RETHINKING CONCEPT DESIGN TOOLS

High-level requirements for concept design tools

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Abstract. In the architecture, engineering, and construction industry there is increasing recognition that design decisions early in the design process create significant project value with relatively small effort. It seems reasonable to investigate what decision support for designers in early phases should look like and what conclusions can be drawn for digital tools that designers employ in those early project phases. This paper introduces and discusses a cohesive set of concept design tool requirements. It explores connections between theoretical approaches in design cognition, experimental implementations, and recent developments in architectural practice responding to very pragmatic problems. The paper communicates results of academic workshops at the Third and Fourth International Conference on Design Computing and Cognition, DCC’08 and DCC’10, respectively, in the context of this ongoing research. At the end, it proposes a systematised model of a desired software tool thus allowing future research to close critical gaps which have hampered progress in concept design tool development.

Keywords: Concept design; requirements; decision support; cognition; software.

1. Introduction

Architectural design activities have been topic of research for considerable time. Since their emergence, digital design tools have been subjects and objects of research, too. Previously, research has focused on specific aspects of digital tools and has produced correspondingly focused results. This paper is part of
an ongoing endeavour to establish a general, yet concise and cohesive, set of requirements for the development of digital concept design tools for the architecture, engineering, construction, and operation (AEC/O) industry within a comprehensive domain framework. The foundation for this research lies in more than two decades of studying and experiencing practices in the AEC/O industry including its supporting software vendors. Since this paper is only the second publication about this research, it is expected to elicit additional discussion, research, and development.

2. Research approach

Because many practitioners and researchers of computer aided design can provide deep insights to this investigation we chose a participatory, discursive approach in the form of a workshop for the crucial part of establishing digital concept design tool requirements. In the following sections we delineate the research domain and establish a set of concept tool requirements based on preceding research. We communicate the results of a workshop about conceptual computational design tools at the Fourth International Conference on Design Computing and Cognition – DCC’10 and proceed with a discussion of the incorporation of these results. At the end, we propose a systematised model of a desired software tool and will conclude with an outline of future research.

3. Research domain

In a previous paper Mueller (2009)1 assembled research results across the domain of computer-supported architectural design and constructed a framework for concept design tool specifications (Figure 1)2.

This framework considers design investigations by all disciplines involved in AEC/O projects throughout the project lifecycle. Adding a third dimension to this domain is the consideration of practice models and related technology. This research aims at pushing higher along the vertical axis, enabling innovative practice models by setting high goals for technology and support digital tools will offer to AEC/O project teams.

Because review of AEC/O industry publications indicates that design decisions early in the design process create high project value with comparatively low amount of effort (CURT 2004) this investigation’s goal is to determine what decision support should be provided to designers in these early phases so that pertinent decisions can be made while the relative effort is low. It is noteworthy, that while the focus of the research is on tools for the early design phases, the overarching concern remains the entire project lifecycle (Kohler et al 1997; Ozel and Kohler 2002). In addition, the design investigations that
need to be undertaken during early design expand in cross-disciplinary col-
aboration as well as in scale spanning from molecular to global, including the
traditional building scale.

Digital tool offerings for the AEC/O industry are numerous. They address
many aspects of the domain; however, none appears to be designed based
on a set of broad aspects and consistent requirements, but focus on specific
features like ease of use or specific types of analyses while neglecting some
essential characteristics. Therefore, we discuss in this paper a coherent set
of requirements that offers opportunity to identify research and development
topics in order to fill any gaps and deliver improved technology for digital
design support, moving the bar higher up the Supporting Technologies axis.

4. Concept design tool requirements

In order to be able to address the increasing complexity of the domain and the
required veracity in project design, we are asking: what qualities are required
in digital concept design tools? A first answer to this question is based on user
perspective, followed by presentation of predecessor studies.
4.1. REQUIREMENTS BASED ON USER PERSPECTIVE

From interviews with practitioners and own experience there arise three fundamental requirements for a concept design tool, with a user’s perspective:

- **Ease of Use**: an important factor for conceptual design tool selection is how non-disruptive they are to the flow of the design process. Tool operation must not disrupt cognitive processes of designing and interfere with ideation. Designers seem to prefer two groups of tools: very simple tools that are limited but highly intuitive, like pencil and paper; and tools that they know well. Interpreting affordance and intuition as expressions of familiarity or experience, one conclusion is that with increasing literacy in digital tools more aspects of them will appear intuitive.
- **Modelling Capabilities**: given ease of use, designers gravitate towards tools they know support generation of the design artefacts that express their formal design intent.
- **Visualization Capabilities**: given ease of use and modelling capabilities, designers prefer tools that let them show their designs in the light and visual expression that align best with the state of their design and highlight the experiential notion they want associated with their designs. A design that cannot be communicated effectively to others is a risk designers seek to avoid.

4.2. REQUIREMENTS BY BERENTE ET AL

In the cognitive sciences the discussion about support of design activities through information technology is over a decade old (Boland 1994 as referenced by Berente et al 2008). Berente et al identify the following principles that need to be resolved by systems capable to support distributed heterogeneous design teams. These principles are relevant to this research, because “Such networks are becoming more prevalent as innovative design activity is increasingly distributed across diverse contexts” (Berente et al 2008):

- **Semantic Coherence** allows design collaborators to use different representations by supporting semantic reconciliation of views.
- **Synchronization** establishes periodically a state of the design by consolidating all changes that have occurred up to that point in time.
- **Representational Flexibility** refers to the need of supporting the variety of representations used by designers, their generation, communication, and purposes.
- **Regenerativity** describes the capability to recreate geometry in order to effectively understand aspects of the design.
- **Temporal Traceability** means the capability to step through a design’s history interactively to understand how the design developed.
- **Spatial Traceability** refers to designers’ need to be able to correlate representations and explore them transverse to their representational planes to understand
4.3. REQUIREMENTS FROM DCC’08 WORKSHOP

In a workshop at the Third International Conference on Design Computing and Cognition – DCC’08, we, together with the other participants, discussed the concept of affordances as approach to defining conceptual design tool requirements. The discussion generated the following list with references to Berente et al:

- **Multiplicity** means support of many designers and many data-flows with various workflows for each designer. It affords method and tool selection based on the design problem. It supports multiplicity of opinions in a community for knowledge exchange.
- **Flexibility** as expansion of Representational Flexibility describes support of changing interface modes, for example 2D, 3D, sketching, and haptic devices; flexibility in choice of representational modes, including mathematical representation of geometry; flexibility in workflows; extensibility as additional tool flexibility.
- **Simultaneity** allows for concurrent models with Semantic Coherence; pursuit of simultaneous, parallel paths of design; side-by-side investigations, for example of parameter set history, relationships, and solution spaces. It includes Synchronization and aspects of Temporal and Spatial Traceability.
- **Representation of the Environment**, like climate, topography, and context.
- **Semantics** as expression of semantic information with Semantic Coherence.
- **Entity Identity** as consistent, non-redundant objects with multiple, unambiguously linked representations.
- **Emergence** as possibility to change the semantics of a representation in order to let it play a different role in the design.
- **Entity Linkages** for dependency relationships between entities or elements including aspects of Temporal and Spatial Traceability.
- Representation of **Abstract Objects** and Phenomena, like ideas, culture, experience, notions, associations, and other non-building information.
- **Support of Diagramming** and Diagrams.

Overlaps between sets of requirements can be at least partially explained by the longevity of the discourse. Some themes have been in discussion for almost one and a half decades. As confirmation of their relevance it is to be expected that themes recur in subsequent examinations of the issue.
5. Unified set of concept tool criteria

5.1. FIRST CRITERIA SET

In order to unify the criteria in support of a consistent discourse, for this research the following set of requirements was considered meaningful:

- Ease of use.
- Modelling capabilities.
- Visualization capabilities.
- Multiplicity.
- Flexibility in interfaces and representations including diagram support.
- Simultaneity including synchronization, temporal and spatial traceability.
- Environment providing full environmental context for design activities.
- Semantics expressing semantic information with semantic coherence.
- Entity linkages including enabling of temporal and spatial traceability.
- Abstract objects.
- Diagram support.
- Regenerativity as capability to reconstruct model data for understanding.
- History from Temporal Traceability, perpendicular to simultaneity.
- Design Space Exploration as consequence of the domain space, as the capability to browse and learn from previous designs or design alternatives.

5.2. CRITERIA SET RATING

In continuation of this discursive investigation, we conducted a workshop at DCC’10. We provided this set of criteria with descriptions to workshop participants. They conducted a survey to establish a tentative ranking of the proposed concept design tool requirements. Participants were asked to rate importance of requirements with 1 for most and 5 for least important. Grading was based on an inverse point system with 5 for most important and 1 for least important (Table 1). According to the survey, requirements in order of importance are: Semantics, Flexibility, Modelling Capabilities, Visualization Capabilities, History and Design Space Exploration, Environment, and Abstract Objects.

In the discussion changes of labels and confluences of some of the requirements were suggested, as well as perceived shortcomings pointed out:

- Visualization Capabilities to Externalization or Representation to emphasize reduction of focus on visual senses.
- In terms of geometric form, visualization capabilities and modelling capabilities are tightly linked.
- Modelling Capabilities should include “automation from abstract rules”.

• Diagram Support and Abstract Objects have common aspects.
• Environment and Abstract Objects have common aspects.
• Attributes like Semantics should be able to be “switched ON and OFF”.
• Regenerativity was misunderstood as “generative modelling”.
• Participants missed support of ambiguity.

Table 1: Concept design tool requirements survey from DCC’10 workshop.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Multiplicity</td>
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<td></td>
<td>3</td>
<td></td>
<td>2.67</td>
</tr>
<tr>
<td>Flexibility</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
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</tr>
<tr>
<td>Simultaneity</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Environment</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td></td>
<td>5.58</td>
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<tr>
<td>Semantics</td>
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<td>1</td>
<td>5</td>
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<td></td>
<td></td>
<td></td>
<td>5</td>
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<tr>
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<td></td>
<td></td>
<td>1.67</td>
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<tr>
<td>(Re)generativity</td>
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<td></td>
<td></td>
<td>1</td>
<td>5</td>
<td>5.00</td>
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<tr>
<td>History and Design Space Exploration</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
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<td>6.67</td>
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</tbody>
</table>

It should be mentioned that the rating of the Requirements represents, other than their importance, also their absence in present software tools. Characteristics that are already available, like geometry representation, for example, are not mentioned, neither high rated even if they are obviously very important.

6. Discussion

These requirements are quite heterogeneous in character and do not stand at the same level of generality. For example, Modelling Capabilities include Entity Linkages and Abstract Objects, while Flexibility may refer to all three: Modelling Capabilities, Representation Capabilities and Semantics. Some of the requirements represent desired modes of work within the design medium, e.g. Diagram Support, while others refer to interactions within and between these modes, like Flexibility and Simultaneity, or to interactions with sources.
external to any one particular software, as does Design Space Exploration. Ambiguity arises from Flexibility of Semantics and Representation Capabilities. Finally Ease of Use is ubiquitous to all of them and depends a lot on the way of interaction with the digital design object; it is a function of the Interaction Medium. This is why the characteristics of a desired concept design tool were schematized, as seen in Figure 2. All mentioned requirements can be found at different places on this diagram, sometimes covering whole axes or regions.

In this proposed model, four major aspects for a concept design tool are identified: Semantics, Morphogenesis (Form Creation), Interaction Medium, Representation. The idea is that there is a continuum of states on each of these axes and a good concept-design tool should offer them all in order to support creativity and architecture well. Examples of combinations from different states on each axis are:

- Directly creating geometry by sketching while the system automatically creates rules from the sketch.
- Generating geometry by scripting.
• Creating architectural objects with semantics through sketching.
• Describing architectural objects with semantics through building information modelling.

These examples represent various modes of work or workflow. A designer should be able to switch back and forth from one state to the other on each axis, ensuring Multiplicity, Flexibility, Entity Identity and Entity Emergence. History can be assured as a function of time. The other, outer, arrows represent characteristics which are linked to the software but are not contained in it and show relations to other software, data or actors in the design process. Studying this scheme, the requirements can easily find their place and the gaps in the present software tools become evident.

7. Conclusions

The sets of requirements described in this paper demonstrate the challenge a high-level approach to digital tool design poses. At each iteration, the criteria set were changing due to lack of agreement about terminology, inconsistent categorical levels in the sources and in discussions, or disagreement in importance of the criteria. Considering the large domain space that a successful AEC/O concept design tool needs to be able to cover, even when focusing only on the initial project stages, this result comes as no surprise.

That is why we propose a systematic schematization of a concept design tool, comprising four major aspects and additional features linking a particular tool to other actors, data, software or context. Even though this is a first publication of this scheme and it would necessarily undergo some alterations suggested by the CAAD community, the idea is that a given piece of software could be mapped to this scheme and examined against its aspects and features, in order to determine what is lacking and develop it according to the rated priorities of requirements.

Continuation of this research will attempt to pursue the following investigations: theoretical testing of the validity of the concept design tool model, determination of the next level of detail to these high level goals, and construction of a wide spread of use cases that occupy various locations in the model.

Endnotes

1. Please refer to this paper (Mueller 2009) for more detail about the domain space and an extensive review of relevant, substantiating references.
2. Figure 1 has been modified for this paper. A horizontal dashed line representing the estimate of the current state of practice has been introduced on the vertical axis. The Discipline Axis has been renamed Design Investigation and additional markers identify
activities mentioned in the 2009 paper but not shown in the preceding version of this figure.
3. Detailed explanations of the items on the axes are in Mueller 2009.

References
CURT: 2004, Collaboration, integrated information, and the project lifecycle in building design, construction and operation (CURT Whitepaper 1202), The Construction Users Roundtable (CURT), Cincinnati, OH.