - *No*: They were either infeasible or rejected by the designer

[17] Students were asked to adhere to their design manifesto of stage 1. Although they were not specifically forbidden to replicate the design solutions they generated in stage 2, most chose to take a fresh look at the problem.

[18] Cited by Andrew Blauvelt, Design Director, Walker Art Center in a narrative on Lynn's work titled "Space". http://www.walkerart.org/salons/shockoftheview/space/: October 2001.

Summary:
Out of a total of twelve projects:

- Three (1–3) had a high, five (4–8) had moderate, and four (9–12) had low level of discovery.
- Eight accepted the transformations caused by digital as useful and desirable (1–8: corresponding to high and moderate levels of discovery) and four did not (9–12: corresponding to low level of discovery).

Discussion
First, computer differed from cardboard in materiality, generative and manipulation capabilities that affected student designs.

- Cardboard explorations were fluid and flexible in how they exploited the material and tactile attributes. For example: some students pealed off the veneer in interesting ways to creating patterns revealed by the inner corrugated texture (2B, 6B, 12B), spliced cardboard along the thickness to create thinner slices that allowed greater flexibility to construct curvilinear and organic forms etc (2B, 3B, 4B, 9B). By contrast, all computer-generated solutions had uniform thickness[19] for the cardboard and constructed forms featured refined (rigid) geometries (example: 4C, 9C).
- Digital media enables the designer to embark on an endoscopic journey by allowing the designer to occupy the design models. One student's digital interpretation (2C) investigated being inside of the cardboard solution (Hagar's helm shown in 2B) using animation as a method resulting in a very imaginative solution (2D).
- On the other hand, digital models do not obey laws of physics, which are inherent to physical media. This is illustrated by the student's work in the figure 1. In this case, digital solution (1C) resulted in a scheme of overlapping volumes, which although was interesting, could not have been constructed in the real world without resolving the intersections and structural issues. Building a cardboard model (1D) helped realize and solve these issues.

- Most students felt that for representation purposes the digital medium allowed greater versatility. i.e., it was easier to resize/reproduce forms (coins in 1B, tentacles packed in the box in 6C, rings in 11C), to build certain forms that may be very tedious and complex to build with cardboard (for example complex organic forms modeled with metaballs to represent a hand holding a carrot in 4C, complex interlocking rings and tubular forms sweeping through space in 11C), cutting holes/sections using Boolean operations (in 6C, the box form was cut open and rotated bi-axially), being able to measure things on the fly (for example distances and angles between lines, surfaces areas, volumes), ability to change color, texture, transparency almost instantaneously (although irrelevant in this project, some students were seduced by this feature. For example, 2C, 4C, 5C, 7C, 8C, 10 C, 11C).

[19] Computer program used in this project provided a tool to generate a shell from a given form to a specified uniform thickness with a mouse-click. Constructing shells with variable thickness require more operations and call for higher level of skills.

Second, there were significant consequences to student learning because of the computer use.

- An important consequence is that the digital medium seduced the designer into exploring what it does best. The lure of facility for generating photorealistic imagery with relative ease had an effect of distraction rather than a design aid on some designers. Almost all students could not resist tinkering with rendering, even though the project did not ask for it and in fact required the project to be ultimately built with cardboard. Students explorative journey took a conspicuous detour from the moves normally permitted by cardboard, to novel image manipulating features of the computer medium. Student explorations revolved around such attributes as transparency (for example: turning the cardboard translucent), reflectivity (making the cardboard shiny), surface patterns (applying decals of such material patterns as sand, wood, metal to change the looks of cardboard etc.). Although this resulted in the creation of spectacular looking imagery, most of these effects were erased when the solutions were fabricated in cardboard eventually. - Example: Project 8 explored the turning the base into a sand-like texture to indicate desert environment. Similarly, project 11 explored transparency and shininess of the form and consequently did not significantly advance during computer design stage. This is consistent with Belfour's [2001: p268] cautions that computers can fool us into believing that we are empowered when, in fact, we are seduced. This is not to suggest that these explorations were futile to the investigation. In this case there are two notable constraints that need to be taken into account - 1. Students were experiencing designing in digital medium for the first time, 2. There were rigid time constraints that might have forced the students to make quick decisions. Some of these textures/rendered effects could have been mapped on to cardboard in an interesting way. For example, in project 8, idea of sand dunes conceived during photorealistic rendering phase, as the base plane to suggest a desert setting, could have been retained as metaphor in the final design solution and could have expressed in a way possible with cardboard. In project 11, making the cardboard porous could have conveyed transparency.
- Cognitive researchers have suggested that playful visual manipulation of images are likely to facilitate the discovery of unexpected features or patterns that were not intentionally created. Project 1 demonstrates this point. This avenue of inquiry broadens the design solution space, potentially leading to more original designs.
- Digital medium is perhaps more suitable for imaginative playful visualization than for memory based visualization - i.e. when students tended to stay close to the first solution (project 9-12), came up with solutions that were not particularly imaginative and also relatively infeasible or difficult to construct.

Third, this effort involved some important instructional struggles. Most important of all is that the teachers should be familiar with the scope and limitations of software, hardware available at hand. When computer falls short, we need to know to use our knowledge of design and teaching to guide computer use. Thus, this presents the design educators an important challenge of creating opportunities for students to develop a critical judgment in when to adapt computers to fit design methodology and vice versa.

Limitations of the study

This study is not scientific and has several limitations. The inexperienced student sample used represents one limitation to the generalisability of our results to practicing designers. Skill of the designer (dexterity with visualization medium), nature of the project, time allowed for design, and the direction provided in the critiques could significantly affect the outcome in a design context. We did not adequately address these issues in analyzing this project outcome.

Concluding remarks

The general consensus among the students is not that one was better than the other, but using them in concert enriched the design process. Employing cardboard to concoct the abstract discoveries helped students to make their design more useful and meaningful by bringing the physical issues to the forefront. This is consistent with Parson's [1994: p175] observations virtual environments have the potential to contribute as much to the design process as traditional design processes if used in conjunction with them. This leadoff project had a positive effect on the subsequent major project by improving the student restraint of irrational possibilities offered by the digital imagery during design development. For example, most students depended more on the digital medium to generate non-photorealistic imagery that allowed them a dynamic experience of moving through the spaces in real time than rendering a spectacular photorealistic still-frame that takes hours to generate. Most students built physical models of their designs throughout the process.

In summary, this paper concludes that incorporating computers in architecture studio curricula calls for changes in course content and teaching practices to develop sensibilities in students about technologies (when/how to use and when/how not to use), and the learning environments to accommodate the interactions of the new media in a way to enrich but not to displace the traditional.

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Biographical Information

Murali Paranandi is an assistant professor and the coordinator for the computer studies at the department of architecture and interior design, Miami University, Oxford, Ohio. Prof. Paranandi's teaching and research interests are in using computers during conceptual stages of design.

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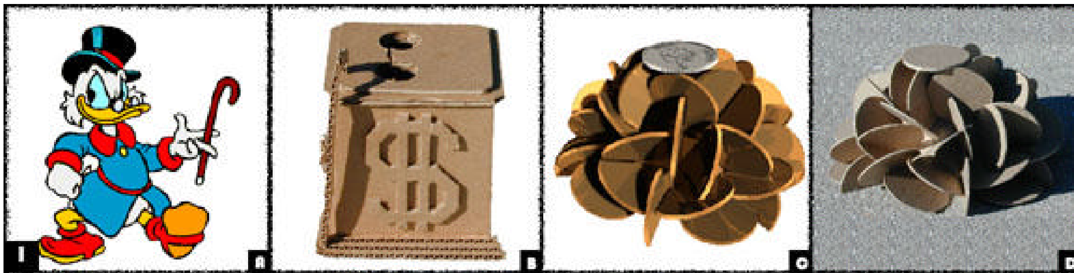
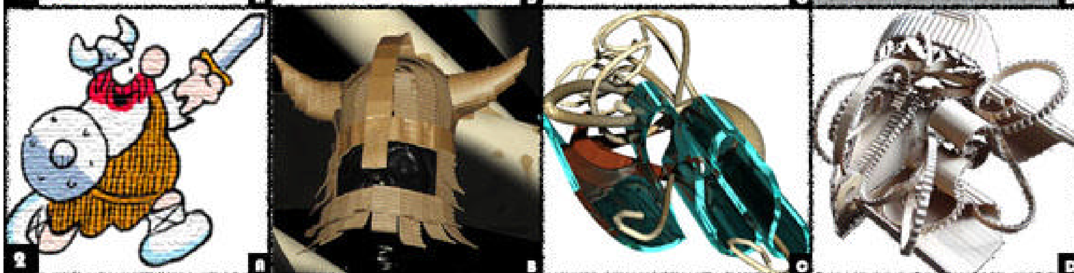
Appendix A

Plates



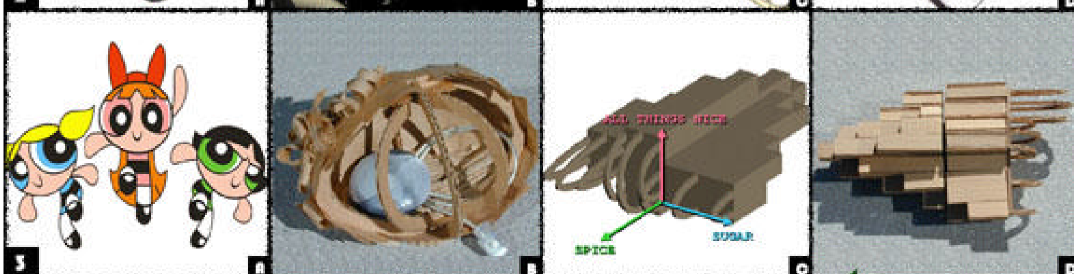
D: High
U: Yes

Comments: Generative logic facility of digital medium drove the design solution.



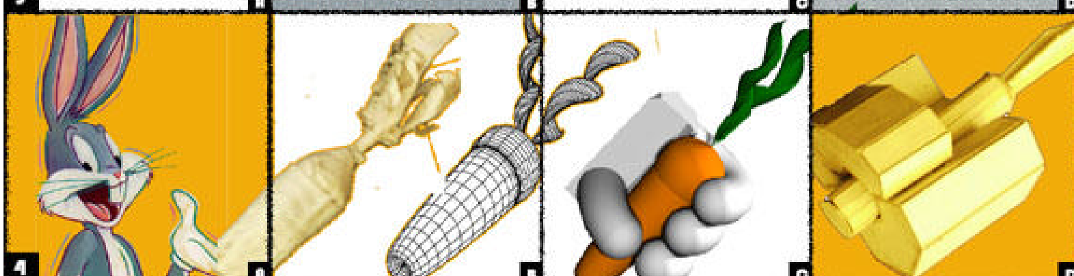
D: High
U: Yes

Comments: Endoscopic visualization and Animation capabilities drove the design solution.



D: High
U: Yes

Comments: Ability to draw and extrude volumes on 3D planes drove the digital solution.

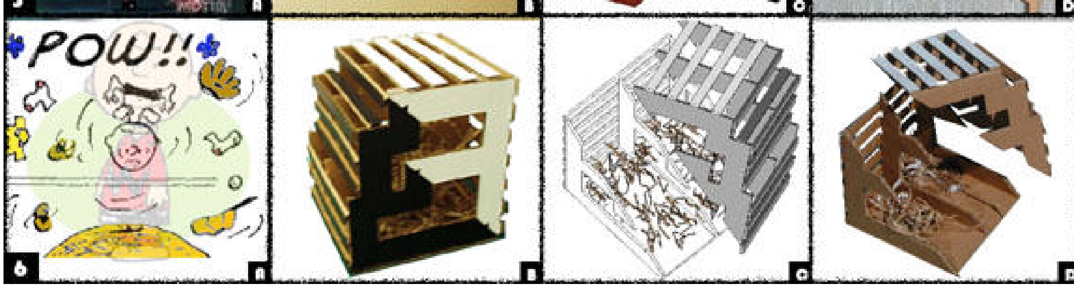


D: Moderate
U: Yes

Comments: Media interactions profoundly reflected.

D: Moderate
U: Yes

Comments: Ease of extruding, cutting, deforming 3D forms with computer fueled investigation.



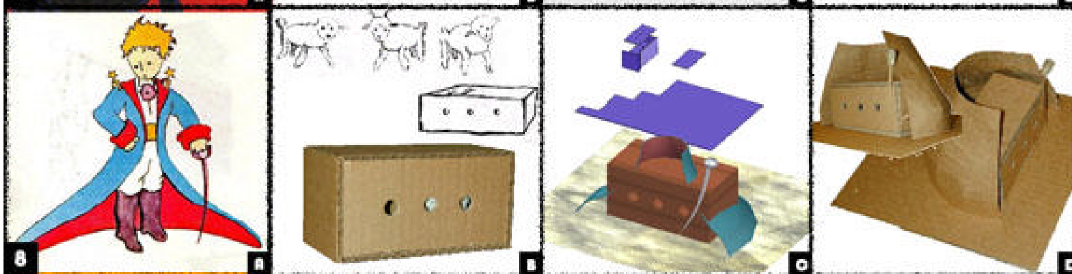
D: Moderate
U: Yes

Comments: Ease of extruding, cutting rotating 3D forms with computer advanced the investigation.

Plate I

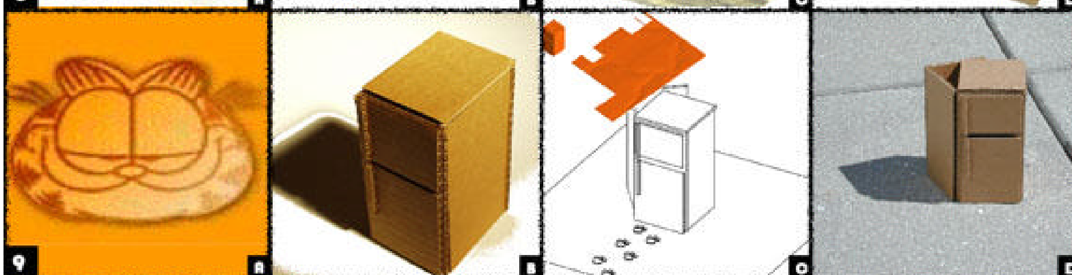
D: Moderate
U: Yes

Comments: *Invisible* connections visualized through digital exploration.



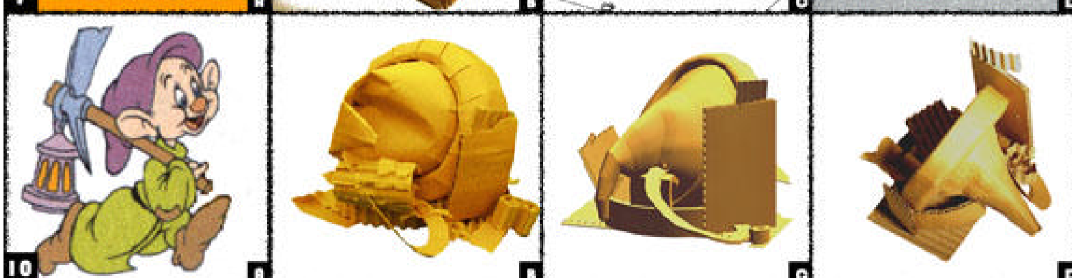
D: Moderate
U: Yes

Comments: Cut & Fold strategy did not work with digital and Intersecting swept form with cardboard



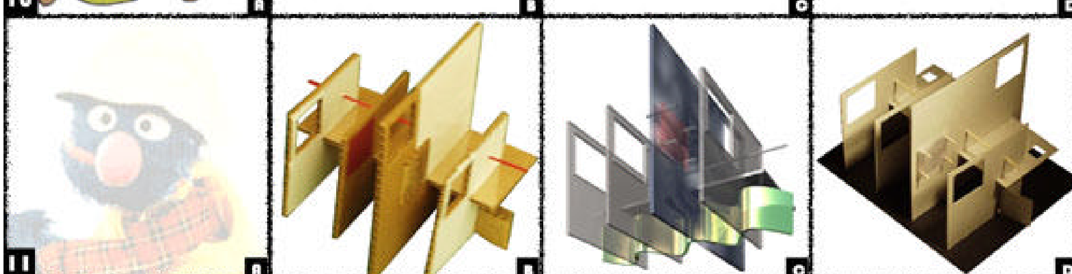
D: Low
U: No

Comments: Low desire to explore the medium, low media interactions.



D: Low
U: No

Comments: Focus on realism in digital realm restrained design transformation.



D: Low
U: No

Comments: Photo-realistic bias, hindered the transformation

D: Low
U: No

Comments: Pursuit of realism resulted in stagnation.

Plate II

Plate III