Towards a Better Understanding of the Case-Based Reasoning Paradigm in Architectural Education and Design

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This paper presents the results of a detailed analysis of systems and concepts which make use of case-based reasoning, a paradigm from artificial intelligence (AI). The analysis focuses on the use of this paradigm in the support of design and education processes, so-called "case-based design aids". The research aims to discover problem areas in current approaches and identify potential areas for further research with a view to improving the practical suitability of existing systems, which offer promising potential yet are rarely implemented in practice.

***Keywords**: Architectural Precedents; Databases; Architectural Education and Design; Case-Based Reasoning.*

Introduction

This paper presents the results of a detailed analysis of systems and concepts which make use of Case-Based Reasoning (CBR) in architectural design and education. A primary motivation is the fact that many existing approaches, although both promising and useful, are rarely employed in architectural practice or in the university education of architectural students.

Following Oxman and Heylighen's statement that "in order to strengthen the field of case-based design it appears that additional theoretical efforts are needed," (Oxman and Heylighen, 2001, p. 336) a critical review of systems and concepts making use of the Case-based Reasoning paradigm in architectural education and design was performed in order to identify reasons for this limited success. The findings also provide indications as to why enthusiasm for the use of CBR in architecture is waning in the international research community.

The results of a parallel investigation of an interdisciplinary teaching project undertaken at the Bauhaus-Universität Weimar are used to illustrate insights gained during the research project. The results corroborate strongly with the overall findings of the research project.

CBR in Design

Based on the notion that architects frequently make use of existing designs, i.e. architectural precedents, to solve current design problems, a number of concepts and systems for supporting this strategy have been developed intensively since the early 1990s (Heylighen, 2000).

Such systems are based upon the KI-concept of Case-Based Reasoning (CBR), a paradigm for the reutilisation of past experiences in solving new problems. CBR describes both a conceptual method for computer systems as well as a model of the cognitive processes involved in the solution of problems (Kolodner, 1991). These are based upon Roger Schank's theory of "Dy-

namic Memory" and studies of analogical reasoning (Aamodt & Plaza, 1994). Schank developed a theory of learning and reminding based on the retention of experience in a dynamic, evolving memory structure (Aamodt & Plaza, 1994). CBR can be seen as a form of analogue reasoning (Kolodner, 1993; Aamodt & Plaza, 1994; Heylighen, 2000) and draws upon the notion of inter-domain analogies (Aamodt & Plaza, 1994). In the field of CBR in design, the term Case-based Design Systems (CBD-Systems) has become established.

A primary argument for the use of CBR-systems in architectural design is the recognition that architecture in general is a "weak theory" domain and that design knowledge and design experience are closely interwoven.

Design problems are typically ill-defined (Maher, Balachandran et al., 1995; Lawson, 1999; Heylighen, 2000, a. o.). Knowledge applied in the design process is difficult to generalise or define in rules and models (Kolodner, 1993; Flemming, 1994; Maher, Balachandran et al., 1995; Heylighen, 2000).

The focus of this research is systems that support designers in their work process – design aiding systems – in contrast to design automation systems (Maher, Balachandran et al., 1995). "The idea in case-based decision aiding is that the computer augments the person's memory by providing cases (analogies) for a person to use in solving a problem." (Kolodner, 1991, p. 53)

CBR in architectural education – a teaching project

An interdisciplinary teaching project undertaken at the Bauhaus-Universitat Weimar deals with the analyses of both contemporary as well as historic approaches to housing. The participating students research and analyse a defined number of housing projects. Characteristic texts and supporting images from selected projects are then entered into a database via a web front-end.

A predefined list of 52 criteria in 8 main categories helped give focus to the analysis. The main categories were building typology, access typology, housing typology, construction, façade, private outdoor space, interior space and use-pattern. The term "criteria" is used as a descriptive label for the properties of architectural projects. Projects selected for the database must include a minimum of 2 such properties to be considered an "innovative design solution". The criteria not only help the students clarify their analyses but also offer a means of structuring the database as well as a means of searching the database. Further indices such as "architect", "geographic location", "year of completion" and "project name" store other factual information.

The database currently contains over 600 housing projects incl. 1140 analysed criteria and is frequently and enthusiastically used by students and professionals alike.

Educational Approach – Use of the database

The project is used in architectural studies by teaching staff and students in three main ways: Students taking part in seminars learn to investigate and analyse housing projects guided by the concepts behind the criteria, and expand their knowledge and analytical skills in the process. Secondly, the database is used as a resource of reference objects (precedents). Teachers use them to illustrate concepts or communicate in consultations for housing design projects. Students learn how to better understand their own design intentions. In the conceptual phase of design, the reference housing projects also serve as a source of inspiration and support analogical reasoning.

Kolodner (1991) differentiates between two kinds of use of case-based reasoning: a problem-solving style and an interpretive style: "In general, the interpretive style of case-based reasoning is useful for situation classification, the evaluation of a solution, argumentation, the justification of a solution, interpretation, or plan; …"(Kolodner, 1991, p. 55)

The architectural projects stored in the database and the innovative solutions they contain are used primarily interpretively. Reasons for that will be explained later in more detail in the section "Case contents – entity and event".

Although the housing database is primarily a teaching and educational project, it clearly exhibits

aspects of CBD in architectural design. In fact, the parallels between our project and the analysed CBD-systems are so conspicuous that they can be used to illustrate the findings of the overall research.

Analysing the teaching project

Two essential characteristics of this database project exhibit aspects that strongly emphasise the findings from the analysis of the CBD systems and concepts.

The first area concerns the selection and assessment of the housing projects. The database contains only projects where at least two of its properties are deemed to be innovative, or where a minimum of 2 innovative solutions for sub-aspects are to be found. The projects put forward and analysed by students are evaluated by a knowledgeable member of the academic staff who confirms the innovative nature of the individual aspects and gives permission for the project details to be added to the database.

The second area is the issue of database content, its form of representation and how it is indexed, i.e. the way in which database searches are supported.

Although the research project concentrates on case-based design aiding systems, the analysis takes into consideration both ways of using the CBR-paradigm in architecture (see "CBR in Design") as the problems faced, such as representation, indexing and retrieval, are similar.

An analysis of CBD concepts and systems

Basis of the analysis

The results of an extensive study of seven CBD systems (Archi-II, CADRE, FABEL, IDIOM, PRECEDENTS, SEED and WEBPAD) undertaken by Heylighen (Heylighen, 2000; Heylighen and Neuckermans, 2001) serve as a basis for the further critical analyses focused upon in this paper. The selection of the seven systems reflects the spectrum of different approaches and their potential to illustrate the wide variety of directions taken in CBD research in the architectural environment.

The outcome of this extensive research undertaking regarding the discovered problems of current systems can be summarised as follows:

- Abstraction of content
- Danger stemming from the view of the design process as a mere problem-solving process
- Lack of dynamics
- Problem of CBD in design education: Fear of design fixation and prejudices
- Problem of retrieving relevant cases

Focus of the analysis

The focus of our own analysis lay in the observation of concrete situations in the utilisation of the CBR-paradigm in architectural education and design: the content of cases, their representation, indexing and the search strategies supported.

This extended analysis of CBD systems, which examined further systems as well as extended concepts for individual problem areas, confirmed the results of the previous study.

The analysis revealed two central problem areas when employing the CBR-paradigm in architecture:

Findings of the analysis

Case contents – entity and events

In order to solve new problems based upon past experience, it is necessary not only to remember the problem but also its context, the solution and the results of the strategy or solution employed. Was the strategy actually successful? Did the solution resolve the original intention? Did it have undesirable side effects? Case-Based Design aiding systems are intended to support the user with exactly this information. Put simply, it enables one to learn from and benefit from the experience of others.

According to the theory behind CBR, a case consists of three components (Kolodner, 1991):

- Description of the problem, situation of the problem,
- Description of the solution
- The outcome, result.

However, an analysis of existing concepts and systems showed that, in contrast to the above, a

more accurate description of the current databases would be an indexed collection of concrete cases, attributed with a set of characteristic properties. "In general, cases document buildings, i.e. design products." (Heylighen, Martin et al., 2004) One can understand the difference between a case in the sense of CBR and the cases used by the analysed systems by comparing entity with event. Entity as the description of a finished design product in contrast to event as the meaningful integrated description of a real experience containing all three above mentioned ingredients.

Analyzed systems do neither contain meaningful problem descriptions nor evaluation of the architectural solution: the outcome.

In order to be able to successfully support a problem-solving style of working, both of these components are necessary components of a case description.

Exactly how collections of indexed images can fulfil part of the role of these components is a further question, not discussed in detail here.

Evaluation of architectural precedents

An important aspect of the conception of CBR-based systems is the question of which cases should be part of the data collection and how they should be represented (see for instance Schmitt, 1995).

It should be noted that most of the systems analysed are based upon "second-hand" project information. "Second-hand" means the projects are not entered into the database by the designers themselves but by others. This also applies to our teaching project. This has primarily practical reasons, though these are not the only reasons.

In addition to the enormous effort involved in preparing and assessing and entering the collected data, a second problem also exists: "… designers tend to sense a psychological threshold to share their ideas and insights with others." (Heylighen, Casaer et al., 2006, p. 32) Even if designers are willing to share the secret of their success, they are unlikely to want to communicate their failures, side-effects and what did not work. As a result the subsequent analysis and evaluation of cases to be entered by a third party is indispensable.

The question of how to integrate the assessment of architectural projects or particular exemplary solutions to be entered is rarely or insufficiently considered in the literature on CBD.

A notable exception is the CBD-system Archie-II: the assessment of architectural solutions in the form of assessments by the different stakeholders in a project is integrated as a source of valuable information (Domeshek, Kolodner et al., 1994).

The question of how best to integrate evaluative aspects in CBD-systems is ultimately connected with the question of how to best fulfil the prevalent demand of integrating only those projects of an "outstanding architectural quality" (Goldtschmidt, 1995; Schmitt, 1995; Donath, 2003; Donath & Stamm-Teske, 2003) into the database.

From our current point of view, this intention can only be legitimated when, in contrast to the actual theory of CBR, cases represent full projects (entities) and the data is not attributed any kind of evaluative properties. However, this approach might be useful in some situations during the design process, it neglects the potential offered by CBR in architectural design and particularly architectural education of storing and conveying both the positive as well as the negative experiences of others.

Search and Retrieval

To solve problems based on experiences made in the past it is necessary to recall a suitable situation or experience from the past in the given (new) situation. One can understand CBR-based design aiding systems as digital collections of past experiences. To use these systems successfully it is indispensable to retain the right case at the right time.

In order to improve the search mechanisms of current systems, it is necessary to consider both styles of using CBR put forward by Kolodner (Kolodner, 1991). A particular problem arises in the support of the problem-solving style of using CBR:

To successfully employ case-based design aiding systems for solving given design tasks (in the problem-solving style), it is necessary to be able to clearly define and categorise the problem at hand. In practice, this is difficult to achieve, particularly in the early phases of the design process. Architectural design is a solution-oriented process rather than a problem-oriented process (Lawson, 1999).

Also, in many cases, and especially for novices, it is not easy to immediately recognise the design problem (Heylighen, 2000). The designer is not yet sure what he or she is actually looking for, i.e. what keywords to use to retrieve suitable cases from a database. In our example project, this problem is not well resolved and relies on the experience of the teaching staff to point students in the right directions, so that they may gather reference solutions to their problems.

However, once a problem has been formulated and identified, the system should then be able to assist in finding appropriate reference solutions, i.e. there is a need for sufficient problem-descriptions to match against.

Future research areas

CBD in teaching

Schank coined the phrase case-based teaching (Schank, 1999; Schank, 2005). In essence this means learning from previous experience, and this can be supported through the simulation of real problem-solving situations. It enables students "… to do things in a realistic context that relates to things that they will actually do later in life" (Schank, 1999, p. 177). Learning from one's mistakes (expectation-failure) is an integral part of this.

The primary 'educational device' in architectural education around the world is the design studio, and actively supports learning from experience and learning by doing. A limitation is that not all conditions an architect might face in practice can be 'simulated': "… one of the perennial problems here is that so much of the real professional world is very difficult to replicate in the college or university. In particular there is usually an absence of clients with real problems, doubts, budgets and time constraints." (Lawson, 1999, p. 7) Case-based design aiding systems containing full descriptions of problems, solutions and results (see the section "Case contents – entity and events") offer a valuable opportunity to assist students and beginners in learning and designing. The following questions need to be clarified:

CBD and a means of assessing architectural solutions

Experiencing Architecture. How can an evaluative aspect be integrated into systems whose cases consist of completed and existing design projects entered by third persons, so that the manual and computer-assisted assessment of architectural projects can be supported?

Experiencing the making of Architecture. Approaches exist, based upon the concept of case studies, where several cases are generated in parallel during the design process. In such cases, the success of the selected architectural 'solution' (the case) must be evaluated and added to the case.

In both of the above, a central question is by whom and according to which criteria should successful solutions be assessed, analysed, evaluated and entered into the case database? The architect? Those involved in the building? The client? The users? Students? Teachers? Everyone?

A further step towards supporting the problem-solving style of using CBR would be to integrate the possibility of searching for particular solutions not just by problem but also by qualities (for example: solutions for staircases for narrow spaces, ecologically favourable, independent of cost)

CBD and how to best support search strategies for solving concrete problems

What means do architects employ conventionally when looking for solutions to tasks or sub-problems thereof that they have identified? The answer to this question can provide insights into how to improve existing search and retrieval mechanisms.

Concluding Remarks

Finding satisfactory answers to the questions raised above would be a major step towards achieving a better understanding of how to successfully use the CBR-paradigm in the field of architectural education and design.

As Shank noted, in order to increase acceptance of CBR-systems, it is necessary to convey to potential users the existence and availability of such systems and the potential they offer, for instance by testing prototype systems. When done so, he notes "Experts are more willing to talk about mistakes if it helps avoid them in future, and they want to make much larger databases of war stories available to their learners." (Schank, 2005, p. 262) The database project discussed here can be seen as one possible approach, even when its development as a powerful case-based design aiding system is still in its infancy.

This research is part of a more comprehensive research undertaking aimed at improving the acceptance and practical suitability of design support systems using the CBR-paradigm. The problem area discussed in this paper represents a narrowed-down investigation aimed at supporting housing design and education.

References

Aamodt, A. & Plaza, E.: 1994, Case-Based Reasoning: Foundational issues, Methodological Variations, and System Approaches, AICom - Artificial Intelligence Communications, IOS Press, 7(1), pp. 39-59.

Domeshek, E. A., Kolodner, J. L., et al.: 1994, The design of a tool kit for case-based design aids, in Artificial Intelligence in Design ´94, J. Gero, F.,Sudweeks, (eds.) Dordrecht, The Netherlands, Kluwer Academic Publishers, pp. 109-126.

Donath, D.: 2003, BBR Forschungsantrag "Innovative Wohnungsbauprojekte und bewährtes Wohnen - Falldatenbank" - unpublished, Weimar: 5.

Donath, D. & Stamm-Teske, W.: 2003, http://www.uni-weimar.de/wohnungsbauaspekte, (last accessed: 02.06. 2006)

Flemming, U.: 1994, Artificial Intelligenz and design: a mid-term review, in Knowledge-based computer-aided architectural design, Carrara, Gianfranco,Kalay, Yehuda E. (eds.) Amsterdam u.a., Elsevier, pp. 1-24.

Goldtschmidt, G.: 1995, Visual Displays for design: Imagery, analogy and databases of visual images, in Visual Databases in Architecture, in A. Koutamanis, Alexander, H. Timmermans, et al (eds.) Aldershot, Avebury, pp. 53-74.

Heylighen, A.: 2000, In case of architectural design - Critique and praise of Case-Based Design in architecture, Faculteit Toegepaste Wetenschappen, Department Architectuur, Stedenbouw en Ruimtelijke Ordening, Leuven, Belgien, Katholieke Universiteit Leuven: p. 232.

Heylighen, A., Casaer, M., et al.: 2006, UnaWare: supporting tacit design knowledge exchange, Int. J. Web Based Communities, 2(1), pp. 31-44.

Heylighen, A., Martin, W. M., et al.: 2004, From repository to resource. Exchanging stories of and for architectural practice, The Journal of Design Research, 01.

Heylighen, A. & Neuckermans, H.: 2001, A case base of Case-Based Design tools for architecture, Compter-Aided Design, 33, pp. 1111-1122.

Kolodner, J. L.: 1991, Improving Human Decision Making through Case-Based Decision Aiding, AI Magazine, 12(2), pp. 52-68.

Kolodner, J. L.: 1993, Case-Based Reasoning, San Mateo, Morgan Kaufman Publishers, Inc.

Lawson, B.: 1999, How Designers Think, Oxford, Architectural Press.

Maher, M. L., Balachandran, B. M., et al.: 1995, Case-based Reasoning in Design, Mahwah, Lawrence Erlbaum Associates.

Schank, R. C.: 1999, Dynamic Memory Revisited, Cambridge, Cambridge Univ. Press.

Schank, R. C.: 2005, Lessons in Learning, e-Learning, and Training, San Fancisco, John Wiley & Sons, Inc., Pfeiffer.

Schmitt, G. N.: 1995, Architectura cum machina - interaction with architectural cases in a virtual design environment, in Visual Databases in Architecture, in A. Koutamanis, H.Timmermans, et al (eds.) Aldershot, Avebury, pp. 113-128.