MULTI-AGENTS FOR ENERGY EFFICIENT COMFORT

Agents for the Energy Infrastructure of the Built Environment: Flexergy

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Abstract: Synergy between end-user, building and the built environment is the ultimate in the intelligent comfort process control concept. This new comfort control technology is based on the use of agent technology and can further reduce energy consumption of buildings while at the same time improve individual comfort. The TU/e (Technische Universiteit Eindhoven) together with Kropman and ECN (Energy research Centre Netherlands) work together in the research for user based preference indoor climate control technology. Central in this approach is the whole building design process including the energy infrastructure which makes it possible to reduce energy consumption by tuning demand and supply of the energy needed to fulfil the comfort demand of the occupants of not just one building but a set of physical or virtual connected buildings.

1 INTRODUCTION

There is a persistent discrepancy between increasing demands for comfort in buildings and the need to decrease use of energy. In Europe comfort in buildings needs 40% of the total energy. With effects of Global warming becoming more and more apparent (Alley et al., 2007) there is a need to reduce this energy demand by comfort within the built environment. Over the years energy efficiency of buildings has increased. At first by better ways of constructing followed by applying better insulation and better glazing. Also the introduction of more efficient building equipment has lead to further reduction of the energy use of buildings.

Present control systems for office buildings already make use of new technical possibilities offered by computer networks from the Building Management System (BMS) about the users, e.g. comfort demands or comfort preferences of the building occupants.

New comfort control technology, such as individual control, offers new possibilities to further reduce energy consumption of office buildings. Dynamic online steering of individual comfort management and building management could save up to 20% of current energy consumption (Akkermans, 2002). The behaviour of building occupants needs to be taken into account as it is responsible for almost half the outcome of planned energy reduction (Claeson-Jonsson, 2005).

As until now the individual comfort profile of each user has not been part of the building comfort system control strategy in offices. New technological development is needed to incorporate the behavior and individual comfort demands of each occupant of a building.

Integration between demands of end-user and building is the ultimate in the intelligent building

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concept. “Connecting” the end-user to a building is complex. User-connectivity, the combination of usability and user interface together, is studied and developed further. Information and communication technology connects people and helps them to communicate with the building (Clements-Croome, 1997).

A new generation of building process control systems is being developed based on agent technology. Experiences from earlier work proved that the traditional approaches are not capable to coope with the increasing complexity of multi-agents structures for energy infrastructures within the total built environment. New approaches are needed.

In section 2 there is a description of experiments with agent technology. The change in the future energy infrastructure is described in section 3. Based on the experiences gained in earlier projects a methodology is developed to cope with the necessary changes, which is presented in section 4. The overall resulting framework to structure and to implement agent technology in a integral way within the built environment is presented in section 5.

2 EARLIER EXPERIMENTS

Previous work by Akkermans (2002) showed that agent technology makes it possible to integrate occupants’ behaviour. Multi-agent systems provide the essential technology for this information infrastructure to connect the end-user to the building systems (Akkermans, 2002);

- large numbers of actors are able to interact, in competition or in cooperation
- local agents focus on local interests and negotiate with more global agents
- implementation of distributed decision making by the negotiation processes between the different local or more global oriented agents
- communication between actors is minimized to generic information exchange between agents.

To cope with different users and their different needs system wide information by agents is the basis. The different agents dynamically and continuously exchange information and negotiate with each other to get the best conditions for their representative. Through this mechanism there is an exchange of information about needs and supplies throughout the whole system. Only in this way the system can cope with the different users and their different needs. In two projects, SMART (Smart Multi Agent internet Technology) (Jelsma et al. 2002) and IIGO (Intelligent Internet mediated control in the built environment) (Kamphuis et al. 2005) this technology was developed and tested.

A different type of technology to incorporate user behavior, Forgiving Technology, was developed in another project, EBOB, Energy Efficient Behavior in Office Building (Claeson-Jonsson, 2005). EBOB investigated new combined technical and socio-economic solutions to make energy efficient behavior natural, easy and intuitively understandable for the end-users of refurbished and new offices. Control scenarios for the HVAC (Heat, Ventilation and Air-conditioning) systems were derived by analyzing occupant’s behavior and its effects on comfort and energy use.

The EBOB project is an European 5th framework program project with eleven partners from five countries. EBOB ran from 2002 until 2005. The field test was held at Kropman’s office at (Grundelius et al., 2004).

The techniques used within SMART/IIGO and EBOB made it possible to use the user representation and combine it with optimalization techniques. The representation of end-users was realized by developing an individual voting system. End-users were represented in the design by Fanger’s comfort model (Fanger, 1970). This comfortmodel predicts user’s evaluations of the indoor climate in buildings. This Predicted Mean Vote model (PMV) is the basis of the indoor climate standards in Europe ISO 7730-2005 and America, ASHRAE Standard 55-2004. This model includes thermo physiological properties of humans, such as sweat production and heat resistance of the skin. Based on what average people consider comfortable, the Predicted Mean Value (PMV) is translated into a percentage of people dissatisfied (PPD). Using the model of Fanger, the percentage of dissatisfied users can be predicted for a given set of comfort parameters. The voting system allowed every user in a thermal zone to enter his vote (warmer/colder) within a voting period (e.g. one hour) while seeing the aggregated voting of other users in his zone at the moment of voting (Jelsma et al. 2002).

The users comfort needs dominate this control strategy. The control strategy is based on the description of the user behaviour and implemented in a BMS (Building Management System). This BMS was extended with an external real-time information system to improve energy and comfort control. A learning curve is built from the user voting behavior. Responses of the user are interpreted differently depending on the overall trend of the comfort level in the building. Overall voting behavior as a function of the time of day is included in determining the action of the local comfort aspect controllers. Within this system the persistent use of user information is a leading strategy.

By starting from the human perspective and using available and new technology (including IT, smart control, user interfacing) this dominate user strategy was achieved. Figure 1 shows an overview of the agent system as part of the building management system with the individual voting behaviour. All the agents are communicating with other agents, representing rooms or the floors of the building. Also there are agents representing the information about the weather forecast and the central process control of the air-handlings unit. The relation between the individual demands and the changing external weather conditions is also shown in figure 1.

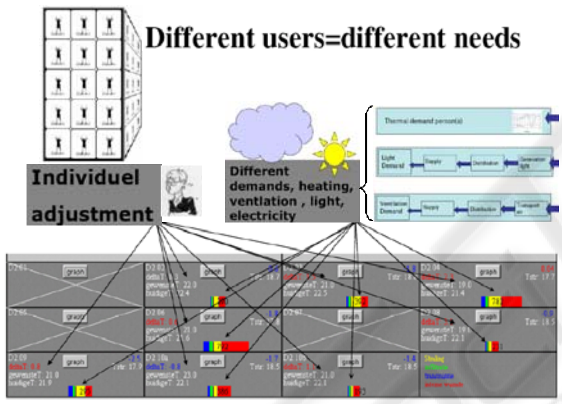

Figure 1: Individual adjustments and different energy demands for each office room shown on the screen of the BMS (Hommelberg 2005).

3 FUTURE CHANGE IN THE ENERGY INFRASTRUCTURE

Due to the change in buildings, equipment and out door climate (growing cooling demand), there is a strongly growing demand for electricity instead of heating. As electricity has a completely different character as energy form compared to heat, a completely different strategy is needed to optimize the energy infrastructure of the built environment. Heat can be stored rather easily and efficient, were as electricity can only be stored in a limited amount in expensive and complex devices. As result of this change the focus of the design process will have to change too. The flexibility of electricity is almost zero as storage possibilities are rather limited and have relatively poor performances.

Therefore it is important to look at energy reduction especially for this growing electricity demand of a building.

Electricity is traditionally generated in large central plants and distributed throughout the country. During the last decades this is changing. More and more decentralized electricity production is done by means of wind turbines, combined heat power units and photovoltaic systems. This will change bit by bit the whole distribution system from a strict top down system to a bottom-up system in which user can supply electricity in to the distribution grid on different levels.

For the users this means that instead of only using centralized electricity production, users can use different electricity sources by their own or others. The making of the built environment and its necessary energy supply grid has become complex.

A flexible energy infrastructure in and between buildings is needed to optimize the combination of decentralized power generation, use of sustainable energy source on building level and traditional centralized energy supply. The energy flows of heat, cold and electricity have to be optimized together. Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable built environment.

Although the experimental field tests applied with the multi agent process control systems proved successful and led to a stable it also proved that a more integral approach was needed to further optimize comfort and energy use in a building. All the energy flows such as heat, cold, electricity have to be optimized in connection to each other not only on the level of a specific building but on the level the built environment. For such a complex system approach the bottom-up approach starting from building segments is not enough for building a integral multi-agent process control. A new design approach is needed to structure the different layers and different functional defined tasks for agents in such an integral multi-agent process control system. To achieve this design knowledge plays an essential role.

New integral design approaches and design support are needed. To achieve this design knowledge plays an essential role. As stated by Gruber et al. (2006) the spectrum of expressiveness and degree of knowledge ranges from simple lists of terms or vocabularies over taxonomies and database schemas up to ontologies (Guarino 1998, Corcho et al. 2003).

4 METHODOLOGY

4.1 Ontology for Design

'Ontology' in philosophy means theory of existence in the broadest sense. It tries to explain what is being and how the world is configured by introducing a system of critical categories to account things and their intrinsic relations (Kitamura 2006). In the knowledge engineering community an ontology is viewed as a shared conceptualization of a domain that is commonly agreed to by all parties. It is defined as 'a specification of a conceptualization'(Gruber 1993). "Conceptualization' refers to the understanding of the concepts that can exist or do exist in a specific domain or a community. A representation of the shared knowledge in a specific domain that has been commonly agreed to refers to the 'specification' of a conceptualization (Dillon et al. 2008).

An ontology aims to capture the conceptual structures in a domain by describing facts assumed to be always true by the community of users. Ontology is the agreed understanding of the 'being' of knowledge: consensus regarding the interpretation of the concepts and the conceptual understanding of a domain (Dillon et al. 2008)

Ontology is generally considered to provide definitions for the vocabulary used to represent knowledge. The ontology role is to reflect a community's consensus on a useful way to conceptualize a particular domain (Aparrício et al. 2005). Ontology building deals with modeling a domain of the world with shareable knowledge structures (Geller et.al 2004).

Based on observations from literature, Uschold (1998) identified three main categories of uses for ontologies (see Figure 1; for further details and examples see Uschold & Gruninger (1996)):

- Communication between people. Here, an unambiguous but informal ontology may be suffcient.

- Inter-operability among systems achieved by translating between different modelling methods,

paradigms, languages and software tools; here, the ontology is used as an interchange format (see Figure 2).

- Systems engineering benefits: in particular,

- *Re-usability*: the ontology is the basis for a formal encoding of the important entities, attributes, processes and their inter-relationships in the domain of interest. This formal representation may be (or become so by automatic translation) a re-usable and/or shared component in a software system[5].

- *Knowledge acquisition*: speed and reliability may be increased

- *Reliability*: a formal representation also makes possible the automation of consistency checking resulting in more reliable software.

- *Specification*: the ontology can assist the process of identifying requirements and defining a specification for an IT system (knowledge based, or otherwise).

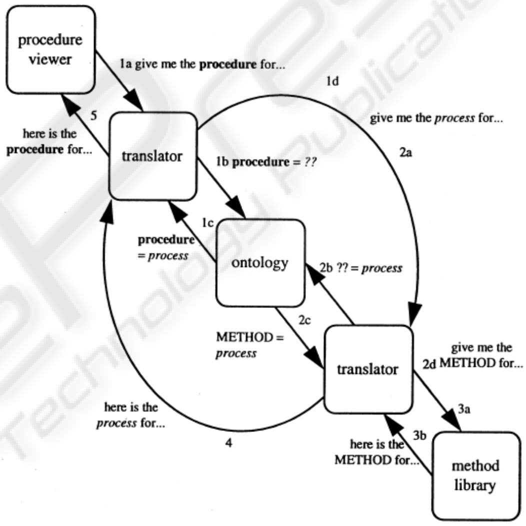

Figure 2: Interchange format example. This illustrates the use of an ontology as an interchange format to integrate different software tools (Uschold 1998).

Ontologies are formal conceptualizations not made l'art pour l'art, but to help achieve a goal or task by an actor. That task involves knowledge-intensive reasoning to understand the world not just static, but to serve practical purposes of action by the actor in his world (Akkermans 2008).

4.2 Prescriptive Design Method: Integral Design

Designing is a creative activity using several kinds of knowledge. The quality of design relies heavily on knowledge applied in the design processes (Kitamura 2006).

Design knowledge sharing is expected to drastically improve the design process. For example, in activities related to design review, an explicit description of the designer's intentions helps other people to understand the original design more effectively. Even designers themselves can gain deeper insights into the designs themselves (Kitamura et al. 2004).

More than two decades of knowledge engineering have shown that there are recurring patterns or stereotypes in the structuring and use of knowledge as an instrument in tasks that involve reasoning and computing. One of these recurring knowledge stereotypes are problem-solving methods; heuristic and stereotypical in the sense that they do not guarantee to solve a given knowledge-intensive problem in general. These problem-solving methods do have demonstrated pragmatic value in solving typical or common cases of knowledge-intensive task that can, moreover, be reused in many different situations (Akkermans 2008). There is a strong analogy between the problem-solving methods and prescriptive design methods.

The design process has been a topic of design research resulting in large numbers of models and theories of design, yet there is no consensus (Sim and Duffy 2003). What is well common among most models of engineering design processes is the depiction of the design process as consisting of conceptual distinct phases or stages of activities that transform the design from a set of requirements to a final design solution (Sim and Duffy 2003). Engineering design can thus be viewed as an articulate process composed of phases, where each phase represents a combinatorial action on the parts the composite object is constituted of (Colombo et.al 2007).

To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design by van den Kroonenberg (de Boer 1989, Blessing 1994) into an Integral Design methodology (Zeiler 2000). The Integral design process can be described at the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution. The design activity can be divided into four phases: clarification of the task, conceptual design, embodiment design and detail design (Camelo et al. 2007). The original methodical design process is extended from three to four main phases, in which different levels of functional hierarchical abstraction, stages can be distinguished. Hierarchical abstraction implies the decomposition of information into levels of increasing detail, where each level is used to define the entities in the level above. In this sense each level forms the abstract primitives of the level above. The contents of the layers are based on the technical vocabularies in use, technology-based layers or levels. Each layer represents an abstraction of the levels below.

4.3 Functional Decomposition Model

In order to survey solutions, engineers classify solutions based on various features. This classification provides a mean to decompose complex design tasks into manageable problems. An important decomposition is based on functions. While there is no common understanding of what a function is, people share the idea that functional knowledge is tightly related to design intention (Kitamura et.al 2004). Functions, as a concept, seems to derive from the designer's intention and it has no clear, unified, objective, and widely accepted definition (Umeda and Tomiyama 1997). Still when designers speak about the 'function' held by an object or by one of its components, they can speak about it because they have sufficient knowledge for associating functions to a suitable object structure (Colombo et al. 2007). Starting by formulating the need, the program of demands is developed and transformed into functions to fulfil. Functions can be regarded as what a design is supposed to fulfil: the intended behaviour of the object.

During the design process, and depending on the focus of the designer, functions exist at the different levels of abstraction. The functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems.

This functional decomposition provides the means for decomposing complex design tasks into problems of manageable size. This functional decomposition is hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is done until simple building components remain whose design is a relatively easy task. So functions play a crucial role in a design process, because the results of the design depend entirely on the decomposition of the function (Umeda and Tomiyama 1997).

The concept of hierarchical functional abstraction levels leads to a structure of different sets of functions for cooling, heating, lighting, power supply and ventilation, see figure 3.

It represents the orderings principle: abstraction levels, main functions and sub functions.

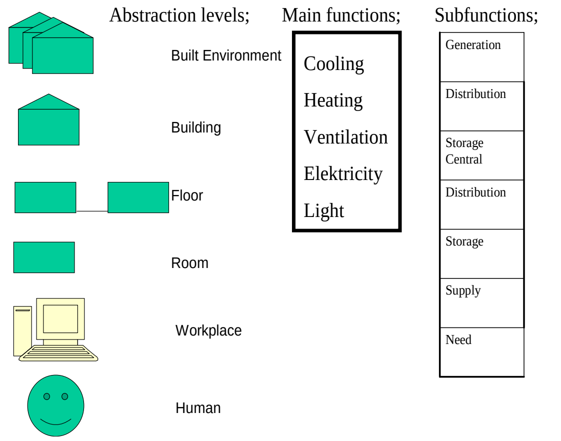

Figure 3: Abstraction levels, main functions and subfunctions.

4.4 Orientations in the Design Knowledge Model

Designing takes place in an environment that influences the process, it is contextually situated (de Vries 1994, Dorst and Hendriks 2001). The context of the model of designing is defined by a “world view”. The model consists of four worlds: the real world R, the symbolic world S, the conceptual world C and the specification world M. Thus, the four levels of aspect abstraction in the descriptive model of design are:

1. Information Level; knowledge-oriented, representing the "conceptual world. This level deals with the knowledge of the systems by experts. One of the essential ideas behind this is that human intelligence has the capability of search and the possibility to redirect search. This information processing is based on prior design knowledge. One of the major problems in modeling design knowledge is in finding an appropriate set of concepts that the knowledge should refer to, or in more fashionable terms; an ontology (Alberts 1993).

2. Process Level; process oriented, representing the "symbolic world". This level deals with physical variables, parameters and processes. The set of processes collectively determines the functionality of the variables that represent the device properties. Modelling at the functional level involves the derivation of an abstract description of a product purely in terms of its functionality. This abstraction reduces the complexity of engineering design to the specification of the product’s desired functionality.

3. Component Level; device orientation, representing the "real world. This level describes the hierarchical decomposition of the model in terms of functional components and is domain dependent. Generic components represent behaviors that are known to be physically possible to realize. They are generic in the sense that each component stands for a range of alternative realizations. This also implies that the generic components still have to be given their actual shape.

4. Part Level; parametric orientation, representing "the specification world". This level describes the actual shape and specific parameters of the parts of which the components exist. Relevant technical or physical limitations manifest themselves in the values of a specific set of parameters belonging to the generic components. These parameters are used to get a rough impression, at the current level of abstraction, of the consequences of certain design choices for the final result.

The four levels of aspect abstraction in the descriptive model of design can be related to the hierarchical levels used within the functional decomposition, see figure 4. The ontology can now be used to generate new possibilities for a flexible process control energy infrastructure in and between buildings to optimize the combination of decentralized power generation, use of sustainable energy source on building level and traditional centralized energy supply.

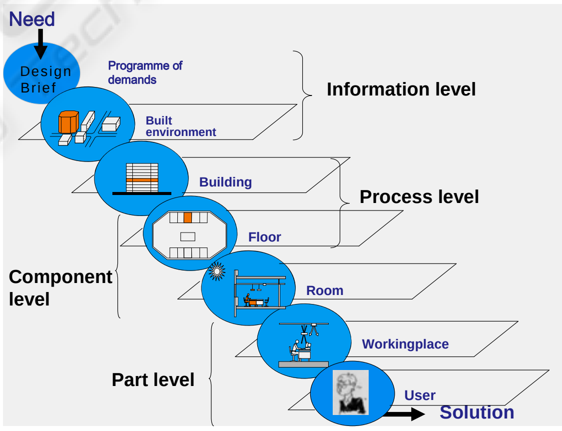

Figure 4: Hieracrchical abstraction levels by functional decomposition.

This makes it possible to integrate in a flexible way the energy flows connected to heating, cooling, ventilation, lighting and power demand, within a building and between buildings and the built environment. This leads to flexibility of energy exchange between different energy demands and sustainable energy supply on the different levels of abstraction in the built environment.

5 DISCUSSION

The research tradition related to "ontology" within Computer Science especially Information and Knowledge Systems is now about twenty years old. The field of ontology has been extremely successful in strictly or in terms of socio-economic or industrial usefulness (Akkermans 2008). Geller et al. (2004) give a thumbnail historical perspective on ontology and its challenges can be found. Looking at conferences held during the last years the ontology penetration rate is high and has become a cornerstone in areas such as semantic web, database, engineering, business and medicine. However looking more closely, it can be noticed that these events are attended by companies and enterprises only in minimal part and the feeling remains that the 'fuss' about ontology is mainly at the level of research and its surrounding niches (Borgo and Lesmo 2008). Industry seems not to recognize the value of applying insights of ontology research.

In engineering practice an important critical issue is the distance, in terms of intuitiveness and perceived complexity, between the engineered ontology and its intended user of application community (Akkermans 2008).

Our proposed model for supporting the design process by the Integral design method process frame work is simular to the functional approach developed by Stone and Wood. They propose a systematic placement of components into a hierarchical ontology (Bryant Arnold et al. 2007), using the functionality of components as a natural framework upon which such abstractions can be built. So they use more a kind of bottom-up approach compared to our integral approach.

6 CONCLUSIONS AND FURTHER RESEARCH

A functional decomposition framework based on hierarchical abstraction is proposed as a theoretical basis for design of the agent process control for the building, its building services systems and its energy infrastructure. We think that the proposed framework supports Multi-Agent technology in optimizing the energy infrastructure within the built environment.

Using two types of knowledge levels modesls (Uschold 1998), ontology and problem solving model, led to an approach in which the characteristics of the combined models offer an added value to design within the built environment domain.

A new integral design methodology has been developed and is used to develop a flexible concept for further development and implementation of the new design and control strategy for new energy infrastructures for the built environment: **Flex**(ible)(en)**ergy**

The TU/e (Technische Universiteit Eindhoven) together with Kropman, Installect and ECN (Energy research Centre Netherlands) work on research for user based preference indoor climate control technology. Central in this approach is the user focus of the integral building design process which makes it possible to integrate sustainable energy more easily in the energy infrastructure and reduce energy consumption by tuning demand and supply of the energy needed to fulfill the comfort demand of the occupants building.

Taking the user as starting point a new Multi-Agents framework is defined to optimize the process control within a flexible sustainable energy infrastructure; Flex(ible)(en)ergy.

At the moment this approach is implemented within the Flexergy project. This project started in 2007 and will continue till 2010.

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REFERENCES

Akkermans, H., 2002, Being Smart In Information Processing. Technological And Social Challenges And Oppertunities, *Proceedings IFIP IIP2002*

Akkermans, H., 2008, The Business of Ontology calls for a Formal Pragmatics, Invited talk 3rd workshop on Formal Ontologies Meet Industry, FOMI 2008, 5-6 juni Torino, Italy. http://e3value.few.vu.nl/docs/bibtex/pdf/HansA2008.pdf

Alberts, L.K., 1993, *YMIR: An Ontology for Engineering Design*, PhD-thesis, University of Twente, Enschede.

Alley, R. et.al., 2007, Climate Change 2007: The Physical Science Basis Summery for Policymakers, *Intergovernmental Panel on Climate Change*, Paris, France

Aparriíco, A.S., Farias, O.L., Santos N. dos, 2005, proceedings Australasian Ontology Workshop (AOW 2005), Sydney. Conferences in Research and Practice in Information Technology (CRPIT),Vol.58.

ASHRAE 55, 2004, ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-conditioning Engineering, Atlanta.

Blessing, L.T.M.,1994, A process-based approach to computer supported engineering design, PhD-thesis Universiteit Twente.

Boer, S.J. de, 1989, Decision methods and techniques in methodical engineering, PhD-Thesis Universiteit Twente

Borgo, S., Lesmo, L., 2008, The Attractiveness of Foundational ontologies in Industry, Formal Ontologies Meet Industry, IOS Press.

Bryant Arnold, C.R., Stone, R.B., Greer, J.L., McAdams, D.A., Kurtoglu, T., Campbell, M.I., 2007, A Function-based component ontology for system design, Proceedings International conference on engineering design, ICED'07, 28-31 August, Paris, France

Camelo, D., Mulet, E., Vidal, R., 2000, Function and behaviour representation for supporting flexible exploration and generalisation in a functional model for conceptual design, 2007, Proceedings International conference on engineering design, ICED'07, 28-31 August, Paris, France

Claeson-Jonsson, C., 2005, Final publishable report, *Energy Efficient Behaviour in Office Buildings.*

Clements-Croome, T.D.J, 1997,What do we mean by intelligent buildings?, *Automation in Construction 6 (1997) 395-400*

Colombo, G., Mosca, A., Sartori, F., 2007, *Towards the design of intelligent CAD systems: An ontological approach*, Advanced Engineering Informatics 21 (2007) 153-168.

Corcho, O., Fernández-López, M. And Gómez-Pérez A., 2003, *Methodologies, tools and languages for building ontologies. Where is their meeting point?,* Data & Knowledge Engineering 46(1), pp. 41-64

Dillon, T., Chang, E., Hadzic, M., Wongthongham, P., 2008, proceedings Fifth Asia-Pacific Conference on Conceptual Modelling (APCCM 2008), Wollongong, NSW, Australia, January 2008.

Dorst, K., Hendriks, D., 2001, The Role of the Design Context: In Practice and in Design Methodology, Proceedings 5th International Design Thinking Research Symposium "Designing in Context" , 18-20 December 2001, Delft

Fanger, P. O. , 1970, *Thermal comfort Analysis and Applications in Environmental Engineering*, McGraw-Hill, London,New York, ISDN 0-07-0199154

Geller, J., Perl, Y., Lee, J., 2004, Ontology Challenges: A Thumbnail Historical perspective, Editorial, Knowledge and Information Systems (2004) 6: 375-379.

Gruber, T.R., 1993, A translation approach to portable ontologies, Knowledge Acquisition, 5(2):199-220

Grundelius, M., Lundberg, S., Brissman, J., Stalpers-Croez,e I., Wortel, W., Bakker, L., Soethout, L., Scholten, J.E., Woksepp, S., 2004, EBOB Total result of WP2, Forgiving Technologies, *Prototype 2 description, D22 2.5 and D17 WP2, 2004-06-30,* www.ebob-pro.com/reports.htm

Guarino, N., 1998, Formal Ontology and Information Systems, proceedings of FOIS'98, Trento, Italy, 6-8 june 1998, Amsterdam IOS Press, pp. 3-15, http://www.loa-cnr.it/Papers/FOIS98.pdf

Hommelberg, M.P.F, 2005, *Careful Buildings, software agents voor een gebouwbeheersysteem*, Master thesis Building Services TU/e, January 2005 (dutch)

ISO 7730, 2006, Gematigde thermische binnencondities. Bepaling van de PMV- en PPD-waarde en specificatie van de voorwaarden voor thermische behaaglijkheid, (in Dutch) guideline, NEN-EN-ISO 7730

Jelsma, J., Kets, A., Kamphuis, I.G. and Worte,l W., 2002, SMART work package 2002 final report; SMART field test: experience of users and technical aspects, *research report ECN-C—02-094*, ECN, Petten.

Kamphuis, I.G., Warmer, C.J., Jong, M.J.M., Wortel, W., 2005, IIGO: Intelligent Internet mediated control in the built environment: Description of a large-scale experiment in a utility building setting, *ECN rapport ECN-C—05-084, October 2005.*

Kitamura, Y., 2006, Roles of ontologies of engineering artifacts for design knowledge modeling, In Proc. Of the 5th International Seminar and Workshop Engineering design in Integrated product Development (EDIProD 2006), 21-23 September 2006, Gronów, Poland, pp.59-69.

Kitamura, Y., Kashiwase, M., Fuse, M., Mizoguchi, R.. 2004, De ployment of an ontological framework of functional design knowledge, Advanced Engineering Informatics 18 (2004) 115-127.

Sim, S.K., Duffy, A.H.B., 2003, Towards an ontology of generic engineering design activities, Res Eng Design 14 (2003) 200-22.3

Umeda, Y. and Tomiyama T., 1997, Functional Reasoning in Design, IEEE Expert, march-april, pp. 42-48

Uschold, M. and Gruninger, M. (1996): Ontologies: Principles, methods and applications', The Knowledge Engineering Review 11(2). (Also available as AIAI-TR-191 from AIAI, The University of Edinburgh.

Vries, T.J.A. de, 1994, Conceptual design of controlled electro-mechanical systems, a modeling perspective, PhD thesis Twente university, Enschede, ISBN:90-9006876-7

Zeiler, W., 2000, Integral Design and Building Performance Simulation, proceedings IBPSA symposium Building performance simulation in the Benelux, 27 October 2000, Eindhoven University of Technology