Interdisciplinary Knowledge Modelling for Free-Form Design – An Educational Experiment

KOCATURK, Tuba and VELTKAMP, Martijn
Building Technology Department, Delft University of Technology, The Netherlands

Keywords: collaborative design, constraint based design, design process, digital design education, free-form design

Abstract: The recent advances in digital design media and digital fabrication processes have introduced formal and procedural effects on the conception and production of architecture. In order to bridge the individual concepts and processes of multiple design disciplines, intensive cross-disciplinary communication and information exchange starting from the very early stages of design is necessary. A web-based database for design learning and design teaching named BLIP is introduced. In this framework, cross-disciplinary domain knowledge becomes explicit to be taught and transferred in Free-Form Design research and education. BLIP proposes a conceptual map through which the user can construct structured representations of concepts and their relationships. These concepts are high-level abstractions of formal, structural and production related concepts in Free-Form design development. BLIP is used for formalizing, organizing and representing conceptual maps of the three domains and facilitates information and knowledge sharing in collaborative conceptual design in context. The paper introduces the application together with its application in two educational design experiments.

1 INTRODUCTION

The digital revolution in architectural design and the adoption of CAD/CAM processes in the building industry can be considered as one of the most radical shifts in architectural history concerning their immense formal and procedural implications. Concerning the formal implications, complex CAAD software – at the disposal of almost any designer today – have provided means to create and describe complex juxtapositions of forms. Parametrics and associative geometry provided designers to create customized transformations of forms according to the rules set by the designers, regulating the relationships between geometric properties of their digital model and its performance criteria (structural, constructability, etc). These operations engender a different cognitive model of design as well as a different vocabulary of forms – so called Free-Form, Blob Forms – than was available to designers accustomed to work previously with straight lines, spheres, cubes, cones and cylinders in modelling (Chaszar 2003). As for the procedural implications, while digital practices provided a digital continuum between design, engineering and production practices, they also brought about a new set of constraints and dependencies between interdisciplinary design domains.

For conventional design and production processes, designers could manage these iterative processes intuitively, given the experience and familiarity with the standardized building elements and construction methods. Nonetheless, the emerging digital processes, tools and knowledge require a new intuition for the design professionals to cope with the emerging relations and constraints between the domain (in)specific information for the design and realization of Free-Form Architectures. Therefore, how to represent the evolving knowledge, to capture the reasoning process and to manage the constraints during the design process are among the most difficult design issues dealing with Free-Form design in current practice. New tools and techniques are required to capture the emergent relations among evolving material properties, structural morphology, manufacturing technology and the architectural form.

The emergence of new processes, tools and methods have also had significant implications on the design research and education as well as design knowledge in general. As part of the two ongoing projects in the Blob research group of the Architecture Faculty of the Delft University of Technology, we have conducted an extensive case study of the constructed Blob precedents. Within an interdisciplinary framework, the main focus was on the form and the processes employed for its generation and realization (e.g., *design methods, form generation techniques, fabrication technologies, representation tools, structural form development*) as well as various context (in-) dependent dependencies between them throughout the initial design to the final assembly of the Free-Form envelope surface and its supporting structure. BLIP database application has initially been developed as a representational framework to formalize and organize the interdisciplinary design knowledge (explicit and implicit) derived from the Blob precedents, focusing mainly on the dependencies and relations between the formal, structural and production related aspects. The challenge of this study is twofold. Firstly, it is an attempt to explicate experiential knowledge of Free-Form design practice and to structure this information in such a way that it can used as a continuous learning and teaching environment where new knowledge can be added, stored and re-used at any time. Secondly, the knowledge captured is formulated in a new domain (in)dependent taxonomy as generic abstractions of overlapping interdisciplinary concepts and their dependencies. In the following sections, the paper will first introduce the development of the prototype for its specific use in education, and then its application in two educational workshops. The aim of the workshops were mainly to test the usability of the prototype with regard to: how the interdisciplinary abstractions in BLIP facilitate teaching in context, the degree of flexibility it allows concerning the storage of new knowledge and its re-use (learning behaviour), and if it facilitates innovation and creativity.

2 DESIGN KNOWLEDGE MODELLING AND REPRESENTATION

Design is a complex process that involves a large amount of information with numerous dependencies. This information is commonly represented and communicated in a collection of design documents of various formats. Several researches and approaches have been reported on the formalization of design knowledge. Logan discusses the necessity of formalization of design knowledge models for providing tools for further research (Logan 1985). He refers to the structure of relationships in design activity and claims that design research should focus on understanding these relationships, rather than solving problems. Akin introduces the formalization of knowledge as a system that explicates the behaviour of the problem solver during the design process, which can also be used in design education for the study of uncertainty (Akin 1986). Landsdown defines design as a transformation of an object from an initial, incomplete state to a final complete one. Since the transformation is brought by the application of knowledge, design can be seen as an information processing concept (Landsdown 1986). In this respect, what makes each design unique is in part determined by how the designer(s) bring different items of knowledge together in varying contexts. Creativity can also be defined as combining different items of knowledge in a unique way. Oxman and Oxman propose a structured multi-level model of architectural knowledge and claim that there should be meaningful relationships between levels, or types of knowledge which should facilitate both bottom-up and top-down operations. A formalism is proposed which represents the linkage between concepts in design stories which are structured as a semantic network. (Oxman and Oxman 1990). Maher et al. provide a valuable reference as a comparative portfolio of cased based systems (Maher and Silva Garza 1997). The comparison is based on the complexity of cases and the way generalized knowledge is handled (e.g. heuristic rules, geometric constraints, casual rules). Their problem solving approach is based on analogy from the perspective of memory and they employ concept of memory organization as a guideline for computer representation.

Many document management and knowledge modelling applications exist, but not all are suitable for the early stages of design or support multi-disciplinary knowledge sharing for the conceptual design. The main reasons why a unified cross-disciplinary knowledge representation has not been developed can be outlined as: 1) Theory is specific to a single domain of practice, 2) a neglect of epistemological and ontological concerns in theory making, 3) a lack of agreement about definitions of core concepts and terminology, 4) Poor integration of theories specific to designing and designs with theories from other bodies of knowledge (Eder 1996, Oxman 1995, Pugh 1990, Love 2002).

Although design knowledge grows in part from practice, the practice of design is only one foundation of design knowledge. As Friedman states: “it is not practice but systematic and methodical inquiry into practice—and other issues—that constitute design research, as distinct from practice itself”(Friedman 2003). In this respect, BLIP database proposes a model, an illustration, describing Free-Form design processes by showing its elements (e.g. processes, forms) in relationship to one another – as different from conventional design processes. These elements are interdisciplinary in nature. The capture and demonstration of their relationships (dependencies, constraints, etc.) is what distinguishes BLIP from a simple catalogue. While offering an interdisciplinary taxonomy, the emerging knowledge is defined mainly as how these elements are brought together in respond to a design problem.

2.1 BLIP

In multidisciplinary knowledge modelling, the task decomposition and integration must be achieved not only through the communication of contents, but also through the communication about the creation and evolution of shared meanings (Lu et al .2001). In other words, design coordination relates to not only the dependency identification among the design decisions, but also the exchange of perspectives between the design stakeholders. Therefore, in a interdisciplinary knowledge model, it is essential to identify, represent and evaluate the influence of one's decision making in a specific domain to others' decision making in different sub-problems. Furthermore, identification of the interdependencies among design activities also plays a key role in solving conflicts.

Building a unified body of knowledge framework and theory across disciplines requires a taxonomy for design participants to declare and share their perspectives. Furthermore, understanding the relationships and dependencies requires clarity about the boundaries between the disciplines, individual terms and concepts, and the design context. For the proposed knowledge model described in the next section, we focus on the experiential knowledge (in the cases) and factual knowledge which are essential source of domain specific, cross-disciplinary and cross-organizational knowledge.

We have developed a methodology that entails the organization of interdisciplinary design knowledge in a web environment, as a decision support and design exploration tool. It establishes a grammar of influences between formal, structural and production related aspects of a free-from development process. These aspects have been conceptualised as a semantic network of keywords by formulating various context independent factors (*features*) that are influential in these processes. Once the *features* are interrelated, documents are entered in the system with reference to these interrelated features (Kocaturk, Tuncer and Veltkamp, 2003). The application is designed to be used for extensive cross-referencing and interactive searches. The links between two or more features also store documents and can also be searched by the user to access more specific information on the relationships between specified features. In the system, users can switch between the documents layer (precedent solutions) and the concept layer (the features and links). In this context, the application provides (Figure 1):

- A high-level multidisciplinary Free-Form design taxonomy (between architectural-structural and manufacturing related processes);
- Structured representations of design concepts and their dynamic relationships in a knowledge-based and precedent-based environment;

- An extensible framework to store/retrieve/share and generate new knowledge (as a conceptual design aid);
- Distinctions of factual/experiential knowledge and different perspectives of stakeholders (in architectural, engineering or manufacturing domains).

Figure 1 Screenshot of BLIP, with on the left the network of keywords and on the right a content document

3 EXPERIMENTAL WORKSHOPS

Two separate workshops were conducted in the design studio in two different semesters, each slightly distinct in their set-up. At the beginning of both workshops, students had first been taught the basic concepts, terminologies, techniques and processes applied in free-form design and construction during which BLIP application was extensively used (for case studies, lectures, etc.). In order to get the students acquainted with the application, they were also asked to analyse precedent Blob design/engineering and production processes and then to extract knowledge to store in BLIP by creating new links between the features which they could use later for their upcoming design task. They were also allowed to add new features into the system as long as they were generic enough to accommodate similar new instances. In the following sections, both workshops will be described and discussed regarding the usability of BLIP concerning how the interdisciplinary abstractions in BLIP facilitated teaching in context, the degree of flexibility it allowed concerning storage of new knowledge and its re-use (learning behaviour), and if it facilitated innovation and creativity.

3.1 First Workshop

The students were asked to generate a double-curved Free-Form roof surface, develop a structural supporting system and alternatives for the fabrication of the structural elements. In this particular design experiment, the students were asked to work as a team in which the team members were all assigned a specific role associated to the three aspects of BLIP: one group responsible for the form-generation, another for the structural system development and analysis, and the last group to investigate manufacturing alternatives (as three separate domains). Although they were given separate roles in the team, they were asked to develop design alternatives together as a group output. The students had been provided with necessary theoretical background information concerning the scope of their individual tasks in the first half of the workshop.

In addition to their design task, they were also asked to record their collaborative conceptual design process and their design alternatives, concerning what constraints they have encountered posed by which team member, how they solved it, why they abandoned a particular alternative and how they justified their choice for a particular design solution. Later on, they were asked to explicate their design experience and store this in BLIP as new knowledge they discovered by creating new links - if necessary - across each domain.

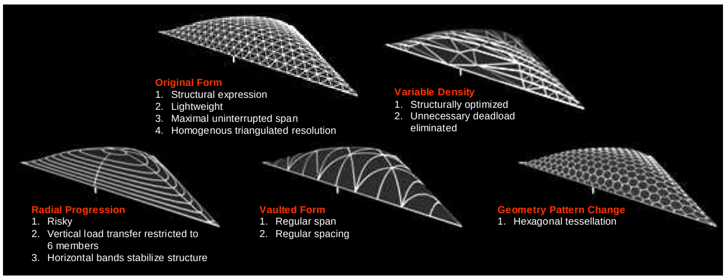

Figure 2 Conceptual design alternatives generated by the group (Image credit: Chris Kievid)

The students were relatively productive in terms of conceptual solutions and alternatives they produced for the downstream processes, together with their own dependent parameters satisfying all of the constraints set by one or more team members (Figure 2). However, they scored relatively poor on the basis of innovation, judged by their approach of dealing with mutual constraints across domains. They were more solution oriented and rather preferred to choose “easy to deal for all” solutions (even for the conceptual design phase) rather than developing new strategies, or methods to cope with them. This was mainly due to their approach to the problems more locally and their reluctance to switch iteratively between bottom-up and top-down approaches. Thus, they were less efficient in generating new concepts and links although they could manage to generate many documents for the existing links in BLIP.

3.2 Second Workshop

In the second workshop, a new group of students was given a free-form double-curved 3D geometry and were asked to develop the given surface into rational cladding components, design a supporting structure composed of curved elements, and find alternative manufacturing processes for the cladding components and the steel structure. Different from the first workshop, they were given two initial constraints to start with. Firstly, they were not allowed to make major changes in the geometry. And secondly, all of the surface cladding components and the elements of the structural system should be *developable*. Developability of surfaces is one of the most frequently applied techniques used for constructability modelling of free-form surfaces. These rolled plane configurations have straight lines of ruling on the surface, where the surface normals at any two points on a given line of ruling are in the same plane, so they can be unfolded into a plane.

Although they had to collaborate throughout the whole design process, this time, each student would develop his/her own design alternatives for one task only (complying with the initial constraints), while considering the dependencies of their decisions across domains. Meetings were held to mutually inform the fellow students about the progress, and the conceptual design variables (formal and procedural) developed by each were discussed together with the emerging constraints originating from the structural configuration on the cladding configuration, and vice versa.

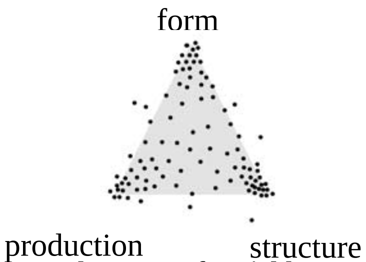

Figure 3 This scheme shows the range of variables produced during conceptual design. The distribution of the dots represents the design variables and their degree of dependencies across domains taken into account for their generation. (Image credit: Antonio Pisano)

It has been observed that in this particular experiment the students were more innovative and creative not only in terms of the variety of design solutions, but also the methods and strategies they have invented to deal with particular constraints and dependencies between tasks (Figure 3).

4 DISCUSSION

The experimental setting for both workshops are evaluated within the two philosophical models of experiential learning as outlined by Kolb and Piaget (Kolb 1984, Piaget 1972). Kolb's emphasis is on the experience, followed by reflection. Piaget focuses on knowledge and the ability of its assimilation. This assimilation is related to the students' cognitive schemata which affects the acquisition of new knowledge. During both workshops, students had also been assisted in identifying different types of knowledge – as declarative (what), procedural (how) and contextual (why) – which contributed significantly to their knowledge acquisition and trans-disciplinary knowledge sharing process.

Experiential learning is the apparatus in which the learner is subjected to situations where he/she develops and assesses his/her critical thinking abilities, thus allowing for freedom of creative thought. Moreover, it provides students with opportunities to reflect on their own learning, and in particular to monitor and evaluate their own processes of working. One of the challenges of these workshops was to develop the students' abstract thinking ability by which they could conceptualize a particular knowledge as a problem-solution-constraint trio so that they could identify similar problems with that of similar solutions within similar constraints in various other cases. This approach is based on the assumption that design is more of a problem-finding activity (as opposed to problem-solving) especially when the designers are not familiar with the design context and cannot predict what problems they will encounter during the course of a design.

The workshops provided valuable feedback on the usability of the first prototype of BLIP with regard to three evaluation criteria. The first criterion was to test how interdisciplinary abstractions facilitated design teaching in context. BLIP represents design solutions and strategies as an answer to a specific relationship between two or more concepts within one across two or more domains. In this respect, both workshops proved that the framework it provides for interpretation and conceptualisation of design concepts, and to communicate them to students were quite effective. This had been reflected in their collaboration process as well.

Second criterion was the flexibility and extensibility of BLIP for storing new knowledge and its re-use (learning behaviour). Although the functionality of the application allows both, it was rather difficult for the students (as novice designers) to conceptualize their own design actions at a generic level. It has been observed to be rather difficult for the students (as novice designers) to switch between the concept (problem) layer and the information (solution) layer iteratively. This is to be learned in time with gained experience. They needed guidance in this process.

The final criterion was to test if the application could facilitate innovation and creativity. The set-up of each workshop, and the difference in students' cognitive schemata influenced the degree to which this criterion was met. In the first workshop, throughout their design process the students were more focused on problem solution rather than relations between concepts. The only dependency type they interpreted between concepts across domains were *constraints*. Consequently, their problem solution approach was mainly in the form of negotiation and compromise between the groups to satisfy those constraints, and the design alternatives were chosen on a formal basis to the degree to which these forms could be produced and engineered with the most ease, which could also be easily represented in BLIP. However, in the second workshop, the students were not as much concerned about finding a solution but rather referred to high level problems abstractions as guidelines to develop alternative strategies to cope with various dependency types between information across domains. Eventually, they were more innovative and creative in their final solutions. However, it has been observed that the current database is lacking the ability to represent these varying dependency types (relations, links) between features (concepts) across domains. Thus, the knowledge structure should be augmented with relations according to these distinct relationship types. These relationships are not only distinct in meaning (e.g., geometric versus non-geometric constraints), but also in form (e.g., uni-directional versus bi-directional relationships). This will allow the system to support the representation of creative and innovative knowledge as well as empower the search function in the system at various levels of abstractions.

5 CONCLUSION

BLIP, as a precedent and knowledge based database, has been developed to categorize, organize and capture the emerging design knowledge in free-form architectural design and production as a teaching and learning tool. As a knowledge and precedent based database, it provides a unified interdisciplinary representational framework in which the emerging relations between three domains can be represented at different levels of abstractions. The major innovation of such environments and tools is the flexibility they provide with respect to the composition and inter-relatedness of the information structure. This flexibility applies when adding new information and relating this to the existing information in the system.

The need for capturing and organizing knowledge has always been an interest in design research. The context of knowledge to be represented proves to be play an essential role on the representational framework for the knowledge structure. Currently, the context of free-form design is still an exception rather than a rule and might well stay as mere formal fantasy unless its full performance is examined and synthesized with innovative structural and fabrication solutions. Therefore, to represent the evolving knowledge, to capture the reasoning process and to manage the emerging relations across domains would be a contribution not only to design education but also to architectural design practice in general. Although it will not require much discussion that master students can not be considered as expert designers, the relatively limited number of precedents, the design complexities and range of disciplines associated with this class of buildings and production processes may require knowledge beyond the direct experience of most practising designers. In this respect, most designers are novices in this context.

ACKNOWLEDGEMENTS

We would like to acknowledge B. Tuncer and J. Beintema for their contribution to the development of BLIP, and D. Lim, M. Cohen de Lara, T. Jaskiewicz, C. Chua, C. Kievid, A. Pisano, J. Hulin and S. Krakhofer who participated in the workshops and provided valuable feedback for this research.

REFERENCES

Akin, Omer. 1986. *Psychology of Architectural Design*. London: Pion

Chaszar, Andre. 2003. Blurring the Lines: An Exploration of Current CAD/CAM Techniques. *Architectural Design* 73(1): 111.

Eder, W.E. 1996. Definitions and Methodologies. In *Design Method*, ed. S. A. Gregory: 19-31. London: Butterworths.

Friedman, Ken. 2003. Theory construction in design research:criteria, approaches and methods. *Design Studies* 24(6): 519.

Kocaturk, Tuba, Bige Tuncer, and Martijn Veltkamp. 2003. Exploration of interrelatonships between digital design and production processes of free-form complex surfaces in a web-based database. In *Computer-Aided Architectural Design Futures*, ed. Mao-Lin Chiu, Jin-Yeu Tsou, Thomas Kvan, Mitsuo Morozumi, and Tay-Sheng Jeng: 445-454. Dordrecht:Kluwer.

Kolb, D.A. 1984. *Experiential Learning: Experience as the Source of Learning and Development*, Englewood Cliffs, NJ:Prentice-Hall.

Landsdown, J. 1986. Requirements for Knowledge Based Bystems in Design. In *Computer-Aided Architectural Design Futures*, ed. Alan Pipes: 120-128. London: Butterworths.

Logan, B.S. 1985. Representing the Structure of Design Problems. In *Computer-Aided Architectural Design Futures*, ed. Alan Pipes: 158-170. London: Butterworths.

Love, Terence. 2002. Constructing a coherent cross-disciplinary body of theory about designing and designs: some philosophical issues. *Design Studies* 23 (3): 346.

Lu, Stephen, and James Jian Chai. 2001. A collaborative design process model in the sociotechnical engineering design framework. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 5(1): 3–20.

Maher, Mary Lou and Andres Gomez de Silva Garza. 1997. *Cased-Based Reaasoning in Design*. *IEEE* 12(2): 34-41.

Oxman, Rivka. 1995. Viewpoint: Observing the observers: research issues in analysing design activity. *Design Studies* 16(2): 275-284.

Oxman, Rivka and Robert Oxman. 1990. Computability of Architectural Knowledge. In *The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era*, ed. Malcolm McCullough, William J. Mitchell, and Patrick Purcell: 171-187. Cambridge: MIT Press.

Piaget, J. 1972. *Psychology and Epistemology: Towards a Theory of Knowledge*, London: Penguin.

Pugh, Stuart. 1990. Engineering Design – unscrambling the research issues. *Research in Engineering Design* 1(1): 65-72.