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Communicating Concepts for Shared Understanding: A Multi-Agent Approach

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Abstract

Capturing and sharing design concepts is necessary if we want to support the design process by means of Information & Communication Technology (ICT). Standardized concepts are important for support at the end of the design process when designs need to conform to set standards and norms, and in order to enable communication, but are less useful in the early design stages. We propose an approach that takes into account a more developmental attitude that will be better suited for design support and the sharing of design concepts. In this approach, design concepts are formalised by means of a technology called concept modelling Capturing and exchange of concepts are based on a multi-agent approach. The whole of concepts that are used in a domain or for a design task can be considered a design ontology. In this paper we outline the motivations for the research, outline the basic approach in the research work, and identify the major challenges and research problems that need to be tackled.

Introduction

The AVOCAAD 2003 Conference focuses on local values in a networked design world. This research paper outlines an approach for concept sharing that takes into account local and personal differences in concepts that design agents may have. Such design agents may be human or ICT-based. A design agent is any participant in the design process who or which has a mandate to be involved with the design. We are thus looking at professionals and organisations that are involved in design, and not for example at the general public or even future (or current) inhabitants of the built environment. These categories are likely to have different information needs and requirements.
Sharing of design concepts has a number of purposes:

- To communicate design ideas among design participants to reach shared understanding.
- To ensure compliance with a set of norms or standards.
- To translate from the preliminary design to the concept design, final design, and shop drawings.

In our research, we are particularly interested in the early stages of design. Throughout the design process, concepts evolve as the design develops. In the early phases, when many issues have yet to be resolved, the architect usually focuses on a limited number of aspects that are gradually developed (Darke 1979). This allows the architect to leave many aspects of the design unresolved and hence open for the possibility of new and unexpected solutions. In such cases, where the architect aims for open-endedness or ambiguity, standardization efforts such as pursued by the International Alliance for Interoperability on the Industry Foundation Classes (IFC's), have limited applicability.

Standardisation efforts in the construction industry generally limit their scope to technically resolvable concepts such as building products and normalised processes in order to be broadly accepted. This kind of standards requires the architect to either commit too early to a comprehensive solution (blocking otherwise possible solutions), to tolerate defaults (which may lead to fixation), or to keep over-ruling defaults (which is distracting). It is an approach that omits formalisation of short-lived and tentative concepts such as those in architectural theory (see Kruft 1994 for an overview until the mid-twentieth century; Nesbitt 1996 for an overview in the late twentieth century) and of individual architects (e.g. Eisenman 1987; 1999, Lynn 1998; 1999, van Berkel 1999; 2002, Habraken 1986; 1998, to name a few). Such concepts are 'problematic' in the sense that they escape uniform and standardised formulations, not only in architectural theory itself (compare for example the debate about the concept 'type' in the writings of Argan 1963; Colquhoun 1967; Rossi 1982, pp. 40-41; Westfall and van Pelt 1991, pp. 140-144), but also in a design methodological perspective (in the case of the concept 'type,' e.g., Heath 1984, pp. 121, 133; Habraken 1985, pp. 23-36; Rowe 1987, pp. 85-88, 190-194; Schön 1988). Notwithstanding these complications, we have to point out that such concepts form a substantial body of literature in architectural writing. They are part of the rationale of designs and design decisions, in particular in the early phases of design, and therefore cannot be ignored. We thus need to find a way to formalise design concepts without loosing too much versatility. A comprehensive collection of concepts that apply to a particular field is termed *ontology*. We are thus concerned in our work with the question how evolving and different ontologies can be supported in the design process and how various agents can communicate about these ontologies.

In this paper we propose both an information modelling approach and a communication technique to automate some part of the information exchange process when concepts are shared between agents. The information modelling approach is termed *concept modelling*. The information exchange process is based on multi-agents communication, formalized in protocols. The paper presents the underlying ideas and aims to indicate their potential.

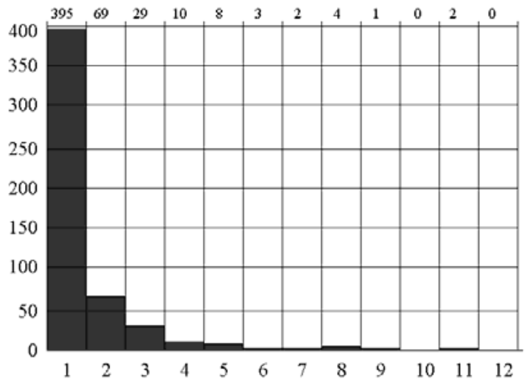
Motivation part 1: Words case study

The diversity of design outcomes for a particular task is a well-observed and documented phenomenon, for example in design competitions (Jong and Mattie 1994). This applies to both the design outcome as a whole (general appearance of the building or urban plan), as well as to its parts (layout, interior composition, doors, windows, etc.) Notwithstanding this diversity, there is also a great deal of similarity, both in the outcome and in the underlying process. Most buildings share to a great extend similar or standardised products; the variation in this case occurs in the outcome of a different choice in the available building components. Design processes also show many similarities, and can be said to consist of a number of typical activities and products (Roozenburg and Eekels 1995, pp. 87-90); the variation here occurs as an outcome of contingencies during the design process, and different design strategies and design tactics (Lawson 1997, pp. 185-226).

In order to get a better understanding of the use of concepts in the early phases of design, we have examined the use of words in a small design task. The task was to design for a large warehouse an Internet lounge that would accommodate a limited number of people. Special focus was to be on the furniture that would integrate resting and surfing the Internet, as well as the general layout of this furniture in the lounge-setting (Segers 2002). Twelve people participated in the design task, most of whom were students. The set time for the design task was 30 minutes. At the end of the task, participants were required to provide a concept design for the Internet lounge. The design process, therefore, although a short one, would likely include at least some divergent activity of idea generation, and some convergent activity to produce a concept design proposal.

We collected all sheets that were produced during the design process and counted the words that were annotated on these sheets. We look at words because they provide a record of the additional thoughts by the designer on what matters in the design task. The number of words ranged from 23 to 77 words (ignoring duplicate use of words). In total, 523 different words were used as annotations. The variety between the participants which words were used was particularly striking. Although all participants had received the same text for the brief, most of the annotations were exclusively used by one designer only, and not by the others (see Table 1).

Table 1: Number of words that are shared between participants. 395 Words are used by one participant; 69 words are shared by two participants; 29 words are used by three participants; and so forth.



The case study indicates that in the early phase of the design process, each designer pursues the design task differently. This is not only evident through the drawings, but also by the words that used in the design process. Based on the brief, the participants discuss the same concepts such as chair, lounge, café, and so forth, but they have quite different associations what these concepts should encompass.

Motivation part 2: AVOCAAD case study

In order to take a closer look at design concepts, we set up a small questionnaire for the AVOCAAD 2003 Conference. It was a one page A4, which had four questions, dealing with the understanding of a door:

1. List relevant aspects about a door, and give for each aspect an example of a typical value for that aspect.
2. Give a short informal textual definition of a door.
3. Sketch a standard door.
4. Sketch a remarkable door.

The questionnaire was handed out during the conference and returned the same day by eight people. The time to fill in the questionnaire varied, but probably took no more than twenty minutes. The short time ensured that the participants did not deliberate long on the answers; this may lead to a closer representation how early design concepts are formulated.

Enumeration task: aspects of a door

The number of aspects that were enumerated for a door, ranged from 3 to 14. When we try to accumulate them, we find that in many cases different terms denote the same aspect, such as:

- "Direction," "functional characteristics," "opening," and "hinge place" were all used to discuss which way the door opens.
- "Door materials" and "surface material" denote the material of the door as a whole.
- "Type" and "functional type" list kinds of doors.
- "Hardware," "equipment," "way to open," and "attachment to wall" describe the additional pieces that are required for a door.

Grouping such terms is based either on similar meaning between two terms, derived from the typical values that such terms can take, or both (Table 2).

Table 2: List of aspects for a door

Aspect	Frequency	Typical value
Width	[8]	800, 900 mm, 09
Height	5	2000, 2100 mm, 21, 2.1 m
Depth	1	180 mm
Direction/functional characteristics/opening/hinge place	4	In or outside opening? Inwards opening left-hinged left-right. At the side.
Touch	1	Metallic
Material	3	Glass, wood, metal, etc
Door materials/surface material	2	Wood, glass, oak panel, horizontal, 130 mm wide sheets
Frame materials/frame material & color	2	Wood, aluminum, wood, white (colour code ###)
Frame thickness	1	130 mm/70 mm
Sill-material	1	wood
Type/functional type	3	Sliding door, automatic door, hinged, sliding, folding, rotating, revolving
Locked/lockable	1	No

Colour/treatment & colour	3	White, any
Hardware/equipment/way to open/attachment to wall	4	Hinges, handles, etc. (separate components?) hinges, handles, locks, etc. with their own detail facts/doorknob
Accessibility	1	Closed/locked
Flow capacity	1	1 person
Link type/“type”/function	3	Office-corridor, exterior/interior/wooden frame/metal frame, inside door/outside door, insulated or not
Fire safety/fire class	2	Low, POAGO (fire-door class A, 60 minutes resistance)
Acoustic	1	Low
Sound	1	Beep beep boom
Visibility/transparency	3	Semi-transparent/yes-no/from 0-100
Function	1	Entrance/shut off
Format	1	Standard valves
Connections with wall	1	Draught-free etc.
Constructive	1	Details of connections
Style	1	Classical, modern, art nouveau, etc.
Scale	1	Residential, monumental
Weight	1	Not so heavy

We can also see regionally different expressions for the values that the aspects can take, such as for example the expression “09” for the width of a door, and “21” for the height of a door. Both basically mean 90 cm width and 210 cm height, but as they imply less precision than 900 mm and 2100 mm, a smaller/wider and lower/higher door are also allowed in the design.

Another thing to note is the wide range in the use of official and informal terms to quantify or characterise aspects of doors. For example, the fire class of a door is characterised as “low” – which is quite informal, and “POAGO,” denoting a “fire-door class A, 60 minutes resistance” as annotated in the questionnaire – which is quite official.

Definition task: informal textual definition

Given the short time to answer the questionnaire, it is not surprising that each definition provided by the participants is quite different from others (Table 3).

Table 3: Definitions of doors

A.	A door is an opening in a wall (a device in a wall), which enables you to go through this wall. A door can be opened and closed.
B.	Useful equipment to enter or leave a room, to preserve privacy, to access an area dedicated to other or similar functions.
C.	A door is a building element that determines (constrains) the activities of entering and exiting a space. Its geometric and material properties relate its interfacing with adjacent elements (esp. walls) and to its ergonomic functioning & performance. In general this interfacing is flexible and straightforward. More intricate are operational aspects that derive from the activities and spaces that are linked by the door. These also relate to ergonomy but also to other functional aspects, generally of a dynamic nature.
D.	(1) An opening in a wall; (2) A through-walkable opening in vertical wall-like structure.
E.	A door arranges access through a connection between distinct situations.
F.	A door is a constructive element, able to close off a room or connection between 2 spaces.
G.	A door is used to physically close an opening of a defined space. This opening is meant for people to enter and exit the space. A door is not necessarily a visual barrier. Doors are made according to a large variety of styles.

H.	Door is the place of connection of different space. Sometime the door is close and we feel that we are safe or… not.

In all cases, the concept door is linked to other concepts, the most notable of which are spaces (between which the door connects) and walls (in which doors are mounted). In general, one might say, there is consensus about the high level meaning of a door. However, if we may interpret the definition as an initial statement what the significant features of a door are, then we note a rather large scope in the way a door is perceived.

Normalisation task: sketch of standard door

The question for a sketch for a standard door yielded eight very similar drawings of a door (Figure 1). Differences occur in the opening direction of the door, and the framing style. Where provided, the plan representation is a fairly schematic plan drawing but with an emphasis on adding handles. In one case, an additional standard door for a particular region was provided.

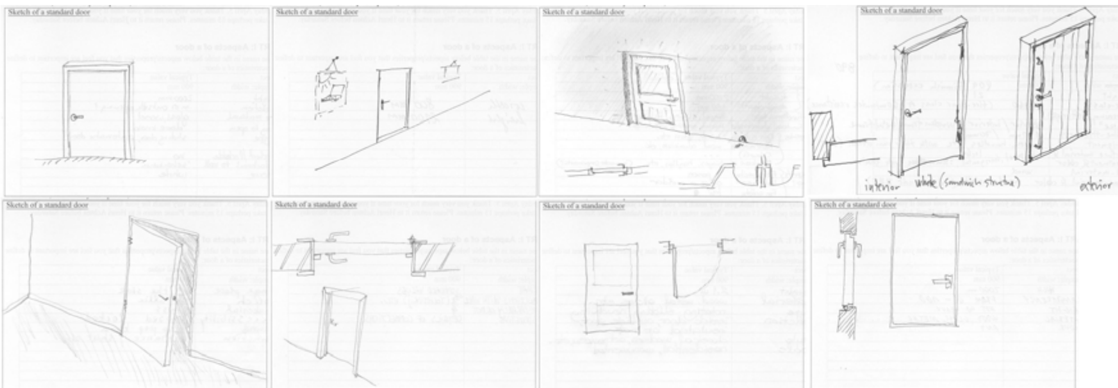


Figure 1: 8 Standard doors as drawn in the questionnaire.

There is, to conclude, a high degree of consensus what a standard door looks like. Because of this, it is very sensible to conclude that a standard definition of a door is feasible for design support. In order to determine the scope of such a standard definition, we need also to determine what the scope of appearance for doors is.

Extension task: sketch of a remarkable door

The question to sketch a remarkable door yielded eight quite different doors (Figure 2).

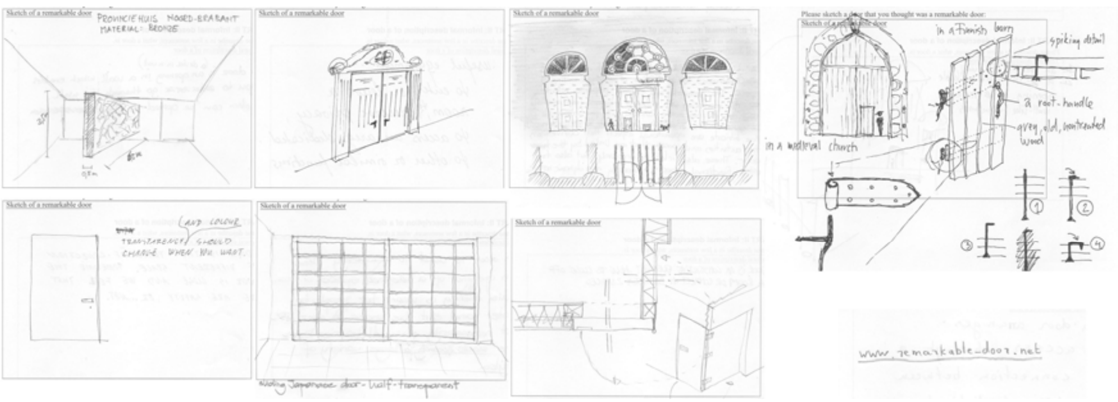


Figure 2: 8 Remarkable doors as drawn in the questionnaire.

The purpose to ask for a remarkable door, is to provide contrast with the standard door. One might propose, that the standard door is what the designer has in mind when there is casual reference to the concept of “door.” The remarkable door however, in all cases is the product of a design effort, and thus the solution to the door *conceived as a design problem*.

Results from the motivating cases

If we compare the results of the four different tasks, and also take into consideration the first motivating case, then we feel they point to the need for a flexible means to capture the wide variety of concepts in the early phase of design. In order to make this operational, we will have to look at technologies for capturing such concepts, and for understanding the differences between such concepts. For the capturing of concepts, we will look at the fields of ontologies and information modelling, and for understanding the differences between concepts, we will look at the field of multi-agent systems.

Ontologies

In design and engineering, an *ontology* is a collection of concepts with their meaning and possible interrelationships. It differs from a dictionary because it only allows the description of concepts in a formal language. Concepts are often hierarchically ordered using mechanisms such as decomposition and inheritance, and are represented in semantic networks. Ontologies, therefore, constitute concepts that are subject of information exchange (Russell and Norvig 1995, pp. 222; Nilsson 1998, pp. 313-314; Sowa 2000, pp. 51; Weiss 2001, pp. 94-95, 361). An ontology can be used in a single application for a specific domain (Gruber 1993b), for reaching shared understanding through multiple applications (Gruber 1993a); or for capturing ‘common sense’ knowledge to enhance automated reasoning over various domains (Lenat et al. 1990; Lenat 1995). Ontologies tend to become sizeable, as they have to define all the relevant concepts for a particular domain. By decomposing a comprehensive ontology into loosely linked sub-ontologies in a lattice structure, the creation, updating and management of ontologies becomes feasible (Gruber and Olsen 1994). Work on ontologies in design has resulted in various approaches such as YMIR (Alberts and Dikker 1994), the activity/space ontology (Simoff and Maher 1998), the MOKA-ontology (Klein 2000), ontologies for knowledge-based systems (Varejao et al. 2000), and product data exchange (Dartigues and Ghodus 2002). These were all meant to facilitate communication between various human and ICT-agents in a specific domain.

Concept Modelling

Concept modelling, which is developed at Eindhoven University of Technology, extends the common product modelling approach as it is used in engineering to become extensible and flexible (van Leeuwen 1999; van Leeuwen and de Vries 2000). Concept modelling has evolved from the previously developed Feature based modelling. The terms Concept and Individual corresponds to Feature type and Feature instance, respectively. A reason for the changed terminology is to avoid confusion with form features, but there are other differences as well that defends a new terminology. High-level information is defined in the Concept, while specific occurrences of the concepts are termed Individuals (the capitals are used to distinguish the terms from their everyday use). It is possible to have relations between Individuals that have not been defined on the concept level. Both Concepts and Individuals can be changed 'on the fly' in the design process when the need occurs. These changes are maintained with a versioning system; the model is persistent and can allow inconsistencies. It is important to note that Individuals are no longer linked to Concepts in a rigid manner: during the time that an Individual is used, it may change its reference to a Concept. The Concepts and Individuals in a concept-model are organised in namespaces. Namespaces can be nested in each other (van Leeuwen and Fridqvist 2002).

There are three processes that outline the relation between Individuals and Concepts:

1. **Concept Instantiation**: suppose there is already a (pre) defined Concept for kitchens, called *Kitchen*. It has components referring to other Concepts that define aspects of the Concept *Kitchen*, such as *Function*, *SurfaceArea*, *Ventilation*, and so forth. When instantiating the Individual *myKitchen* the components from the Concept *Kitchen* can be instantiated. The user may choose however, not to instantiate all of the components.
2. Derivation of a Concept from a collection of Individuals: a user may start modelling a design on the basis of very generic Concepts (for example by simply drawing shapes, adding function names, and so forth). This collection of individuals incrementally represents the design. At some point in the process, two options may occur:
    a. The collection of Individuals may describe something that the designer wants to keep as a Concept. The Concept is then defined on the basis of the Individuals. This is termed **Concept derivation**.
    b. The system recognises that the set of Individuals corresponds to an existing Concept. This is termed **Concept recognition**. The user can subsequently choose to add the recognized concept to the Individual's definition.

Motivation part 3: The design case study

The Concept Modelling framework has been applied to describe changing concepts in a concrete design project provided by an architectural firm (Achten and van Leeuwen 1999). In that work, the framework used the terms Feature Types and Feature instances.

In the case study we found that changes that may occur to a design concept in the design process are "identification" (first mentioning of a design concept), "generalisation" (relating the design concept to a higher-level Concept – superconcept – that encompasses the concept), "extension" (adding aspects to a design concept), and "modification" (changing parts of the concept by means of substitution or deletion). For example, in the beginning of the design process, there may be mention of a 'kitchen': the Concept is *identified*. At some point, the kitchen may be assigned a preliminary shape in a composition: the Concept is *extended*. During a few cycles in the design process, the shape of the space is adapted regularly to fit in the overall composition: the Concept is *modified*. When the architect talks about spaces in general, including the kitchen, the Concept is *generalised* by the superconcept 'space.'

With concept modelling, we have a flexible means to model information in the design process, which is feasible for the early phases of design. A collection of Concepts in effect constitutes an *ontology*, which can be either general for a domain (for example architecture), or specific for a designer, a design project (a particular building), or an industry (for example the building component manufacturers). A particular characteristic of the concept-modelling framework is the sharing of information concering Concepts and Individuals. Sharing information, as opposed to exchanging information, keeps information at its source, where it can remain tied to the processes that form the context of the information.

As concept-based models are suited for capturing the information in the design process, it is likely to expect differences in concept-models between various projects. At some point in the design process, these differences need to be identified and cleared, for example when the design needs to meet set standards. Communication about these concepts serves the purposes outlined above in the introduction section: to communicate design ideas among design participants to reach shared understanding; to ensure compliance with a set of norms or standards; and to translate from the preliminary design to the concept design, final design, and shop drawings. We therefore need an approach to communicate about differences between various ontologies. For this purpose, we look at the field of multi-agent systems.

Multi-agent systems and ontologies

Multi-agent systems developed from Distributed Artificial Intelligence (DAI). Such systems consist of multiple agents, each of which is an autonomous entity (which may also be a human) with specific capacities and the ability to cooperate or compete with other agents. The question of communication is a central issue in multi-agent systems. Ontologies are acknowledged as helpful and necessary, yet are still not very well developed (Aylett et al. 1998; Nwana and Ndumu 1999). Exchange of ontologies is tackled through translators such as Ontolingua (Gruber 1993a) or communication protocols such as KIF (Weiss 2001) and KQML (Finin et al. 1992). These works are in development stage, and apply on the general question of communicating across different ontologies. There is not much work in the discipline of design and design support. Most ontologies in this area focus on a single standard that does not evolve with the design process. Although standardisation of concepts is important when a preliminary design needs to be worked out into final design and shop drawings, this occurs at the end of the design process. As argued above, we feel that the early stages of design (concept design, sketch design, and preliminary design) require a different approach.

In our opinion, a lot can be gained if we draw a parallel with designers working on a design: they have knowledge about the design at hand, and resolve questions by communicating with other designers or experts about the design. Thus, each designer builds his own knowledge of the design (ontology) and can establish consensus with others by exchanging information about its design concepts. In this way, we can avoid the need for a single standardised ontology to which all the participants have to comply. It is important to note however, that with the same techniques, compliance to standards can be achieved by viewing the data store that holds the standards, as yet another agent to communicate with about concepts.

Communication about concept-models

In order to establish ontologies for design and have agents communicate about these, we start from the following (see Figure 3). Agent A has a namespace N_A for design A. In the namespace, all Concepts C_A and Individuals I_A are stored. It has for example a concept $C_A(i)$ for "door," where i is the pointer to that concept in the namespace N_A. The particular doors in the design that are instances of the concept door form a set $I_A(V_x)$, where V_x is the set of pointers to the instances. In the same manner, Agent B has namespace N_B for design B, concept "door" $C_B(j)$, and instances that are doors $I_B(W_y)$.

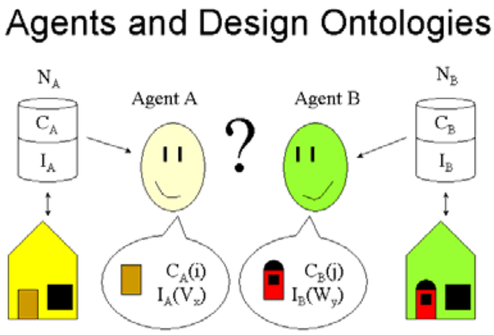


Figure 3: Each agent represents a particular design and can communicate about the stored concepts.

In order to find the concepts for doors, we need additional layers of meaning on top of the concept model (see research questions below). Given that such structures are available, Agent A and Agent B can now communicate about the doors that are in their respective designs A and B.

Communicate about Concepts	
Action	**Meaning**
$C_A(i) - C_B(j)$	Detect the surplus of components of concept $C_A(i)$ with respect to concept $C_B(j)$.
$C_B(j) - C_A(i)$	Detect the surplus of components of concept $C_B(j)$ with respect to concept $C_A(i)$.
$C_A(i) \cup C_B(j)$	Create a more comprehensive Concept that includes all aspects of concepts $C_A(i)$ and $C_B(j)$.
$C'(C_A(i)) \cap C'(C_B(j))$	C' denotes: finding the superconcept of a concept. If this is not $\varnothing$, then the superconcept C' can be extended to include both concepts $C_A(i)$ and $C_B(j)$.

The operations stated above form the basis for more sophisticated reasoning and communication about concepts. Identified differences can be used to detect discrepancies between concepts that various agents use about designs. The amount of difference (proportion of mismatching aspects of a concept) can be an indication whether such differences are serious and warrant further elaboration.

Research questions

The current work makes a modest attempt to tackle some of the problems that need to be addressed. After a preliminary theoretical investigation (Achten and Bíla 2002) we are now ready to develop and test a number of protocols. Some of the most immediate questions are identified below.

- *Concept identification*: a concept-model of a building design consists of many concepts and individuals that describe the design. If two agents are to communicate about a particular concept, such as 'space,' they need to find the Individuals representing this Concept in the model. A particular problem here is the concept boundary: where to stop adding Concepts and Individuals. Concept identification can be enhanced using the mechanisms of Concept derivation and Concept recognition. This addresses the problem that occurs when the design concept is modelled without explicit reference (e.g. the concept model contains Concepts and Individuals for square meters, function, dimensions, but no Concept or Individual for "space.")
- *Concept matching check*: when both agents have identified some concept, they have to determine whether they are actually discussing the same design concept. In the simplest case, we face problems when the labels of concepts have dissimilar values but denote the same design concept (e.g. 'handle' and 'lever' for the means to open a door). The techniques outlined above help to identify the differences between concepts. More complex cases occur when one design concept is more elaborated in one set of concepts and individuals than the other design concept (e.g., door 'A' would be defined as a door without glass and wood finishing, and door 'B' would be defined the same but additionally with kind of wood pattern, colour, fire-resistance value, and dimensions). Thirdly, the case may occur that parts of the concept model are merged in the other concept model (e.g., the lock and doorknob may be integrated in the same object rather than as two separate objects in the door).
- *Meaning map*: labels can have dissimilar values (such as in the 'handle' and 'lever' example, but also 'material' and 'handle'). In order to identify whether this is the case, it is useful to verify if there exists a mapping between the values of the labels such that the meanings will connect. The simplest way of doing this is by storing extensive lists of synonyms for values (e.g. {lever, bar, machine, simple machine, lever tumbler, tumbler, open, open up}, {**handle**, grip, handgrip, hold, appendage, manage, deal, care, …}, or {knob, projection, **handle**, grip, handgrip, hold, node, thickening, convex shape, convexity, pommel, decoration, ornament, ornamentation}) and see whether one of the words in the lists match. Such methods have limited applicability (in the example, there is a match between handle and knob, but not between lever, handle, and knob). A more extensive approach could utilise a building thesaurus or a natural language ontology such as WordNet (Miller et al. 1990) to find possible connections. It is important to note

that any of these strategies will require a lot of additional reasoning about the links that are found.

- *Communication protocol*: when agents are communicating about concept models, they will need a protocol to structure the communication. The data structure that is used will be based on concept-modelling technology. The protocols will have to address the following communications: (*i*) Find another agent / Allow another agent to find it; (*ii*) Contact another agent / Receive contact request from another agent; (*iii*) Request another agent to share concepts or individuals / Receive from another agent a request to share concepts or individuals; (*iv*) Share information about concepts or individuals with another agent; (*v*) Contact an information store with standardized concepts; (*vi*) Use a concept from an information store with standardized concepts; and (vii) Add a concept to an information store.

Discussion

The presented work is still in a theoretical stage and needs to be implemented in order to test our assumptions. Based on the theoretical exploration, we feel the current approach holds much potential to accommodate the evolution of design concepts in models that can be communicated among (automated) design agents. The properties of the concept-modelling framework; flexible and extensible definition of Concepts and Individuals, combined with the sharing point of view, are well suited to model information in the early phases of design for dispersed designers. The conversation-like approach in a multi-agent system can help to communicate differences between personal(ized) ontologies and later to make designs conform to standards.

Acknowledgements

The concept-modelling framework was first initiated, developed, and formalised by Jos van Leeuwen. Together with Sverker Fridqvist he is currently working on an application to store, manipulate, and share concept-models in distributed environments. This application will be a tool to actually test the outlined research in this paper. The work on design ontologies is done in collaboration with Prof.Ing. Bíla, Dr.Sc., of the Division of Automatic Control and Engineering Informatics of the Faculty of Mechanical Engineering of the Czech Technical University in Prague.

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