Knowledge Modeling and Processing in Architectural Design

Buthayna H Eilouti, Ph.D. Architecture
buthayna@just.edu.jo
Associate Professor of Architecture
College of Architecture and Design
Jordan University of Science and Technology

ABSTRACT
Knowledge is essential to most design activities and during most designing phases. However, in most cases it exists in implicit and inaccessible representations. This is especially the case in the architectural design universe of discourse where most knowledge is tacit, unstructured and multi-layered. Moreover, storage and retrieval tasks that are usually associated with design knowledge management are redundantly repeated for each design assignment. This paper introduces a set of structured prototypes that help model raw design knowledge embedded in documented precedent designs in more explicit and accessible constructs. It also explores methods of design knowledge recycling and processing. Knowledge modeling is illustrated by examples of model implementation in real design studio settings.

Keywords: Knowledge modeling, Knowledge Recycling, Architectural Design, Design Engineering, Design Informatics

1. INTRODUCTION
Designing is central to many human production activities. Many of its processes are based on knowledge intensive tasks [1-7]. Design derivation uses knowledge in all of its various phases: pre-design reasoning, design processing and post-design evaluation. In all of these phases, design adapts parts of previous knowledge for its routine tasks and excludes others that include known solutions for generating innovative products. Many design-related knowledge-based activities are redundantly repeated over and over again in each design assignment. Recycling and transforming knowledge from one framework to another become increasingly necessary to eliminate redundant repetitions and to facilitate accessing and applying previous knowledge to new designs [8-13]. Structuring both areas; knowledge modeling and recycling, to make them more reusable is the main goal of this paper. Such a re-structuring is expected to present informed and systematic design processing and development approaches.

Research in knowledge processing, modeling and recycling is significant for design theory, practice and education. It aims to reveal new inspirations for concept derivation and to help in the transformation of some abstract knowledge constructs into applied design models. When clear transformation methods are described, the applied knowledge can be implemented to derive more optimum processes and perhaps more innovative designs. Similarly, the research may contribute to mapping complex problems to potential solutions through grouping combinations of sub-models to generate various alternative solutions. Each of the developed transformation and mapping methods may provide guidance with which designers can avoid the problem of ‘reinventing the wheel’ and reach satisfactory design solutions with relative ease and speed. In addition, the generated hybrid models are expected to contribute to the education of design through explicit and externalized templates. Furthermore, the applicable models and processes can be developed into computer aids that may assist designers generate their products more efficiently [14-16]

The research methodology combines theoretical and action designs. The first is used deductively to develop models for knowledge representation. The second includes model implementation in real design studios and reflections about this experiment. Both research designs focus on concept generators in design knowledge modelling prototypes.

2. KNOWLEDGE PROCESSING OCTAGON
In the context of architectural design, the most significant activities associated with knowledge processing are:

1. Knowledge generation
2. Knowledge management
3. Knowledge modeling
4. Knowledge implementation
5. Knowledge communication
6. Knowledge documentation
7. Knowledge analysis, and
8. Knowledge evaluation

These eight design-related knowledge areas are illustrated in Figure 1. The knowledge aspects are illustrated as a design knowledge octagon where the transition from one triangle into the next requires additional layers of interpretation to clarify its premises and presents its processing phases and resultant products. Some of these areas were emphasized in previous researches [17-18]. In this octagon, the design knowledge processing sequence starts with design generation. Upon its generation, design knowledge needs management to organize its contents and possibly categorize them based on pre-defined criteria and goals. Based on knowledge organization, it becomes possible to model knowledge
either in easier to understand abstract models, or in easier to implement applied models. Knowledge represented in applicable models can then be applied to produce new designs. This cycle from knowledge generation to implementation uses layers and components of knowledge in an inductive reasoning approach to conclude wholes from parts. The design activities included in this cycle are synthetic, where design compositions are assembled from basic elements as embedded in generated knowledge forms. The next cycle departs from the knowledge-based implemented designs. These need to be communicated graphically or in other forms. The communicated representation needs then to be documented for future reference. This cycle from knowledge implementation to knowledge documentation encompasses post-design activities and mainly is concerned with re-presentation of produced designs in different formats. Upon knowledge archiving and documentation, knowledge from documented designs can be extracted, analyzed and evaluated to deploy reusable parts for the generation of new knowledge. In terms of design, this final cycle represents the case study prescriptive phase where precedent cases are analyzed deductively to conclude design layers and systems. The two main areas of concern of this knowledge processing octagon are the knowledge modeling and knowledge recycling. This latter recursively loops between documented design knowledge and generated one. These two knowledge areas- modeling and recycling- will be discussed in more detail in the following sections.

The transition from each knowledge-related activity to the next in the processing octagon requires a major task that is possibly associated with multiple minor ones. For example, the main task needed for the transition from knowledge generation to knowledge management is the organization of its associative data and information. Similarly, a prototyping of organized data is required to prepare managed knowledge to be modeled in more usable formats in the next stage. This task uses typology and classification to help prototype given knowledge body in recognizable and reusable structures. Upon modeling in more usable formats, knowledge-based prototypes require adopting a clear methodology to explain how it will be implemented to generate new products. When implemented, the product designs need to be presented in different formats including text, graphics, and mock-ups to make them executable and comprehensible by other design parties. After the proper communication of product design, its associative knowledge requires archiving for future reference. The documented representations of design take typically the form of precedents or design cases. From this station the design recycling loop starts. It requires reasoning to analyze existing knowledge. Upon analyzing its contents, precedent-based knowledge can be subject to constructive criticism to evaluate what parts can be reused and how they function. Finally, new knowledge can be inferred from evaluated previous experiences to generate new guidelines that may inform future designs.

Figure 1: Knowledge processing octagon: stations and tasks

3. KNOWLEDGE MODELLING

Design knowledge modeling, that is illustrated in Figure 1 as the third station of the knowledge processing octagon, represents a major station in knowledge processing that helps transform generated knowledge as developed from previous designs and other resources into applicable formats that facilitate the implementation of previous
knowledge in new designs. In this section, design knowledge is introduced in a hierarchy of three levels (see Figure 2). In the first, knowledge is proposed as a design language framework that consists of abstract design prototypes. In the second, the framework branches into seven models. These include: 1) the vocabulary elements of design language, 2) the grammatical structure that controls its syntax, 3) the morphology that explains how the vocabulary elements are related and organized, 4) the possible scenarios that can be visualized to take place in its structures, 5) the abstracted templates that could be generalized for its functional or formal prototypes, 6) the systems that hold and organize the functionality and integrity of its elements, and finally 7) the intangible semantic layer that underlies design structures. In the third level, each of these seven models branches into two sub-models.

The vocabulary model includes the design component layer and the clusters or patterns that highlight component grouping methods. The design language grammars consist of language syntax and procedural accumulative processes. The morphology model includes the topological relationships that control how components are spatially organized, and the structures that explain, for example, the proportional system or part to whole relationships. The scenarios apply an imaginary what-if game that helps visualize how the design may function when used after it gets built. These models include possible events that may take place in the design on a daily, weekly, monthly or yearly basis. They also include user sequence diagrams and user potential utilization of spaces. The templates can be usually concluded from the study of groups of previous designs that were considered successful when evaluated according to given criteria. The templates may be proposed as formal prototypes, or functional ones. For example, from the study of existing airport designs, it is possible to conclude what forms seem to work well internally and externally, or how spaces should be clustered to function properly. The systems a design may include can be classified into internal and external ones. The first controls the integration between the relationships of design components. The second constitute the interface between a design and its context. The semantic-based models include intangible information about design concepts and philosophy. These are rarely explicitly expressed, and need to be inferred from other design representations. This design knowledge modeling hierarchy is illustrated in Figure 2.

![Figure 2: The seven knowledge models](image)

### 4. DESIGN KNOWLEDGE RECYCLING PENTAGON

In the context of architectural design, design is the core and ultimate goal of knowledge cycle. This cycle starts from data as embedded in precedent documented representations (see Figure 3). Upon interpretations of raw data and assignment of semantic attributes to make data more meaningful, it mutates into information which, by organizing and classifying its contents, can be transformed...
into abstract knowledge prototypes. These, in turn, subject to proper representation methods and formats can be translated into applied knowledge models. Combined with informed design methodologies, the applied knowledge models can be implemented to produce new designs that may be documented to represent new precedents that if communicated properly may represent a new point of departure for future designs.

This cycle—from raw data as embedded in design precedents into an emergent design as documented again as a new precedent—represents a recursive loop that is internally called from each model structure. In other words, each model of the seven calls this cycle from equivalent structures that are extracted from previous precedent designs to generate new concepts.

The seven models of design knowledge belong to the “abstract knowledge” station of Figure 3. The intension of these models is to translate their contents into applied knowledge that can be transformed into new designs. They can be arranged in the pre-design phase of designing to embody chunks of knowledge as needed in order to interpolate their information to derive new alternatives.

5. DESIGN KNOWLEDGE MODEL IMPLEMENTATION AND DISCUSSION

The seven models introduced in section 3 were presented and explained in a design studio to empirically study their use in architectural design. Students of third year architectural design studio were asked to apply the seven models to analyze previous relevant case studies, derive new designs and evaluate alternative solutions. The generated products were documented. Students’ reflections and feedback were surveyed through oral representations, jury discussions, tutor observations and structured questionnaire.

An example of model implementation is illustrated in Figure 4. The example applies a scenario model as extracted from a previous design of a shopping center into a proposed alternative that considers events that may take place in the proposed design on a daily, weekly, monthly and annual basis in each scenario. In the light of these possible events, the proposed designs are altered to accommodate in space, size, geometry, topology and relationships to other spaces any predicted event. This example highlights the visualization of unforeseen space utilization scenarios and strengthens the predictability and evaluative competences of participant students.
As applied in the architectural design studio, the framework for model implementation was tri-fold. It consisted of pre-design, design and post-design phases. The first, in turn, consists of three stages: data collection, in which precedents were searched and selected; data analysis, in which precedents were investigated and information was extracted, classified, restructured and represented in the form of one of the proposed models; and design programming where design elements and requirements were listed and detailed. The second phase was the synthetic one where a given design problem was mapped to relevant models; sub-solutions of the two were matched, synthesized and adapted. The third phase included the solution alternatives comparison and evaluation. Within this framework, the sequence needed in the implementation of each of the seven models was:

- **Design precedents were represented in as complete and discrete forms as possible.**
- **Information was extracted and screened.**
- **Information was organized, classified and restructured to fit the model of emphasis, which was one of the seven models presented above.** It could be represented as text, sketch, directed graph, diagram, mathematical calculation, associative images, 3D models, geometric abstractions, 2D geometric model or a list of rules and vocabulary elements.
- **The classified information formed a library of prototypes and tools that was presented as a repertoire for future retrieval and reuse.**
- **Models in the library were mapped to a given design problem and retrieved as needed.**
- **Sub-solutions drawn from the retrieved models could be combined in a bottom-up or a top-down approach to derive new solutions.**
- **Alternatives inspired and assisted by the models were evaluated and refined until a satisfactory solution was attained.**
- **A new design was communicated with a possible help of the techniques suggested by the models' toolkit of previous designers' methods of media employment.**
- **Each of the seven models could be used retrospectively to analyze precedents in the earlier stages of design processing and to evaluate existing designs by comparing them into proposed solutions; and prospectively to develop a new design solution in the later stages.**

The implementation of the design analysis, prototyping and synthesis tasks as suggested by the knowledge-based models shows that they can inform and organize layers of unstructured data that is embedded in previous design products. They can also inform the design synthesis process if the sub-solutions offered by the models can be combined and refined. Furthermore, the design/precedent mapping approach facilitates the matching of the similarity of systems, relations, design processes, and commonality of the components to evaluate designs. It also allows designers to adapt old components to the new situation using derivational replay with a minimum of extra work.

The examples generated by precedent knowledge-based model implementation (see Figure 4 for example) help shed light on some of the advantages of starting a design from the models. These are:

- **The problem of architectural design derivation can be dismantled into more manageable sub-problems.**
- **The models help bring to light classified pieces of design knowledge from expert designer's repertoire.**
- **The trade-offs in the solutions/sub-solutions found in each precedent become possible.**
- **The model representation restructures knowledge in a format not likely to be directly found in books or other resources.**
- **The complexity barrier of innovation can be broken.**
- **The models help to make explicit relationships between various design considerations and aspects.**
- **They provide an opportunity to investigate new ways to represent design knowledge.**
- **Because of the partial representation of precedents, the exchange and combination between elements or layers can generate new unpredictable alternatives.**
- **The models provide new analytical tools that enhance the investigation of design in rational and logical inferences.**
- **They help to externalize parts of the experience of experienced designers that is usually inaccessible to novice designers.** Such an externalization enhances the development of an external memory of designers, which forms a step that encourages the continuous accumulation of experience and knowledge for design practice, education and evaluation purposes.
- **They help bridging analysis conclusions with synthesis guidelines.** Such a bridging is a common weakness for architectural design students.
- **They support representing the information harvested from different local and remote resources as input for design processing.** New strategies for solving design problems and new pluggable sub-solutions may result as output.
- **They add layers of interpretation and concretization that transform the raw information underlying precedent designs into reusable design knowledge base.
In addition to these benefits, the models seem to contribute with an additional interface that enables the translation of abstract knowledge into other workable applications. For example, a grammar-based design model was derived from a set of design precedents that belong to an architectural style and formulated as a theoretical framework for a generative system for that style ([19]). The grammatical model was further translated into a computerized framework for the automatic generation of the style instances [20]. Similarly, a morphology-based model that is extracted from a set of precedent designs collected from the notable works of Andrea Palladio was applied to explain the formal language of Palladian palazzo facades [21]. Furthermore, most of the findings discussed in this paper also support similar ones that resulted from a related study [18].

This precedent-related knowledge-based modeling approach is not without its critics. For example, a major concern is that starting from the seven models may limit the creativity of designers or channel their imagination in narrow scopes. More applications in real design environments to test the benefits and limitations of these models are needed.

6. CONCLUSION

Seven prototypes for knowledge modeling in architectural design are introduced and discussed. Design knowledge aspects and activities as used in architecture are also discussed. Knowledge areas and models are presented within the larger framework of possible knowledge recycling applications. Models for design knowledge processing and recycling are proposed. Their implementation in design studios is discussed and evaluated. Results about their applications emphasize their advantages and suggest venues for their development to overcome their limitations.

7. REFERENCES