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Design patterns to support collaborative parametric design

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Design is inherently collaborative. However, current computational design (CAD) systems are based on a single-user model in which the end artefact may be shared among several people, but the process is poorly represented and supported. We aim to understand and evaluate the mid-level patterns of work that recur across designers and tasks in the context of collaborative parametric design. The hypothesis is that making such patterns explicit will result in improved expert work practices in design collaboration. Since 2007, we conducted a series of user experience studies based on Bentley's GenerativeComponents™, and found clear evidence of designers using patterns in practice. In this paper, we report on a participant observation study conducted in SmartGeometry workshop to understand how design patterns work to support collaboration in design. The paper motivates the use of design patterns in architectural practice, describes the study and provides some initial insights on the improvement of condition

Keywords: design patterns, collaborative design, parametric modelling, participant observation, design education

1 Introduction

Design is inherently a creative collaborative process. Almost all complex artefacts, including physical artefacts such as buildings and airplanes, as well as informational artefacts such as software, organizations, business processes, plans and schedules, are designed through the interaction of many, sometimes hundreds of, participants working on different elements of the design. This collaborative design process is typically expensive and time-consuming because strong interdependencies between design decisions make it difficult to converge on a single design that satisfies these dependencies and is acceptable to all participants. Research from the cognitive science and complex system negotiation literatures has much to offer to the understanding of principles of motivation[1] and dynamics of this collaborative design process.[2]

Architectural design and urban planning – at least for sophisticated projects – have always involved highly cooperative tasks. Individual phases within a project often change between close cooperative situations, for instance, during design and review meetings, and individual work carried out by the participants or third parties. During the design and review meetings problems are discussed and solutions or alternatives are proposed. Broll et al argue that "the actual preparation of particular solutions is once more performed by the individuals (leaving the final decision to one of the following meetings). Real collaboration is often limited to the creation of early paper-based sketches".[3] In such a collaboration meeting, both reviewing a detailed process of individual design and recording all the alternatives the group has suggested are both difficult to achieve. From an architect's point of view, it would be desirable to have additional support to introduce the design ideas, explore alternatives, improve the cooperation, and accelerate design and review cycles.

1 Fischer, G. (2002). Beyond "Couch Potatoes": from Consumers to Designers and Active Contributors, Peer-Reviewed Journal on the Internet, 7
2 Klein, M. et al (2003). The Dynamics of Collaborative Design: Insights from Complex Systems and Negotiation Research, Concurrent Engineering, 11**,** pp. 201-209
3 Broll, W. et al (2004). ARTHUR: A Collaborative Augmented Environment for Architectural Design and Urban Planning, Journal of Virtual Reality and Broadcasting, 1**,** pp. 1-10

Many research projects propose complex and expensive tools or systems such as augmented environments to support collaborative design practice.[4] We argue that larger effects are to be found in the asynchronous exchange of well-considered design representations. A set of parametric design-based patterns can empower discourse during both individual design work and discussion and innovation in design groups.

2 Background

Conventional architectural Computer Aided Design (CAD) software comes in two flavours: drawing tools with symbol libraries and *intelligent* tools that offer component-level design (e.g. walls, doors and windows). With drawing tools, edits to the design may impact hundreds of drawings, which must be done manually and require informal *ordering systems*.[5] At this manual editing stage, the task is pure tedium error detection and repair. Yet designers must pay full attention during this important contractual and legal process. Many small mistakes on the drawings are hard to detect. Consequently human error is a critical contributor to lapses in system design.[6] The "intelligent" solutions aim to overcome this by using object-oriented design but these concentrate on producing documentation and usually fail to model buildings with innovative form. These restrictions in current systems are impediments to exploratory prototyping and comparison of potential solutions, as every small change has to be manually managed and coordinated between collaborators on the project. In addition, the technological tools deployed today are designed to service the unique needs of each separate discipline, not to integrate information across disciplines to improve accuracy and reduce time.[7]

2.1 Parametric Design Systems and Their Features

Parametric design is an approach to product modelling that associates engineering knowledge with geometry and topology in the product model by means of constraints.[8] Parametric modelling systems such as Bentley's GenerativeComponents™ (GC) introduced into practice computational mechanisms and interfaces for representing variation in design.[9] Using parametric modelling, it is possible to develop models that support discrete variation, but it is very difficult to understand the range of possibilities entailed by such models. Parametric modelling interfaces thus provide partial support for expressing variation and, because they are increasingly used in practice, a means by which new variation techniques can be explored and tested in actual use.

GC has been used in practice, reaching firms such as Foster and Partners (whose recent works include the British and Smithsonian Museum courtyard roofs and the SwissRE headquarters in London), Arup Sports (Beijing Olympic Stadium) and Kohn Peterson Fox (World Bank headquarters). Through ongoing workshops run by an independent organization, SmartGeometry, the community of GC users is evaluating and improving the structure and interface to make it more communicative and supportive for architects, civil engineers and constructors. These events provide an opportunity for us to observe, understand how people use the system to design collaboratively or individually, and suggest new ideas to support the process of collaborative design.

4 ibid

5 Schmidt, K. & **Wagner, I.** (2004). Ordering Systems: Coordinative Practices and Artifacts in Architectural Design and Planning. Computer Supported Cooperative Work, 13**, pp.** 349-408

6 Wickens, C.D. et al (2004). An introduction to human factors engineering Upper Saddle River, Pearson Prentice-Hall, NJ

7 Beck, P. (2001). The AEC Dilemma: Exploring the Barriers to Change, Design Intelligence, Greenway Communications

8 Anderl, R. & **Mendgen, R.** (1995). Parametric Design and Its Impact on Solid Modeling Applications, the Third ACM Symposium on Solid Modeling and Applications, ACM, Salt Lake City, USA

9 Aish, R. (2003). Bentley's GenerativeComponents: a Design Tool for Exploratory Architecture [195.250.185.245:8080/MyWeb/get/Bentley_training/GenerativeComponents.pdf]

10 Beck, P. (2001). ibid
11 ibid
12 Alexander, C. et al (1977). A Pattern Language: Towns, Buildings, Construction, Oxford University Press, New York

2.2 Parametric Systems Support Collaborative Design

The design and construction industries are in the midst of a fundamental transformation towards so-called “digital practice”.[10] This is driven by a confluence of factors: parametric modelling, digital fabrication, high bandwidth communication, and the globalization of practice. A feature of this transformation is that it is being aided by an unprecedented collaboration across firms and schools. There is a crucial need to share information, learning, and techniques at an explicit level. Parametric design systems support this process of collaborative design in several ways:

- *Share the process among collaborators*: In traditional CAD systems, the modelling outcome or 2D drawings are the only artefacts for communication. The information of the *process* – how they were designed - has been lost. It is easy to copy the items, but very hard to duplicate the process of making something different but with the same logic. Parametric design systems record the creation process, retaining the design logic so that collaborators can interpret the originator’s work. As a result, other designers can reinforce the sense of design in the group.
- *Make design exploration possible*: Traditional CAD systems only show one instance of a design. In a collaborative environment, participants want to explore different alternatives together and decide on the best choice. Until now, paper-based sketching remains the usual exploration method. In a parametric model, it is straightforward to review different variations through adjusting the parameters. A built-in recording tool can record key steps and stages for further analysis.
- *Communicate with other professionals*: Outside the design group, architects need to collaborate with clients, engineers, fabricators, and contractors. In many cases, architects have to adjust the design slightly here and there to meet others’ needs. Editing parameters is much more direct and secure than editing the values of an existing artefact.
- *Facilitate interdisciplinary design*: Experts in fields such as computer science, mathematics and engineering are usually peripheral to the architecture domain but increasingly need to be part of the design conversation.[11] Parametric modelling makes use of explicit computational and mathematical expressions, making it easier for these experts to contribute their knowledge and help architects to understand and implement complex geometry problems in their design projects.

Parametric modelling is transforming practice, both within and between firms, but it is evident that this transformative technology imposes new needs for a higher level of support for its communities of practice. We conjecture that design patterns are a good device around which to structure such support.

3 Design Patterns

3.1 Definition of Design Patterns

A pattern is a generic solution to a shared problem. In modern literature, the concept of a *design pattern* originated with Christopher Alexander to describe an established architectural configuration, its context of use and consequences.[12] Patterns express design work at a tactical level, above simple editing and below overall conception. Architects may use the same pattern in different circumstances and may also derive new patterns as they work. This concept originated in urban architecture but has been adapted successfully to software engineering[13] and extended to other disciplines such as workplace design,[14] user interface,[15] web usability,[16] education science,[17] participatory design[18] and communication.[19] Alexander emphasizes that each pattern describes the core of the solution to that problem, in such a way that "you can use this solution a million times over without ever doing it the same way twice".[20] In the Software Engineering area, Gamma et al. adapted the metaphor and recorded their experience in designing object-oriented software as design patterns.[21] Each design pattern systematically names, explains, and evaluates an important and recurring design in object-oriented systems. Their goals for patterns were to help users choose design alternatives that make a system reusable and avoid alternatives that compromise reusability. The publication of Gamma et al.'s book tipped the concept of design patterns to worldwide popularity in the domain of software engineering and other fields.

Patterns are useful because they provide a language for communication among designers. Rather than having to explain a complex idea from scratch, the group of designers can just mention a pattern by name. Everyone will know, at least roughly, what is meant. In this sense patterns are an excellent vehicle for the collection and dissemination of shared and semi-formal ideas.

3.2 Structure of Design Patterns

Alexander defines a pattern as a three-part construct: a certain context, a problem and a solution. A pattern is represented in a common format: a *picture* (showing a typical example), an *introductory paragraph* (setting the context), a *headline* (essence of the problem), a *long section* (body of the problem), a *paragraph* explaining the solution, and a *diagram* of the solution.[22] Gamma et al use graphical notations to describe design patterns and argue that concrete examples are essential.[23] Tidwell's UI patterns have a clear and strong structure: *name, diagram* (usually made by example screenshots), *what, use when, why, how* and *examples*.[24] Patterns can be presented both in a formal structure and as a set of flexible ideas. We built largely on the structures of OOP patterns[25] and UI patterns[26] to develop a structure for parametric modelling design patterns as follows:

- *Name* is a noun phrase that describes the general function of pattern briefly and vividly.
- *Diagram* is a graphic representation of the pattern.
- *Intent* states a one-sentence description of the goal behind the pattern.
- *Use When* describes a scenario comprising a problem and a context.
- *Why* states the reasons to use this pattern.
- *How* explains how to adopt the pattern to solve the given problem.
- *Samples* illustrate, with working code, how the patterns can be used in several different contexts
- *Related Patterns* show the connections among different patterns.

Of the eight pattern elements, *samples* are distinctive in our work in that the provide concrete, working code as pattern instances. Our work does not emphasize the *language* aspect of patterns. Although many pattern designers aim to build up a complete pattern language that model a design functional hierarchy, there is still no real "completed" pattern language. In fact, Week's work of several in-

13 Gamma, E. et al (1995). Design Patterns: Elements of Reusable Object-oriented Software, Reading, Addison-Wesley, MA

14 Week, D. (2002). The Culture Driven Workplace: Using Your Company's Knowledge to Design the Office, RAIA Publication, Australia

15 Tidwell, J. (2006). Designing Interfaces, O'Reilly, Beijing,Sebastpol

16 Graham, I. (2003). A Pattern Language for Web Usability, Addison-Wesley, London

17 Bergin, J. et al (2001). Patterns for Gaining Different Perspectives: A Part of the Pedagogical Patterns Project Pattern Language, Pace University

18 Dearden, A. et al (2002). Evaluating Pattern Languages in Participatory Design, CHI' 02 Extended Abstracts on Human Factors in Computing Systems, ACM, Minneapolis, USA

19 Ronteltap, F. et al (2004). A Pattern Language as an Instrument in Designing for Productive Learning Conversations, World Conference on Educational Multimedia, Hypermedia & Telecommunications (ED-MEDIA), Lugano, Switzerland

20 Alexander, C. et al (1977). ibid

21 Gamma, E. et al (1995). ibid

22 Alexander, C. et al (1977). ibid

23 Gamma, E. et al (1995). ibid

24 Tidwell, J. (2006). ibid

25 Gamma, E. et al (1995). ibid

26 Tidwell, J. (2006). ibid

formally defined workplace patterns[27] and Tidwell's growing UI pattern collection[28] use simple categories of patterns and have achieved wide recognition with users and other experts. Our study begins with several small but useful patterns.

3.3 DesignPatterns.ca: Observe, Author & Publish Patterns

Borchers compares different pattern languages and states that an important goal of any pattern design team is to capture the reasons for design decisions and the experience from past projects to create a corporate memory of design knowledge.[29] Ideal patterns should be the result of user experience. In our review, most of those patterns may come from authors' own experience or existing cases. However, what are the experiences, how has the experience been captured and what kind of users have been involved? To fully exploit the power of design patterns we need to understand the process of their creation and use, but there is to date little reported research. The objective of our research is to characterize how practitioners use design patterns in parametric systems and how they may support collaboration.

Through a series of workshops and in collaboration with developers and practitioners we collected and developed an initial set of design patterns.[30] We developed an online repository.[31] During this development process, people from the worldwide GC user community began to visit the repository; we received informal feedback from this user community throughout the pattern development process. In this online repository we published twelve completed design patterns of parametric modelling based on the platform of Bentley's GenerativeComponents: *Controller, Goal Seeker, Increment, Jig, Mapping, Organized Collection of Points, Place Holder, Projection, Reactor, Recursion, Selector,* and *Transformer*. These form the basis of the current study.

3.4 What we do not Know about Design Patterns

During our research, we reviewed patterns existing in various disciplines, interviewed GC's system chief designer and professional tutors, observed GC users in different settings, and encoded their design experience into the form of design patterns. There are things we do know and obviously also things we do not know about our patterns.

- We *do know* that patterns of Object-Oriented Programming (OOP) have become a *lingua franca* for the exchange of mid-level ideas in Object-Oriented software design.
- We *do not know* if designers, as immature programmers at best, can use patterns with their necessary abstraction, to convey and reuse ideas during their design collaboration.
- We *do know* that the fine structure of patterns is worked out in every community that uses them.
- We *do not know* if this fine structure is appropriate for communication and collaboration in the parametric modelling community.
- We *do know* that patterns originate through groups of experts.
- We *do not know* if, in the design community, groups of experts will accept (even further develop) such patterns since we can see some potential risks. Firstly, design is by definition open-ended. It is in the deepest ethos of a designer to look beyond provided solutions to new insights. Secondly, experience

27 Week, D. (2002). ibid
28 Tidwell, J. (2006). ibid
29 Borchers, J. (2001). A pattern approach to interaction design, Norwood, Mass, Books24x7.com
30 Qian, Z.C. et al (2007). Participant Observation can Discover Design Patterns in Parametric Modelling, ACADIA 2007: Expanding Bodies, pp. 230-241.
31 Qian, Z.C. et al (2008). Developing a simple repository to support authoring Learning Objects, Journal of Advanced Media and Communication, 2:2, pp. 154-173 [www.DesignPatterns.ca]

is sobering. Alexander's 253 urban architecture patterns consumed years of effort but failed to achieve a result of wide acceptance in design practice. Indeed, we encountered a strong initial anti-pattern bias among several designers, largely because they identify all patterns work with Alexander's.[32]

We began to explore these questions of what we do not know through a participant observation study.

4 The Study

As we are interested in exploring what we do not know about design patterns in the collaborative design rather than measuring the efficiency and quality of patterns, we carried out a qualitative participant observation study in which the observer was also a participant in training the users.

We conducted the study with volunteer participants in the context of an international workshop.[33] In such a condition, the benefits are that all the participants are highly skilled professionals and they are very motivated. The obvious disadvantage is that they only have very limited time to learn the software and use it to solve problems in the real projects (but this can also be seen as an advantage because it reflects typical conditions in a real working environment).

4.1 Method of Participant Observation

Participant Observation is a research method in cultural anthropology, as well as a common feature of qualitative research in other disciplines - sociology, education, health sciences.[34] DeWalt and DeWalt highlighted that its advantages as: "enhancing the quality of the data obtained during fieldwork, enhancing the quality of the interpretation of data, and encouraging the formulation of new research questions and hypotheses grounded in on-the-scene observation".[35] It is important to recognize that this method combines two somewhat different processes: observation and participation. Spradley suggested a continuum of levels of researcher participation.[36] At the minimal end are nonparticipation (i.e., only observation from outside the research setting) and passive participation (i.e., researcher is present but does not participate or interact). At the opposite end are those who are active participants engaging in activities to gain a greater understanding of cultural norms and mores. Most studies fall somewhere in the middle of this continuum. Meyer discusses that participant observation is a way of thinking distinct from that traditionally used in the research associated with the physical science.[37] The researchers use their reactions to understand others' view and to formulate hypotheses about the other participant's reactions. In this sense, participant observation is a kind of "disciplined subjectivity". She advises the knowledge engineer to expect to be uncomfortable with having a marginal status of not being wholly a researcher, nor an actual insider while doing participant observation.[38] This qualitative method has been used in various projects such as identifying the differences between how novice and experienced designers approach design tasks,[39] understanding how architects integrate sketching and parametric modelling in the design process,[40] and designing an evaluation protocol for learning object development.[41]

4.2 The Researcher's Role

We used the approach of active participation.[42] We, as researchers, are engaged

32 Alexander, C. et al (1977). ibid

33The SmartGeometry (SG) Workshop and Conference (2008).

34 Suzuki, L.A. et al (2007). The Pond You Fish In Determines the Fish You Catch: Exploring Strategies for Qualitative Data Collection, The Counseling Psychologist, 35, pp. 295-327

35 Dewalt, K.M. & **Dewalt, B.R.** (2002). Participant Observation: a Guide for Fieldworkers, AltaMira Press, Walnut Creek, CA

36 Spradley, J.P. (1980). Participant observation, Harcourt Brace Jovanovich College Publishers Orlando, FL

37 Meyer, M. (1992). How to Apply the Anthropological Technique of Participant Observation to Knowledge Acquisition for Expert Systems, IEEE Transactions on Systems, Man and Cybernetics, 22**,** pp. 983-991

38 ibid

39 Ahmed, S. et al (2003). Understanding the Differences Between How Novice and Experienced Designers Approach Design Tasks, Research in Engineering Design, 14

40 Sanguinetti, P. & **Abdelmohsen, S.** (2007). On the Strategic Integration of Sketching and Parametric Modeling in Conceptual Design, Conference of Association for Computer-Aided Design in Architecture (ACADIA), pp. 242-249

41 Giordano, R. & **David, B.** (2000). Participant Stakeholder Evaluation as A Design Process, ACM Conference on Universal Usability (CUU 2000), pp. 53-60

42 Spradley, J.P. (1980). ibid

in most of the same activities as our subjects as a means to learn the rules of their behaviour. A 2-day pre-training workshop designed for training novice GC users preceded the 4-day formal workshop. Some experienced GC users still chose to attend the pre-training since they wanted to be more familiar with the application before the "real work" starts. We gave a series of tutorials with examples composed of some pattern concepts and samples to more than seventy participants in a standard classroom setting. Apart from providing them all the script files we were demonstrating on the central projector, we went around the room to answer questions as they arose.

During the formal workshop, we acted as tutors for designers (workshop participants), simultaneously observing and discussing how they were working. We posed little overhead on any particular designer as the discussion and observation is essentially what already happens in a tutoring session. However, due to our own previous experience, we brought certain biases to this study. Although we made every effort to ensure objectivity, we were aware that our biases may shape the way we view and understand the data we collected and the way we interpret our experience. For example, our personal experience and skills might interfere how we understand a subject's problems and actions. For certain kinds of problems, we may have the solution of a certain pattern in mind and thus ignore other alternatives. To avoid such validity issues, while chatting with subjects about their problems, we tried to make our advice suggestive instead of determinative.

4.3 Settings

This study was conducted at the Arabella Sheraton Grand Hotel in Munich Germany from February 29th to March 3rd 2008. The participants (more than 150 and mostly architects and civil engineers) were selected into six groups (structure, environment, fabrication, form, computation, and architecture). Every group occupied a work room and had three professional tutors (Figure 1). These participants had been competitively selected by the workshop organizers though adjudication of their project proposals. Before this workshop, they all had attended at least a pre-workshop that introduced the basic functions of GC. Participants used their own laptops during the intensive 4 day session.

Figure 1 Settings of the formal workshop

4.4 Participants

Six subjects from the pre-training workshop with some previous experience with GC volunteered for the study through a public process. These comprised one female and five males (the female-male ratio in the larger event was about 18% - 28 out of 154), all between the ages of 25 and 45. Three of them were graduate students, two were industrial professionals and one was a design firm director. Five were architects and one was a civil engineer. Four planned to use the workshop to solve design problems in their current commercial projects. Two focused on academic studio designs. All participants were part of larger teams in their work environment. All of them had learned GC for at least 3 months and it was the first parametric modelling application they had ever learned.

4.5 Workshop Tasks

Every participant had previously submitted a project proposal centred on one or more design problems in a current architectural project. These were related to the usage of parametric modelling, such as solar analysis and panel arrangement on a free-form structure. While all of the architecture projects come from teams, only one representative of the project was in the workshop. In one case, two members from the same work team participated (Hank and Tom): they worked on separate parts of the design project and had to integrate them at the end.

4.6 Events

Apart from three meals and presentation sessions after dinner, our participants spent most of their time focusing on the design projects, aiming to complete them by the end of the workshop. They sometimes had short chats with their teammates and neighbours or negotiated solutions with their tutors (Figure 1).

In order not to interrupt their work, we interviewed the participants by request, when they were taking a break or during moments of relative calm. We engaged them in short conversations (3-10 minutes) two or three times a day. We chatted about the progress in their projects, problems they encountered and potential solutions toward those problems. The conversation length depended on the topics emerging during the process. Audio from these conversations was digitally recorded. We also collected other data such as photos of physical models, digital sketches and hand sketches, screenshots of existing problems, script segments and successful models, and all the GC feature and transaction files at each stage.

Since many participants were familiar with us from the pre-training workshop, some (including tutors) approached us for possible solutions for their problems, to share their progress, or chat about their work. With their permission we recorded these conversations. By the end of the workshop, we also had the necessary data from four other projects (all involving members from the same external work teams). We consequently had data from ten projects overall.

5 Data Analysis

We analyzed the data using ATLAS.ti 5.0. Data included text data (interview transcripts, GC feature and transaction files), images (screenshots or photos taken during the process) and audio data (recordings of short conversations). We packaged all the data of one participant's activities as a single unit. Boyatzis introduces three approaches to developing themes systematically: theory driven,

43 Boyatzis, R.E. (1998). Transforming Qualitative Information: Thematic Analysis and Code Development, Sage Publications, Thousand Oaks, CA

prior data or prior research driven, and inductive.[43] Our study to search for phenomena of use adopted the inductive (data-driven) approach because of the lack of coding theory. In term of this evaluative study, the data analysis goal is to search for early signals of how patterns exist in designers' work and communication.

We firstly defined four basic categories (codes): *collab-adapt*, *collab-struct*, *collab-internal*, and *collab-external*. For example, in a conversation recording, a subject's statement related to using the pattern's structure to discuss will be coded as *collab-struct*. If this information is specifically related to the Name part in the pattern structure, the higher level *collab-struct-name* code would be assigned. We also used the thirteen pattern names as basic codes, such as *pt-repo* (Reporter), *pt-plho* (Place Holder), and *pt-proj* (Projection). During the coding process, we realized that there were instances that participants suggested new pattern ideas. A basic code of *pt-new* was added to the list to anchor such conditions. In total, there are eighteen basic codes. All other codes have to add extensions upon these basic ones.

Two coders participated in the coding process. Naturally, different coders see different things in the data; when differences arose, we discussed the data until some agreement was reached. In some cases, this was resolved with a new code, in other cases the data was coded into more than one category. The results were then compared to our original research hypotheses.

Upon 68 short conversations recordings, 53 GC script files, and 137 screenshots (collected during the four days), we were able to locate the eighteen basic codes more than 200 times. For example, 49 locations for *collab-adapt*, 36 locations for *collab-struct*, 34 locations for *collab-internal* and 17 for *collab-external*. Place Holder (*pt-plho*) and Controller (*pt-cont*) turned out to be the most popular patterns in the repository. Each of them had more than 20 locations. Instead of using ATLAS.ti's network function to investigate the logic connections among codes, we dived inside these eighteen code categories one by one to read the stories and understand real use cases. The six subjects we recruited at the beginning were Tom, Sam, Don, Nik, Jon and Jill. We report our findings with respect to the data-driven codes we developed and our previous questions of what we do not know about design patterns.

5.1 Designers find, use and adapt pattern content

One design goal for the design patterns was to improve expert work practices through reflecting the community's own problem solving strategies for reuse and adaptation. Our first observations revolve around the frequency and type of pattern use, both individually and between users. We identified three scenarios of using patterns in practice: *directness, unawareness* and *serendipity*.

5.1.1 Directness: use the patterns to solve problems

Some participants were very comfortable with the concepts of design patterns. They either had a clear plan of how to use them in their projects or recalled some experience in using related concepts. For example, in our first interview, subject Jill said (observer comments in *italics*):

> I am trying to achieve geometric construct movement and different morphologies within the possibilities of constraints *What is this on your screen?* This is a single

> unit. By studying these single units, I am trying to propagate these deployable parts in the overall structure. What you have seen now is just one of the configurations, so the next step would be more complicated. I heard of your design patterns was in Delft in a lecture Professor XXX gave us. Then I started to look at your website ... For this project, I think it would be many as I can use: the *Transformer* approach, the *Controller* approach and definitely the *Place Holder* approach.

Figure 2 shows images of Jill's project: the upper images were the ones we mentioned during the first interview. The bottom images were her final outcomes with GC. From coding her scripts, it is clearly that she had made full use of several patterns. She mentioned that she would use the elegant foldable structure on a complex gym roof surface her team was currently designing.

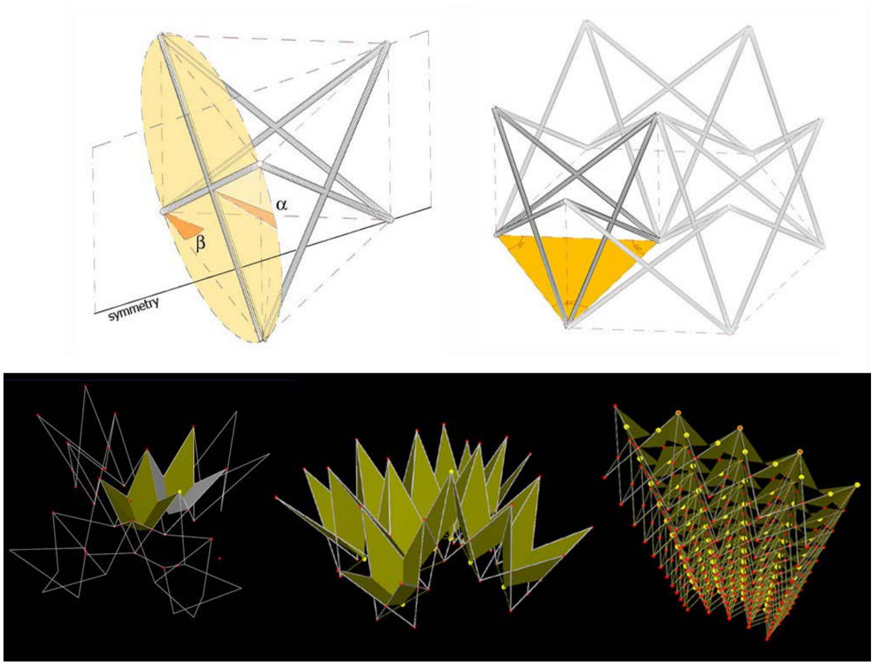

Figure 2 Screenshots of subject Jill's foldable structure

During the pre-training workshop, subject Jon came up to us during a coffee break and recommended himself as a subject to us.

> I had never heard of your patterns before. But today when I looked through the repository, wow, I really can point out several of them I had already used in my previous projects. When I was using them, I didn't realize that they were strategies, I mean, patterns. … I am going to at least use the *Projection* pattern in the project tomorrow. It is about a skin, trying to wrapping up the structure behind it and I am also going to design proper components that can populate the skin that can do some sort of solar tracking. It is a *Place Holder*, right?

Jon used several patterns to generate a skin to wrap up the imported structure (left image in Figure 3) provided by his external (i.e., real-world) school design team.

We note that in both these cases, the designers were familiar with the concept of explicit strategies for their individual tasks, but were also intending to use the patterns to demonstrate to their real-world teams how they had extended and amended the original designs.

44 **Roberts, R.M.** (1989). Serendipity: accidental discoveries in science, Wiley, New York

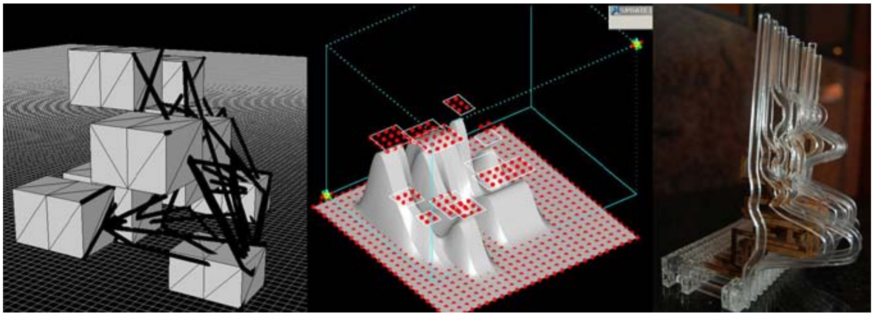

Figure 3 Images of Jon's project progress

5.1.2 Unawareness: use the patterns without noticing them

Subject Nik became aware of our design patterns through searching in Google for GC files when he started to learn GC a couple of months ago. During the interviews, he stated several times that he would not use patterns:

> No, I do not think I am going to use them (design patterns. See? I am programming to get what I want. It would be more direct and controllable than your approaches.

However, he used more than two patterns. For example, he used the *Controller* pattern to control the shape and height of the curved brick wall (Figure 4).

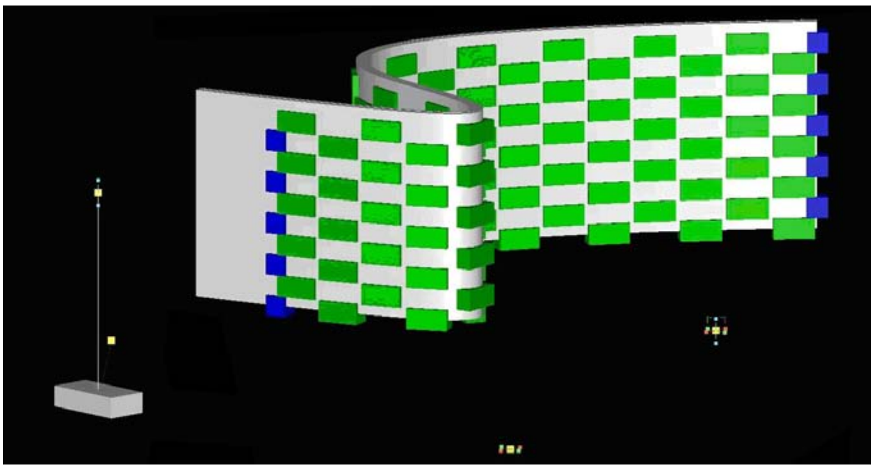

Figure 4 The possible Controller in subject Nik's brick wall

The fundamental principle of pattern *Transformer* is to keep the shape of the rigid body no matter the orientation and location is. Defining each object's initial coordinate system and calculating the relations among these coordinate systems are the essential steps. Nik calculated the coordinate system for each brick carefully so that the size would not be stretched when the curve changes (Figure 5). He used the idea of *Transformer* without awareness.

5.1.3 Serendipity: finding unknown patterns in unexpected ways

"I find that a great part of the information I have was acquired by looking up something and finding something else on the way".[44] This definition of *serendipity* accurately describes our discovery of multimodal pattern using styles during the collaboration. Most participants started to read our patterns in the pre-

45 De Certequ, M. (1984). The Practice of Everyday Life, University of California Press, Berkeley

training workshop and tried our samples following our step-by-step demonstration. We assumed that going through the tutorials would be the main way for them to learn. During the interviews, we realized that the conditions were much richer.

- (Nik) I found the tutorial information insufficient, at least for me. I searched for any GCT file (GC file) in Google and found your site. I scanned through it- interesting! Some useful ideas (were) there for our project.
- (Tom) Sorry, I didn't pay attention (to the pattern tutorial). It was my teammate Hank, we are working on this tower together, he wanted me to create a *Place Holder* with correct input so that he could apply it vertically to his model. He also wants me to look at *Goal Seeker*....
- (Sam) When I planned to buy GC for my firm, I joined the GCUsers forum first. I want to see how people evaluate it. Somebody there recommended me your site. I've learned a lot … Now, I am familiar with most of your sample files.
- (Tutor Gord) Hi, we met this problem in my group...I looked through your site and thought *Recursion* would be the solution. But we don't quite understand the function. Can you go through the scripts with us? ... Hmm, it seems that that is not what we want. Anything other examples in your site you can recommend?

Ward and Ben were not our subjects. They were widely acknowledged as having done a great job in their collaborative project and in demonstrating multiple interpretations of their design ideas. Ward told us that he scanned through the samples in our site, downloaded one sample file (left upper image in Figure 6) in the *Transformer* pattern and used it directly as an inclusion in their hexagon structure (left bottom images) to make it slide to open. When we looked at the representations of this project (Figure 6), we did not notice this direct adoption at all. Maybe Michel de Certeau's concept *poaching* is a proper description of this form of use.[45]

5.2 Pattern Structure Serves Communication

During the workshop, participants could access our pattern repository online. We also distributed a DVD on which twelve complete patterns were packaged. Most of the pre-training workshop participants copied the content of the DVD to their laptops and were able to read the patterns and try the samples directly. The structure of our patterns was based on the review and comparison of pattern languages in different disciplines. We noticed that subjects deploy different strategies in using patterns for communication.

5.2.1 Names identify transferable ideas in communication

From the second day of the pre-training workshop, participants started to use pattern names in their team discussions. For example, both Jill and Jon mentioned several pattern names in their interviews to describe how they planned to implement the projects. When subject Tom was discussing the twist tower project with his teammate Hank, Hank advised Tom to use two patterns. The names Hank mentioned were the anchors for Tom to find the correct patterns in the repository to read.

However, we observed that some participants misinterpreted the meaning of the patterns and used the names incorrectly. For example, pattern *Recursion* was mixed with a two-dimensional loop in the function, and setting a global variable was understood as the *Controller* pattern. In some cases, participants also confused the name of the sample with the name of the pattern, or created new names based on the appearance of the sample. For example, "roof pattern" and "paper folding pattern". We believe it is not necessarily bad because some "new" name is so vivid that participants can immediately associate it with the "official" pattern ideas. Concepts of the patterns are much more important than the names, although it is clear that, at least in a team, having a unique name was important.

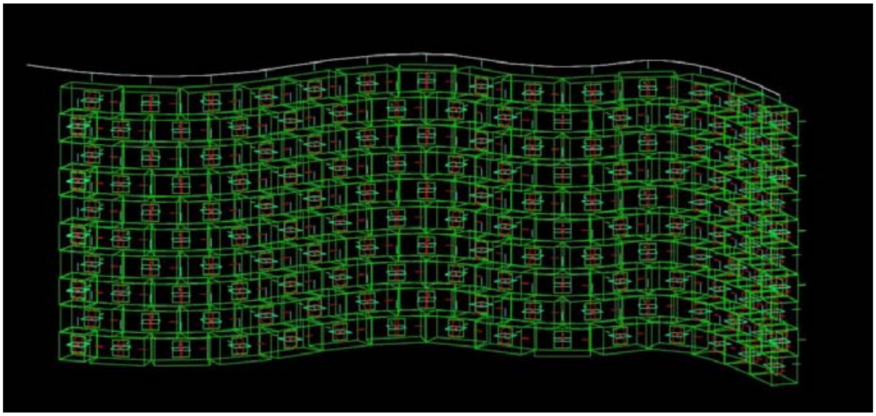

Figure 5 Complex coordinate systems in Nik's project

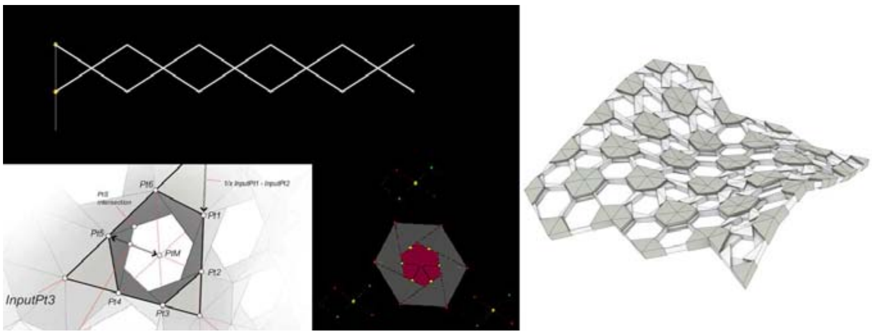

Figure 6 Images of Ward and Ben's breathing surface project

5.2.2 Samples are critical elements in pattern exchange

During the interviews or coffee breaks, when participants started to talk about patterns with us, they quickly engaged in detailed discussions of certain pattern samples or even certain transactions in samples. For example, the first chat between Jon and us was to answer his question about a sample script in the *Reactor* pattern (This sample was outside of the pre-training tutorial. Jon looked into the sample to check if it was appropriate for his project). Participants mainly scanned through the pattern repository for solutions. Samples provided concrete code that help participants (as amateur programmers) to understand the overall pattern by following its transactions step by step. Although we devoted much effort to writing the explanatory text, it was the samples that actually bridged between specific design ideas and the generality of patterns and helped participants adapt in collaboration.

When we were designing the pattern repository system, we wanted to present the patterns online in 3D. An "ideal" solution would have been to allow users to manipulate the samples directly online, but that was developmentally expensive. As a compromise, we decided on animated transitions with Macromedia Flash™, as

46 **Bartram, L.** (1999). Enhancing Information Visualization with Motion, IEEE Information Visualization, IEEE Computer Society, San Francisco

animation is a well-established way to guide a user through process and change.[46] We devised a solution to have the Flash file generate an animation by automatically picking up a series of images from a folder to ease creation and editing by designers.

We noticed that most participants spent much more time viewing the animations of samples than reading their text explanations. Ward told us that he scanned through the animations in our repository to look for useful scripts:

> I want to enjoy the writing part. But finding what it can do is much more important for me than finding how to do it. I mean, in that environment, I have to find quick solutions.

5.2.3 Pattern diagrams are not used in exchange

Among the eight parts of a pattern structure, pattern names and samples have been found to be very useful. Participants also read the text parts (*intent, use when, why, how,* and *related patterns*) to understand our interpretation of patterns. A subject even commented that the structure was very clear. However, we did not find any evidence favouring the diagram. Diagrams are the graph representations of a pattern to hint and present its meanings. It seems ironic because both the diagram authors and readers are visual people. Compared with the animation representation, the diagram is obviously less useful.

5.3 The community accepts patterns

It might be easier for individuals or small teams to learn and use the patterns. We also want to comprehend the acceptance of the GC community. Our participant observation was not purposely designed to answer this question, but there was useful information from the data to gauge the community's response.

5.3.1 Diffusion within groups

In the SmartGeometry workshop, there were 154 participants and 24 senior tutors. More than 70 participants and 7-8 tutors (who arrived earlier) attended the pre-training workshop. In the first day of the formal workshop, we had to introduce the pattern repository and offer the pattern DVD. From the second day, there was no such need. Many participants introduced themselves and said that they had heard about this repository and had copied the DVD content to their laptops.

> No thanks! No need for the DVD. I have already got your pattern files. XXX told me that they were good stuff ...

During the middle of the workshop, one of the Smart Geometry directors heard about the pattern discussions from the big group and came up to us to ask for detailed information.

5.3.2 Participants and tutors suggest new patterns

We authored patterns based on the practice observation data gathered in 2007 and 2008's GC events. Our patterns also inspired new ideas, not only from participants but also senior tutors who had instructed GC workshops for years.

- Subject Don was working on determining the shape of building through analyzing the sunshine and shadow relations. He failed many times when he was trying to determine the proper building elevation through calculation. At the end, he got the accurate shape through unionizing all possible sunshine rays and trimming the tower as a whole (Figure 7). Don argued that it was an approach of thinking reversely in parametric modelling and recommended this new idea to us.

- Subject Tom suggested a pattern idea “mediator” in which item B can inherit some (not all) properties of item A and connect with item C. In such a pattern, all the properties of A could be preserved, and a connection between A and C could be built up.
- Senior tutor Gord came to us to ask if we have a pattern “data organizer”. In several cases he met in the group he was tutoring, he had to re-organize the data structure of an index or a collection, such as sorting a linear index of random points to a two-dimensional collection based on the Z translations of points. When another tutor MS dropped by our conversation, he said he was working on something similar and demonstrated what he was able to do through a small GC file.
- Senior tutor Karl was responsible for the environment group. He realized that there were common needs to calculate a collection of vectors based on more than two influence sources. On the room’s white board he drew the diagram of “gradient of vectors” (left image in Figure 8) and distributed his sample file around the group. We got to know this through subject Sam. Sam did some further implementations based on Karl’s sample – analyzing the gradient of vectors from a three-dimensional perspective and representing such as gradient through coloured layers (Figure 8). Sam said that it was really a useful pattern idea.

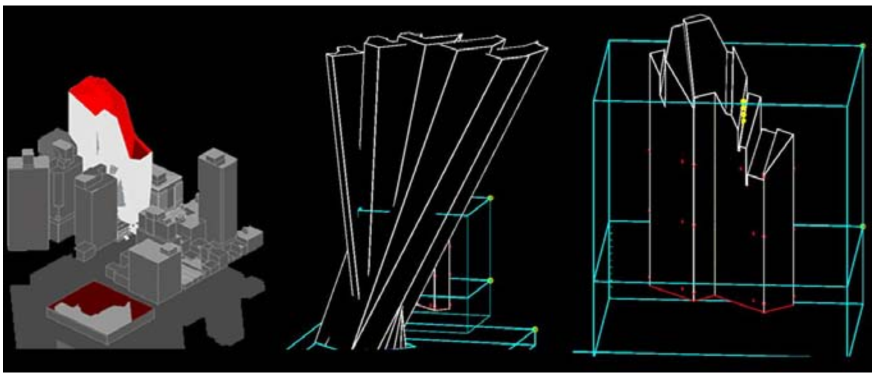

Figure 7 Images of subject Don’s sunshine shaping project

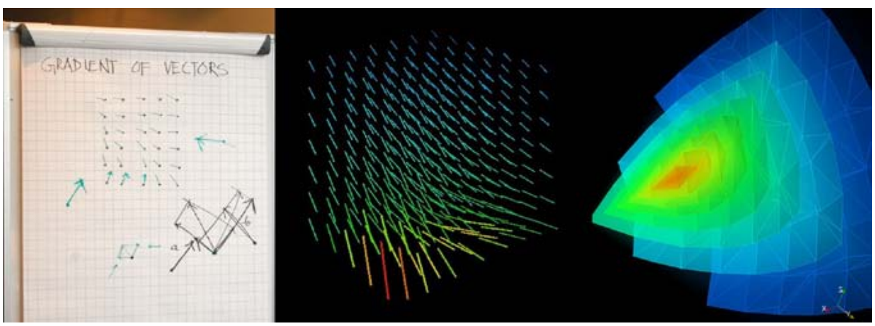

Figure 8 Images of potential pattern Gradient of Vectors

5.3.3 Extension leads to scaling

Apart from suggesting new patterns ideas, participants and tutors were also interested in improving our solutions and recommending new sample files in existing patterns. This kind of discussion went on beyond the limit of the workshop. For example, here is one email sent by subject Don one month after the workshop:

> I am just writing to say I have found a way to find the maximum and minimum x and y values of a line. It can improve your *Goal Seeker* pattern … The whole idea is that you change the graphs to get different solutions for the extrusion and the max and min extents will update. If you know of an easier way to do this I would appreciate your input.

Subject Jon also packaged some GC files he created before and sent them to me by email after the workshop. He believed that he had used some pattern-related strategies in those works and wanted us to filter out some samples to enrich the repository.

The extension of collaboration also took other forms. Participants Kevin and Rick from Chicago were working on a system that limit amount (27) of hexagon shapes can spawn infinite kinds of net layout structure (Figure 9). During the workshop, they had got the spawning principles done, but they needed somebody who can script in GC to really solve their problem in the design practice. A collaborative design relationship was built between their team and ours since 2008. Three graduate students were involved in this collaboration and the final design was submitted successfully in the middle of 2009.

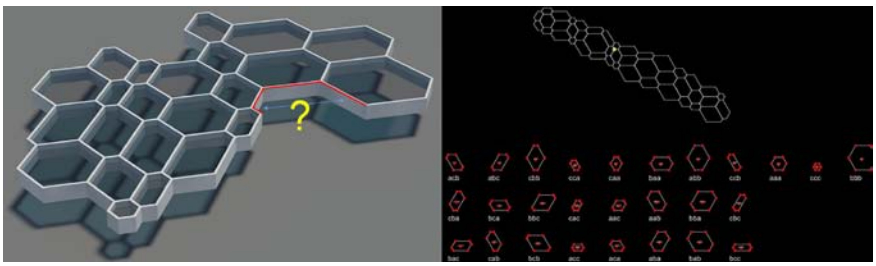

Figure 9 Kevin and Rick's hexagon spawning project

6 Discussion of the study

We designed and conducted a participant observation study to understand things we *do not know* about design patterns in the real design context; specifically, how subjects felt about the patterns utility and how they fit into the process of design. While this is only the first study of many, we have discovered the following.

- *The variety of pattern using models shows patterns are sophisticated chunks for communication and interpretation*. Starting from the same pre-training workshop, participants took different approaches to access and use patterns: some adopted them directly, some used the concepts without awareness, and others accessed and accepted the ideas through team discussion, peer recommendation or detailed analysis. It appears that designers can use the abstract structure of patterns to find, convey and reuse design ideas. Much such interaction though was mediated by our *samples*, the concrete (and adaptable) realizations of patterns in code.

47 Arch534, parametric bridge design
48 Woodbury, R. (2010). Elements of Parametric Design, Routledge

- *Patterns encourage designers to treat design problems logically and to construct their shared tasks effectively.* Patterns divide design tasks into small individual tasks logically instead of physically. Some patterns make the direct transformation possible in teams (Tom and Hank, Ward and Ben). Just like computer programming, in a team somebody can work on the general structure, others can work on detailed elements or different sections. Patterns do seem effective as for communication and collaboration of aspects of design team work.
- *The structure of pattern helps designers to understand and communicate the design problem*. Participants scanned through the pattern repository for solutions. The fact GC records the transaction history helped participants to follow the steps in the samples. Rich sample files of our patterns were more welcomed by the audience than the text explanations. Flash animations in page were not just "eye candy". They served as a useful shortcut for participants to explore possibilities without downloading and opening samples one by one.
- There is evidence that at least this particular design community (GC) is beginning to accept and develop the design patterns: quick diffusion across the groups, pattern idea recommendations from participants and tutors, continuous communication on specific solutions, and pattern-based project collaboration. The multiple suggestions for new patterns indicate active and effective engagement with the patterns.

The answers from the data were not always positive. For example, also as a visual representation, the diagram design proved unsuccessful. We intend to explore more fully which representations are most suitable for communication and shared exploration for the parametric design community.

6 Knowns and Unknowns

Design patterns support the communications when groups are working on parametric design problems. The results of our SmartGeometry workshop study were not able to answer directly how significant can patterns enhance collaborative parametric design, but the wide acceptance demonstrates that design patterns have become an important mediator in the process of collaborative design. The idea has been seeded well in the community. Since 2008, we delivered the parametric workshops with design patterns world widely in different academic and design events. The pattern content has been further developed with collaborative contributions. For example, a university educator used our repository directly to teach an undergraduate course[47] in 2009 fall semester after accessing patterns in our 2009 ACADIA workshop. He sent the link of his students' design outcomes and suggested that we adopt some of them as sample patterns. We, as educators, also started to use patterns to teach parametric design in the Purdue University since 2010 fall semester. The pattern repository has gradually become a formal tutorial resource for GC international workshops. Warmly requested by the pattern users, based on the content of design patterns and the series of empirical studies, Dr. Rob Woodbury published the book of "Elements of Parametric Design" in the summer of 2010.[48]

From this study:

We *do know* that the current group of parametric design patterns can augment designer' practice when they are using Bentley's GenerativeComponents™. There are two main types of practice in parametric CAD systems: one that constructs the models from low-level primitives and the other that involves connecting pre-defined model components with parameters and algorithms. GC adopts the former while others such as Maxon Cinema 4D[49] and Rhino Grasshopper[50] belong to the latter type. We *do not know* if the concepts of current GC patterns can directly transfer to the other type of parametric CAD applications. If not, adjustment at some level should be made to make these patterns benefit users of other applications.

We *do know* that it requires a long time frame to see complete pattern effects. Reflective thinking helps users to access and employ stored knowledge, make inferences about new information, and determine implications.[51] It is how people actually learn. The short time frame available in workshop studies only informs us of early signals of use. We *do not know* how parametric design patterns engage in prolonged design practice. If we want to investigate patterns' effects in such a direction, what should the proper methods and criteria to inspect and measure that be?

We *do know* that there is a loop in which parametric design strategies cycle from design practice to theory and then from theory to design practice. This research focuses on augmenting, contributing, observing, enhancing, and evaluating such a loop with the metaphor of design patterns. We *have not seen* the full loop for patterns in design collaboration. There is one piece in the loop we have to investigate further - how designers' contributions can feed back to the patterns, and how a pattern and its samples can be polished and enriched by designers' active involvement and communication.

These unknowns indicate our future research directions as follows:

- Generalizability: assess and adjust patterns in other parametric design systems.
- Durability: adopt other research methods to investigate the prolonged learning effects.
- Independency: develop the pattern recycling system to filter useful practice data back to pattern repository and encourage the community collaboration.

49 Maxon.net (2010). Cinema 4D Prime - Professional 3D Starts Here [www.maxon.net/products/cinema-4d-prime]

50 Davidson, S. (2010). Grasshopper: Generative Modeling for Rhino [www.grasshopper3d.com]

51 Norman, D.A. (1993). Things that Make us Smart, Addison-Wesley, Reading

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> **Beckett K.L.** and **Shaffer D.W.** (2004). Augmented by Reality: The Pedagogical Praxis of Urban Planning as a Pathway to Ecological Thinking, University of Wisconsin, Madison
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