# ONTOLOGY SPECIFICATION FOR DESIGN COMMUNICATION


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## SUMMARY

As a first manifestation of a recently launched international research project, this position paper outlines an approach to use ontologies as a means to tame the high degree of complexity involved in most collaborative (architectural) design projects which derives from the involvement of their numerous participants. Traditionally, these various involvements have tended to be structured hierarchically and/or temporarily according to general flow diagrams outlining collaborative structures towards project completion. The advent of (potentially synchronous) digital communication worldwide has broadened the scope for creative collaboration and added to the, often less than subtle, language challenges across discipline boundaries a possible added ingredient of great physical distance. This paper explores the need for, opportunities and potential challenges in research to develop and test generic ontology-based support systems for design. On the following pages we will lay down the foundation for this extensive project by defining the term ontology, setting out our theoretical position towards this subject matter, briefly covering examples of alternative online (design) collaboration support tools and describing what we currently believe might be a possible solution to common design communication problems and the nature of what could be an appropriate product to support it.


## INTRODUCTION

Since the term ontology, in particular its meaning we use in this paper, is still largely unknown in the design field, it appears appropriate to first provide a definition for it before proceeding to introduce the research problem and objective of this project.

### Definition: Design Ontology

In the field of Artificial Intelligence, the term *ontology* denotes a statement of a formal logic to describe objects, their elements and relationships. The aim of such descriptions is to enable multi-tier agent systems to communicate about those objects without necessarily sharing the same or complete knowledge about an area of interest (problem domain within which the objects in question exist). Hence, an ontology is a consensual and formally organised set of interdependent data describing some part of the world (a problem domain model) with the purpose of allowing communication about that problem domain between machines and/or humans. This use of the word *ontology* is not to be confused with its meaning in Philosophy where it denotes a branch of metaphysics concerned with the nature and relations of being or a particular theory about the nature of being or the kinds of existents. The two meanings of the term are however not completely unrelated: on the following pages we will outline our intended application of ontologies in design for describing the logic composition of artefacts and for *bringing artefacts into existence*.

**Project Background**

Most design is to some extent collaborative and to a greater extent cooperative. (Kvan 2000) Very few projects are sufficiently simple for all the creative input to emanate from and all the necessary knowledge to reside in a sole designer. Thus design, design collaboration and design communication are generally inseparable. This is certainly true in genuinely collaborative enterprise where the contribution of every participant is distinct and fundamental to the overall conception. Thus it may be said that an ontology for design communication is in some measure an ontology for design.

The design of physical objects is particularly challenging as a domain for an ontology-based system. Firstly, designs are inherently partial—they are incomplete statements about an incompletely known object. Secondly, in most design work the concepts used and thus the ontology applied must change throughout the process. Thirdly, designers are inherently concerned with alternatives—different ways in which design spaces are explored and design products might be realised. Fourthly, the design of physical objects necessarily has a strong geometric component; once represented, even “free-form” is no longer free of geometry (i.e. topology).

Working towards suggestions for artefact specifications, designers work in a context of partially specified objects. At any stage of a design process, a particular design is almost never a complete specification for the artefact that is to be built. It rather stands for all possible things that are consistent with the design. The implications for an ontology-based system are twofold. First, inference is needed—a partial design and an ontology together can provide more information than the design alone. Second, the system must gracefully accept partial structures—what might be known (or not known) about a design cannot be predicted in advance

This research aims at developing an open ontological framework to support collaborative design using digital technology. Ontology technology has emerged from the field of Artificial Intelligence and has proven useful in many *closed* fields (that is fields which have easily formalisable procedures and objectives) such as knowledge management in e-Commerce and search engines (see Fensel, 2001). Due to the *open*, ill-defined nature of design problems we will deviate from the application of ontologies to *content structures*, as it is common in the fields mentioned. Instead, the aim of this project is to introduce ontology technology to the design field by its application to *design communication*. After providing a definition of the technical meaning of ontology, we will explain this choice in more detail below. We shall, however, first proceed to outline this project’s background discussing collaboration support approaches we have applied and examined before as well as the case study we intend retrospectively to analyse and that we will prospectively apply our findings to.

## Project Case Studies

The Aegis Hyposurface©, a responsive, interactive dynamic wall, is the product of a collaboration between a diverse group of individuals distributed around the world coordinated by dECOi architects.It was conceived as a competition entry for an artwork for the new Birmingham Hippodrome Theatre in England and from the first, its most essential quality: its ability to move, the ways in which it might do this and how this could be represented,  gathered an expanding group with complimentary skills starting with mathematicians, programmers and animators joining the architects and soon growing to include engineers, systems analysists, ballistics experts, mechantronics and robotic specialists. The Aegis Hyposurface© was chosen as the first investigative case study because the design (knowledge) communication between its participants, the tracking and storing of information in a way that all relevant participants had access to it, had proved extremely challenging. Firstly, a fundamental language problem was encountered between disciplines. Some participants wrote long lyrical emails, some wrote only very brief summaries of profoundly complex technical issues. There were dialogues between two or three specialists that were not fully comprehensible to the architect as project coordinator. Words such as “fluid” had, it transpired, as many different meanings as there were disciplines participating.
An (albeit incomplete) archive of email correspondence over a period of two and a half years, relating to the design and realisation of prototypes for the wall will provide a first case study. We intend to analyse this archive to identify how conceptual ground was negotiated through relatively unstructured communication and what the resulting implications were for the project. Applying participant-observer techniques we will develop a thick description of the process, tracking causal links and identifying, if

possible critical issues or events in shaping the process. This will be developed in parallel with a formal and generic description of this project communication that will form the basis of both an ontology and a performance brief for a system support design. The thick description will be used as a benchmarking tool against which to assess the accuracy and usefulness of the ontology(s) derived through database search and analysis of the archive. It will also be used to modify the initial performance brief for an ontology based tool that would overcome some of the difficulties identified.
Part of this research is to test to what extent ontologies and type hierarchies derived from a very specific project context can be applied more generally. The tools developed will be tested as part of this project by application to a live project; the internationally distributed and multidisciplinary team researching the continuing construction of Gaudí's Sagrada Família Church in Barcelona.

Without anticipating the particular findings of the research, the kinds of issues that these tools might seek to address could be a) ensuring that current information or communication reaches all those for whom it is relevant at the right time, b) that there is a very complete information archive easily accessible to all participants through a simple query compiled on the broadest basis, applying spatial approaches to representing, organising and navigating information, task completion up to the limit of explicit information on hand could be automated through executable communication. Clearly all this would have to be achieved in ways that do not inhibit the flow of communication and within an ontological context that can change and grow as the project progresses.

## Existing collaborative software solutions

There are wide ranging new products already on the market that offer, for instance, concurrent access to the same information by reducing a complex model to elemental database entries or extranet project management systems integrating a wide range of applications. Here, we will discuss these tools and their characteristics briefly in order to describe existing approaches to the problem we intend to tackle. Bentley's ProjectBank (http://www.mason.co.uk/bentley1.html) for instance is defined as a database without a query system, a Schema and briefcase. It can warn users of conflicts when changes are submitted and it includes a complete project history. ProjectWise is Bentley's extranet solution for project management. It integrates with engineering, constructing and office applications along with their data, user access management, workflow management, version/revision control and information publishing and so on. Tools like these are of great value in eliminating the hazards of missed information, or out-dated design data in complex collaborative environments with many participants. However, while greatly extending the scope of activity within shared environments, these packages are still generally aimed at particular disciplines such as engineering or construction. There is other collaborative software that extends the scope of real time shared virtual space (such as the Groove Desktop Collaboration Software: http://www.groove.net). These programs are generally focused on day-to-day communication and interaction, have collaborative graphic and virtual spatial interfaces that go well beyond email functionality through sophisticated graphic tools and shared access to the design data space. Although these systems might have scope for extension in the design project management direction, they are not primarily designed and regarded as formal project management applications.

## Parametric Design

In parametric design, variations and expressions of artefacts are generated by applying parameter sets to given abstract topological descriptions of these artefacts. Interrelationships of different elements of a design product can expressed logically and algorithmically to let parametric changes in one part of a design drive appropriate consequences in other parts. Software solutions facilitating this approach (such as Dassault's CATIA5) have recently been extended to encompass a broad range of functionality within a single integrated software package. Associative geometry, describing objects not as explicit instances but as abstract hierarchies of relationships, are extended to parameters related to but not limited to the geometry itself by incorporating for instance material libraries and structural features such as centroids, structural forces, and resonant frequencies. This approach of 'filling in blanks' of a pre-described structure can be understood as an equivalent to the instantiation and variation of objects with variable attributes in object-oriented programming. The initial material to which parameters shall later be applied required definition and expression in the early stages of the design project, which requires a very good understanding of the design problem already at the outset as well as decision-making about the approach to structuring the design product. Parametric design retains a large degree of flexibility with respect to the (formal) design outcomes throughout the design process because within the “global” parametric model particular parameters or parametric (sub)systems can be apportioned to individuals or groups of specialists. This makes parametric design a very good candidate for collaborative projects where non-linear, parallel strategies are required for structuring diverse inputs from multiple contributors so that design is not unduly or unnecessarily weighted for particular criteria by the management of the process. This line of attack is however based on the assumptions that a) the initially defined basic structure of the design outcome is remains unchallenged and b) that parametric subsystems which are under control of different collaborators are and remain independent of each other throughout the remaining part of the design process. Wherever these two assumptions are not met, an extensive amount of design communication is required to allow accommodating the respective newly occurred design knowledge within the parametric model. As noted already, there are software packages that begin to orchestrate collaborative enterprise in this way. Given our previous experience in the parametric design field we assume that co-ordination of multiple collaborators will pose a major future challenge for these new tools and we believe that a semi-formal design communication platform will help overcoming this challenge.

## Broad scope collaboration

Regardless of formal collaboration mechanisms (platforms, protocols, technologies) that are already in place, large parts of important future design communication content will occur in relatively unstructured communication, verbal, written and/or sketched (not to mention implicit assumptions that will always remain unexpressed). Collaboration tools will increasingly allow this to happen in real time with streams involving more than two participants simultaneously but many decisions, reasoned arguments for decisions, transfer of information, discussion leading to new approaches is still likely to lie buried in email archives or be transferred ad hoc to individual file systems.

We intend to examine collaborative design that is highly dispersed both in terms of disciplines, working methods, organization and geographically. Many of the issues are expected to be common to intra-organisational working situations and more constrained, less diverse situations. But by taking a situation in which an unusually diverse team attempts to work together, on very novel design problems, distributed around the world in a way that means the team never meets in one place at one time and there are different first languages and regional language use involved, it is hoped to encompass many of the potential communication challenges likely to be encountered in a collaborative design project. The initial knowledge of this project suggests, as might be expected, that the conceptual and language schisms between disciplines are far more fundamental than language or regional culture. In this sense our personal ontology or way of being is more strongly shaped by education than other context. This directs the way we work, what we hear and what we understand from communication and how we prioritise information.

# ONTOLOGIES IN DESIGN

### Research Objective

The problem this project sets out to tackle is a very challenging one as well as being one that most experienced designers are very familiar with: the difficulty of co-ordinating relevant knowledge, expertise, ideas and concepts within the highly complex situation of (distributed) design collaboration. Sharing a common understanding of a design problem and strategies to solve it appears to be a key problem in design projects, even if they do not cross the borders of disciplines, cultures or languages.

With this aim, we find ourselves confronted with a controversial situation: on one hand, ontology technology promises cross-domain communication of domain knowledge via formally specified data sets. On the other hand, design work is to be known for its “wicked” openness, informality and barely predictable nature. In the following, we will debate the pros and cons of ontologies in design in the form of a prosecution-defence dialogue.

# PROSECUTION

While ontology applications in other fields (such as knowledge management in e-Commerce and search engines) have been reported to be fairly successful (see Fensel, 2001), we should be careful and not prematurely generalise the potential of this technology and expect it to be equally successful in design. Accounts on ontology application in design are very rare. The one we could find (Emandat and Vakalo, 1998) should be examined very carefully as it focuses rather on outlining a development intention than reporting results. Moreover, the described application to shape grammar design immanently reduces the "design spaces" involved to well-confined sets of operations. This might not be of primary interest in a generic design support system.

Design processes are highly unstructured. There is no definitive number or sequence of operations. Designers can be observed, their considerations and decisions might even be recorded very closely and the resulting (data) structure might easily be stored and *retrospectively* analysed by computational means. A *prospective* preparation of an entire open design space in the form of a generic data structure however should be barely achievable. Moreover, we have to acknowledge the fact that in design it is not as easy to agree on consistent cross-domain semantics. Identifiers might not only be unknown, they might be mistaken because they are interpreted differently. Differing semantics are not only a problem between domains but also along the time line: an identifier might change meaning even within a knowledge domain.

The key concept here is "interpretation". Today, we are used to casual talk about "Information Technology" ignoring the fact that symbol-processing machines (computers) only handle *data*. Turning *data* into *information* requires *interpretation*. This entails mapping identifiers onto concepts known to the machine, which, in the case of a *programming language interpreter* is possible, as all concepts in question are immanent to the machine itself (CPU instructions). Mapping identifiers onto external concepts can work provided the concepts involved (as well as modes of concept extensions) are well-defined, finite and consistently agreed on by all parties involved. But this is what we cannot expect in design communication. Here, concepts come and go and are changed continuously. After all, the introduction, interpretation and challenging of concepts is what design is about and what designers are trained and paid for (This argument has already been made in Fischer et al., 1999 and was supported by Szewczyk, 2002.). An ontology application for example in inter-library transactions or for online search-engines can be described as the use of well defined, finite identifiers with static internal relationships for achieving one well-known objective. In design communication, we will find the exact opposite: Open sets of identifiers with unknown relationships for achieving a multitude of objectives (at least one new product or solution in every design process).

Another problem we need to address is that of communication protocols. When we talk about multiple *agents* in Artificial Intelligence applications using ontologies, we are talking about software programs. It is fairly easy to enable software to communicate in a formal (let's say 'query and reply'-) language. In design communication, the agents involved are human. How realistic is it to expect human designers to communicate with a shared knowledge database in a formal agent protocol? From a practical viewpoint we have to ask: How much can we expect designers to comply with any formalisms at all? Other types of formal multi-tier coordination formalisms such as PERT plans appear to be successful to only a very limited extent, as measured by the designers' general difficulties to meet deadlines.

A further difficulty crops up as we ask ourselves: what are the exact situations we want to support? We want to provide automated semantic moderation between multiple communication participants. As we are talking about human participants who can be expected to possess a fair amount of knowledge about the world already, two basic communication situations can be expected: understanding and misunderstanding. In the case of one party understanding another, we obviously do not need moderation at all. In the case of misunderstanding, it is very likely that when dealing with an open set of vocabulary, the concept in question needs to be added to the ontology. Hence, the basic requirement of *explaining* will not be eliminated. We rather introduce a new party to the communication (ontological system), which requires explanations. Admittedly, this system might theoretically be suitable to communicate its new knowledge to any number of other communication participants, which bears the economic potential of streamlining information exchange. But what if understanding is assumed falsely? How could a software agent identify this situation? For the sake of completeness we also have to bear in mind that misunderstanding could be generated intentionally as part of a particular design methodology. This requirement indicates the scope of flexibility we need to expect and support in human design communication.

The building, testing and maintaining of knowledge bases of any kind requires extensive investments. As in design communication we are mainly talking about one-off projects (and hence require one-off knowledge bases) this investment would represent a significant overhead on top of the anyway high costs the high degree of complexity in multi-tier design collaboration calls for. The prosecution hence pleads 'non-applicable'.

## DEFENCE

It is obvious that the development of a complete ontology for any reasonably sized domain is a mammoth task. Lessons from simpler developments for the architecture, engineering, and construction (A/E/C) domains have underlined the enormity of the task. The IAI's (IAI: 2002) development of data models for specific processes in A/E/C (currently containing over 600 classes and types in the IFC 2.x model) established over five years is recognised to be the tip of the iceberg of the data models which will be required in this domain. The LexiCon (Woestenenk: 2002) project, which is enumerating vocabularies and classifications from A/E/C domains internationally, currently has a small fraction of what is known to exist in this domain.

The scope of this project, however, is more moderate. By focusing on ontological support for design communication the universe of discourse that needs to be considered is substantially reduced. Since the focus is on communication this domain is also very explicit as communications have a tangible form and are easily identified and examined. It is also clear that the ontologies that are developed can be formed to support varying aspects of communication, providing varying levels of benefit. Some areas which could be supported include:

Communication process: The communication between parties in a project is facilitated by a small number of well-established media. The structure of these communications is well regulated and open to simple description. An email for example has a structure consisting of sender, recipients, subject, attachments, etc. Individual communications are initiated for a small set of very specific requirements, which are generally understood by all participants in a project such as requesting particular information, clarifying misunderstandings, communicating a project brief and so on.

Project process: All communications in a project support a particular part of the design process. Projects have explicit process specifications, which are centrally maintained and tracked by a project manager and well understood by all the participants involved in a particular sub-process. With the design process encoded in an ontology it would be possible to provide support for the process management of a project.

Project design: The intent and design concepts embodied in a communication are a much broader field to support and move us toward the problems being tackled by the IAI and LexiCon developments. However, the level of design concepts, which need to be represented, is not clear, in terms of the benefit that would be provided to the project, and this is an area to be explored in this project.

It is clear that all participants in a design process will have differing ontologies. Those participants working in similar areas and on similar tasks (e.g., two structural engineers within a particular organisation) are likely to have the closest match for their ontologies, while those from different parts of the industry with very different responsibilities (e.g., in the Gaudí project with material scientists, entomologists, botanists, biologists, architects, structural engineers, geologists, mathematicians, dental technicians, and plaster model makers) will have the greatest disparity between their ontologies. However, it is certain that there will be some overlap between the ontologies of any of the participants (otherwise there could be no understanding between them). It is also clear that, in terms of design collaboration, it is not necessary to represent the complete ontology utilised by any one of these participants. This is due to the observation that what is communicated does not represent information from their complete knowledge base, but a shared subset which can be understood by the likely recipient of their communication. So while the project must deal with differing ontologies, and methods for merging those ontologies in order to establish a canonical form of the communication space in the project, the percentage of each participant's domain specific ontology to be handled will be reduced by the human coding for communication.

The creation and maintenance of individual ontologies is obviously a major task in most domains. However, the restriction to design communication provides a generous source of information from which to develop and maintain an ontology. Documents created by individuals for communication to other project participants contain concepts and relationships that represent subsets of an individual's ontology. By mining these documents it should be possible to extract many of the required concepts and relationships for their ontology. This builds upon a standard process for establishing ontologies within a domain where documents from that domain are used to identify the significant concepts. Through the continual monitoring of design communication it should also be possible to ease the load of maintaining a participant's ontology, as additions to the communicated ontological base will be evident from new communications, and modifications to their existing ontology should also be clear from conflicts between new concepts and old concepts. This is an unproven approach to the management of ontologies, but, as it builds upon current methods for creation of ontologies, we are confident there will be some level of benefit from this approach. We believe that this approach will provide beneficial input into the simpler developments in this domain such as the IAI and LexiCon by providing exemplars of concepts and relationships that can be mined for vocabulary and data structures.

How the project participants will interact with their ontology prescription and the canonical form utilised within a project is an area of research that has not been comprehensively addressed. Obviously, this will be a major concern within this project as it will be incumbent upon individual project participants to maintain their ontological specification and to provide input to the process of extending and modifying the canonical ontology for the project to cope with new concepts and relationships they introduce. Work will be required in the interaction between existing communication systems and an ontology manager, both in terms of labelling communications with the correct terms and with updating the ontology. As a variety of approaches to melding these two systems will be trialled during the project there will also be measurement of the benefit accruing from the use of ontology-based collaboration tools. This may be evident in reduced miscommunication, better quality information served to participants, faster notification of relevant project information, reduced project errors, faster identification of information, etc. A range of measures will be tracked to provide some quantifiable measures of the impact that the ontologies have on the project versus current practices (this will also include negatives, such as the extra time required to manage the ontologies).

While the path described above seems to give a reasonable chance of developing ontologies for design collaboration, and a method of measuring their benefit, there are still fundamental issues in the theory of ontologies, which will have to be addressed within the context of this project. This includes extensions to current ontological systems to handle the specification of partial and incomplete structures, being able to model and manipulate a range of alternatives within the design context, being able to handle concrete geometrical representations, and managing changes to an ontology without disrupting the representation of the whole project.

The defence illustrates that by reducing the scope of a project to design communication we reduce the size of the problem being tackled and provide ourselves with a source of information about a participant's ontology to an extent where we believe the application of ontologies will be realisable and beneficial in the overall context of a large project.

## OUTLOOK

The descriptions of design discussed by the prosecution are based on very ideal, free and rather 'academic' situations. In more professional/commercial design contexts, procedures are often more restricted with respect to communication, tool choice, timing, methodologies, preferred types of products etc. The defence shows that by limiting the scope of the project, this becomes a problem with realisable solutions.

The full subtlety of successful design, predicated on invention, changing rules, and making novel connections has so far tended to elude computational design space exploration methods just as communication in analogue, digital or virtual environments is a very pale imitation of face to face human dialogue in real space. An ontology-based design collaboration system may still have far to go in terms of equalling the potential variety and depth of inference or broadly inclusive approach to contradictions inherent in human design communication. We nevertheless believe that attempting to model these processes presents a promising avenue in contributing to our knowledge of collaboration in design and to the potential for an unobtrusive digital administrator or project manager even for very loosely structured collaborative enterprise.

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