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The feasibility of developing a new document-oriented concept for BC eWork environments

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This paper discusses the feasibility of developing an innovative, ambient, intelligent and document-oriented paradigm as an integrated working environment for the building and construction (BC) industry. The goal is to provoke investigating an environment and its resident intelligent multimedia agents as a means to (1) maximising automation of the complete information and knowledge life cycle, (2) achieving semantic interoperability between stakeholders and (3) improve communication, collaboration and process control of complex multi-actor one-of-a-kind projects. The Next Generation Internet and the Semantic Web allow multimedia project information sharing domain-specific ontologies marked up to the needs of the receiver (human or machine). By integrating content, knowledge and services, project information and knowledge can be continuously and autonomously updated from various resources over the Web, providing a new way to organise information and knowledge logistics. Arguably such an environment is made of 'responsive' documents for improved information and knowledge sharing, communication, collaboration and control of multi-actor, multi-cultural, multilingual and one-of-a-kind processes. In its broader sense these documents form the basis for a knowledge network representing (domain-specific) knowledge sources within organisations as well as acting as focal points for virtual testing of BC products and materials.

Keywords: ambient, intelligent, responsive, virtual testing, document

1 Introduction

Documents have been used to communicate meaning over space and time ever since humans learned to express thoughts in symbols carved in wood and stone. They were intended to pass information down the generations as historical records (e.g. the Biblical Ten Commandments on stone tablets and the pyramid inscriptions in Egypt). Papyrus was used for portable documents (messages) and couriers (messengers) to carry them. This method of communication still continues in the 'snail' mail and postmen of today, albeit with paper replacing papyrus and the word processor the stylus.

The leap forward in mass communication came with the invention of the printing press and print technology that could mass produce documents, enabling the 'same' document to be distributed in many directions simultaneously (broadcasting the message). Technology is always accompanied by the need for education, and schools were established to educate (more of) the population in the communication skills necessary for society to benefit from the new technology (i.e. reading, writing and numeracy). Societal benefits manifested itself in the form of globalised business and trade, and it became the equipment of individuals to learn in order to take an active part in society.

The computer was invented to calculate, but soon became the brain for the recording and storage of 'electronic documents'. The emergence of digital communication dominates business and personal domains. Furthermore, the Internet has provided the ability to be in contact anywhere at anytime. In this respect the truly mobile office has removed the space and time constraints. Throughout this process of continuously changing technologies, the document has survived to be the major vehicle for encapsulating information and knowledge.

With the arrival of the Next Generation Internet and the Semantic Web, process information and knowledge can be based on shared domain-specific ontologies and marked up according to the needs of the receiver (human or machine). Moreover, by integrating content and services, process information can be continuously and autonomously updated, deriving new information from various resources over the Internet (or intranet), thus providing a new way to organise information and knowledge logistics. In addition, recent advances in computational intelligence (including soft computing, distributed artificial intelligence and artificial consciousness) provide a whole new research domain in the area of cognition, involving self-awareness, perception-guided mental modelling and selective knowledge extraction.

The goal of this paper is to provoke an investigation into the feasibility and potentials of a new document-oriented paradigm, i.e. the concept of a virtual 'living' intelligent multimedia environment of building documents, as a means to (1) maximise automation of the complete information and knowledge life cycle, (2) achieve semantic interoperability between stakeholders and (3) improve communication, collaboration and process control of complex, multi-actor, one-of-a-kind development projects. The crucial question here is to view document is a broader context (content, syntax, function and form) rather than what it has traditionally been its purpose and form.

Formal, often authorised (BC) project-related documents, such as design drawings, bills of quantities and work orders, play a major role in the communication between BC stakeholders; they form in fact the information and knowledge backbone of these multi-actor processes. Typical characteristics of the heterogeneous datasets contained in these documents are the uncertain and *dynamic* nature of the information and knowledge; meaning that changes take place until the last minute. Another important characteristic is that the multimedia content of these documents is highly interconnected, making it all the more difficult to preserve the integrity of the project document base. The inflexibility of traditional, project-related Business Information Systems is widely known and most often results in insufficient information and knowledge logistics, i.e. necessary information and knowledge is simply not available, too late, not up to date, or in the wrong format, especially if something unexpected happens. In this paper we debate the possibility of a broader view of the concept of document extending it to an ambient and responsive phenomenon capable of performing tasks that were originally associated with a building document that is also capable of performing tasks such as record tracking, scheduling, ordering and virtual testing of building materials and products.

2 The need and objectives

Documents have proven to effectively entail several managerial and informational functions in diverse communication processes. For centuries, documents have provided the possibility for information packaging, personalising and filtering of content. However, current electronic documents only achieve a fraction of these capabilities and do not integrate well with efficient ICT-enabled operational processes or with adjacent knowledge processes over a document's life cycle. Current document models neglect a large variety of real-life aspects of document-based working. The formal electronic representation of a document

has to be extended and enhanced with all capabilities required for supporting a document-based BC eWork environment. The paper aims at debating the possibility of introducing an innovative new concept of proactive,[1] mutually interrogative,[2] ambient,[3] adaptive[4] and responsive[5] documents that are self-aware, user-aware, knowledge-aware, process-aware, control-aware and content-/context-aware. Hosting various types of multimedia content, documents can react to mining or analysis requests as well as actively exchange and share both content and knowledge with other documents and their users within the BC eWork environment (the same building projects, projects carried out elsewhere and projects already realised).

Within the innovative new concept, documents are regarded as semantic-based and context-aware 'cognitive' systems to acquire, organise, process, share and (re)use complex, dynamic information and knowledge. This cognitive system will be distributed among associated documents of the environment and is able to interact, exchange information and perform tasks. Furthermore, this cognitive system is able to evolve (by learning,[6] adapting and improving) in order to achieve a level of autonomy and performance in activities requiring context-specific (situation or task) information and knowledge. This environment aims to maximise automation of the complete information and knowledge life cycle and to achieve semantic interoperability between actors/stakeholders in multi-disciplinary processes. Formal process documentation is kept up to date through content mining of the dispersed process data available over the Internet of Intranet. Semantic-enabled systems and services are self-organising, robust and saleable and enable better mastery of complex, dynamic information and knowledge spaces populated by numerous documents.

Providing new flexibility for packaging and representing electronic information in documents, the innovative new concept allows for the utilisation of ICT systems of BC enterprises to a new level of competitiveness and effectiveness.[7] A large variety of migration strategies enables an organisation to improve its effectiveness on various technological and business levels. The proposed innovative new concept allows existing BC eWork environments improving competitiveness, easing the establishment of new knowledge, work and business processes supporting new dynamic businesses as well as improving the quality of knowledge sharing and reuse. Moreover, the innovative new concept increases the ability to improve knowledge exchange between enterprises and systems of rather diverse nature, such as businesses, authorities and customers that as yet have not established adequate technological infrastructures to support a document-based work environment. Furthermore, a sustainable technological development is strongly promoted by the innovative new concept. On the one hand, it aims at bridging the gap between model-based information management and complex knowledge-based processes. On the other hand, it aims at the integration of highly specialised work processes which traditionally are performed in isolation and hence are not supported by integrated electronic document systems for information exchange and knowledge sharing.

This innovative new concept can arguably strengthen the competitiveness and effectiveness of the BC industry utilising and developing its knowledge assets and integrating its business processes. Building on the standardised semantic technologies, the main goal of the concept is to make semantic-based knowledge sys-

1 'Proactive' is the ability of a document to learn during the document life cycle and to act accordingly.

2 'Mutually interrogative' is the ability of a document to consult and negotiate with other documents and to synchronise and/or update its content. In addition to its 'self-awareness', a document is able to exchange experience with other documents.

3 'Ambient' is the characteristic of the virtual BC eWork environment wherein documents operate.

4 'Adaptive' is the ability of a document to adapt its behaviour or content to changing circumstances, users, conditions, platforms and devices.

5 'Responsive' is the ability of documents to carry responsibility, i.e., try hard to reach their goals, report the required information and knowledge (multimedia content) to the right users, at the right time, in the right format and language (both human and computer languages), on the correct device (i.e. multi-modal), in the correct media (e.g. voice, text, graphics, VR, AR) and at the right place (i.e. the correct geographic location). This ability of documents and the ability to keep users well informed about their progress enable users and systems to trust upon documents for their reliability and consistency.

6 Learning from data and information models as well as from operational context information provides a clearer description of users' view of the real world or particular documents, and helps clarify-

ing the corresponding rationales.

7 Reusing and reintegrating information captured in only unstructured or semi-structured electronic documents is of vital importance for effective information and knowledge management. The semantic gaps between model- and document-based information management hinder the creation of added value in various areas such as interdisciplinary and inter-organisational communication. BC eWork environment helps to overcome these gaps by using and enhancing existing technologies to their full potential as well as developing additional technologies expressed in the context of BC eWork environment concepts. Therefore, BC eWork environment truly enhances work quality and enables well-grounded (e.g. performance-driven) decision making at any time.

tems usable and affordable on all business levels and especially foster BC knowledge exchange and reuse. The overall competitiveness of the BC industry is also improved by the contribution to standard technologies connecting information infrastructures at various levels as well as across different industry sectors and disciplines. At the same time, the concept extends common as well as successful commercial concepts. Furthermore, the concept establishes links with standardisation and industrial developments to ensure coherence in a world-wide technology deployment and in the creation of a new open framework for fair competition and business process innovation.

3 The concept and supporting technologies

The scientific and technological objectives of this concept can be exploring and accessing new potentials of a new generation documents as an enabling technology for enhancing BC eWork environments. Within this new concept, documents are regarded as semantic-based and context-aware cognitive systems to acquire, organise, process, share and (re)use complex, dynamic information and knowledge. In other words, this research project aims at physically constructing an instantiated or embedded system that can perceive; understand the semantics of information conveyed through their perceptual input. This cognitive system will be distributed among associated documents able to interact and exchange information. Furthermore, these documents as cognitive systems are able to evolve (by learning, adapting and improving) in order to achieve a level of autonomy and performance in activities requiring context-specific (situation or task) information and knowledge.

It is possible to envisage a class of formal documents considered in the BC eWork environment as context cognitive documents with ‘self-knowledge’, i.e. documents that: (1) are able to update their multimedia content if needed, (2) translate and present their content in different languages, both human and computer languages, (3) use different multimedia techniques and devices for presentation and information processing (even print the content on paper) and (4) behave differently in different circumstances, for example applying different local rules in different locations or countries. The new definition of a document goes beyond the paper-based representation of documents (text, drawing, etc.); it is a container for definition, representation and presentation of streams of information and knowledge. It is this extended definition of documents that the innovative new concept addresses. The semantics of information and knowledge are captured in shared taxonomies and ontologies. In this regard, documents provide a meaningful link between semantics and content (e.g. shape, VR, text, voice, multimedia, calculation, virtual testing).

Applying these new document concepts have been (partly) the subject of a number of international research and development projects. Two interesting international efforts are Microsoft’s InfoPath and Adobe’s XMP. In both approaches, documents are seen as entities which are able to understand their content and to act as holders of streams of multimedia information. While understanding their content, these documents are able to update their content and represent themselves in multiple ways. Although these new approaches are certainly a good step forward, applying these concepts to multi-actor, one-of-a-kind, document-based processes is extremely difficult as the stakeholders usually have no prior

experience of such type of collaboration. Only self-awareness is not good enough: awareness should be extended to a level that the documents are able to understand the world and other documents around them, including the ability to understand processes, actor roles and contexts they are used in. Therefore the innovative new concept combines semantically enriched content with multi-agent technology supported by domain-specific ontologies in support of knowledge-intensive tasks, especially for modelling and optimisation of collaboration, communication and control of multi-actor, multilingual, multicultural, one-of-a-kind projects. The innovative new concept addresses the functionality of cognitive systems supporting complex, multi-actor, one-of-a-kind projects resulting in a new generation of documents and supporting tools to support automatic acquisition, analysis, annotation, (re)organisation, browsing, filtering, processing and presentation (e.g. as graphs, diagrams, technical drawings and 3D models) of dynamic multimedia content embedded in formal project documentation. This new paradigm document-oriented lays the foundation for a new generation of communication, collaboration and control tools to be used in complex multi-actor, multicultural, multilingual, one-of-a-kind processes (Figure 1).

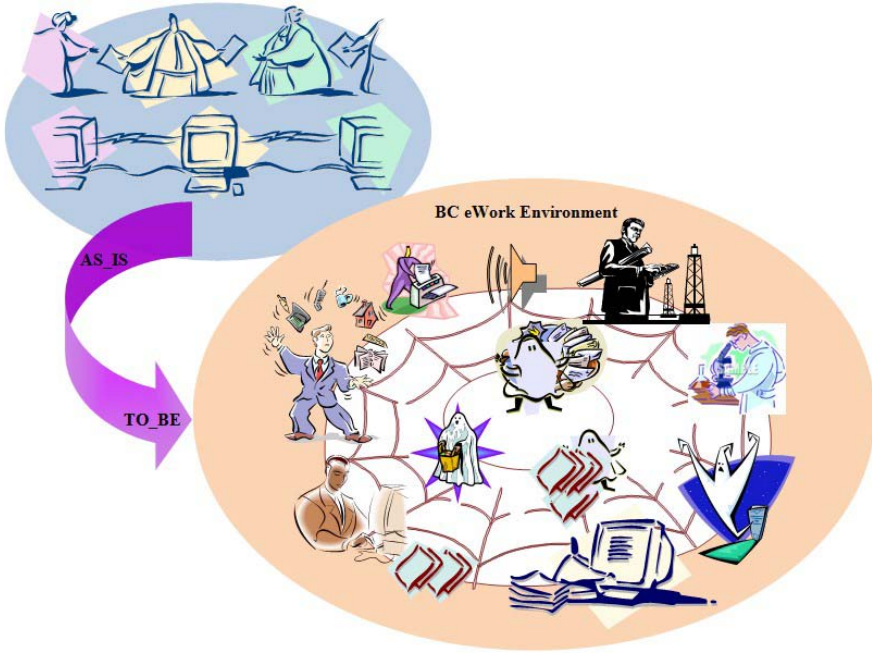

Figure 1 The main idea, explaining the AS-IS and TO-BE situations regarding document-based communication. The latter will be supported by the innovative new concept.

In the area of fundamental methods, the innovative new concept puts a new light on the prevailing document paradigm. The formal electronic representation of a document has to be extended and enhanced with all capabilities required for supporting a document-based BC eWork environment. The innovative new concept present an concept of proactive, mutually interrogative, adaptive and responsive documents that are documents that are self-aware, user-aware, knowledge-aware, process-aware, control-aware and content-/context-aware.[8] In a more implicit way, it considers standards and approaches from various trends related to web

8 Self-awareness is the ability of a document to combine the content with a definition of its internal structure allowing for automatic decoding of the content. User-awareness is the ability to extract and present information and knowledge for a type of user (i.e. role-based) according to the user profile. Knowledge-awareness is the ability to find and retrieve knowledge from knowledge repositories that provide the necessary knowledge about the 'outside' world, including knowledge about the role of the user in relation to the 'document type(s)' requested by the user. Process-awareness is the ability to understand (in addition to knowledge-aware) the business processes, activities and responsibilities attached to user's role. Control-awareness is the ability to evaluate and implement the degrees of control regarding users (actors and stakeholders) responsibilities and roles in relation to the documents. Furthermore here we refer to the interrelationship between documents themselves.

content, web platforms and web users in order to avoid the mismatch that is happening between these trends. The technology to develop such documents is largely available and includes (but not limited to): *cognitive reasoning* (emerging field of *artificial consciousness* and *distributed artificial intelligence*), *semantic web* and *XML* technology, *web services* and *integrated web platforms*, *artificial intelligence* and *soft computing* technologies, *document services* (including Microsoft's InfoPath and Adobe's XMP), *mobile* technology and *text/multimedia recognition*.

As mentioned earlier, the main idea is that a document is able to interpret its content and extract knowledge from it. In this regard, the content of a document is not static. It contains a dynamic overlay component that is able to re-index the content (and thus the view) of the document according to the conditions of its appearance. Self-awareness is of extreme importance in this process because the end user is not required to participate in the interpretation process. The document decides and restructures itself according to the context, platform and specified conditions. A high degree of soft computing is involved in this task. First, a learning component is useful since the exact response of the document to the environmental conditions need not be pre-determined. The response is acquired via an unsupervised interactive incremental learning process that results in a response 'attitude' given certain conditions. The crucial point in this approach is the ability of a document to transfer (copy or merge) this conditional attitude (i.e. its knowledge) to other documents it interacts with, thus reducing the overall learning curve for a set of interacting documents. Soft computing is also involved in the reasoning process associated with the document self-restructuring. The inference engine must be pre-programmed in the document in order to manage efficiently both the appearance (view) of the document and the dynamic change of its content. The self-awareness part is constructed using some of the common knowledge representation methods suited for this purpose. Therefore also methods of the (relatively) new emerging field of 'artificial consciousness' are considered.

4 The impact of the innovative new concept

In many industrial businesses with complex multi-actor processes *formal* documents play a vital and dominant role. In the BC process, formal project-dependent documents can be seen as views on a 4D project model (space and time of the artefact and the process). Changes in the process and resulting systems must be reflected in the documents. In particular, if the number of actors is large and several processes interact, then process control is extremely difficult and complicated, too often resulting in time and cost overflows.

The recent advent of XML-based documents introduces a new document paradigm where the content is separate from the mark-up and many mark-ups can be automatically produced from the same content. It seems that these XML-based documents have 'self-knowledge' (i.e. they 'know' their own content). Moreover, this new generation of documents is context sensitive, for instance, the European IST eConstruct project (section 5.3) demonstrated the presentation of the same multimedia content in different media and different European languages dependent on the context.

As discussed in the previous paragraph, the innovative new concept' objective is

to push the new document paradigm further, exploring and developing a new innovative technology wherein documents become (more or less) 'alive' somewhere in a virtual document space that is Web-enabled. These new documents, 'know' their user and their user's wishes, and have a purpose in life (i.e. fulfilling their user's wishes). Documents are, to a certain degree, 'autonomous' (i.e. able to do something on their own) as well as 'social'. The latter refers to the ability of documents to interact with each other in order to share information and knowledge.

A key concept for documents is the way these innovative new documents can take over (some) process control tasks. Process control is in fact the result of an aggregation of many decisions (control structure), by many actors and stakeholders, where each decision depends on previous decisions. Changing the control structure is not easy with current technology and process control is therefore quite rigid. This rigidity leads to many process-control problems, for instance, with respect to budget, planning and quality. By attaching a form of process control to the documents that are the prime carriers of information and knowledge, we create a flexible and dynamic platform for controlling complex, multi-actor, one-of-a-kind processes.

As a first example of the perceived role of documents, consider a timesheet that office workers of a company have to fill in each week. If such timesheets are implemented as documents, then these can gain the responsibility of automatically capturing the hours of the office workers and process this information in a form that can be presented to the salary administration. As a second example, think about an order made by the procurement department of a contracting firm. This order searches the Internet for a vendor's catalogue (ideally a live catalogue) and together they provide an optimal solution for the procurement. These two documents can create an offspring, in the form of an offer. This is the result of the fact that documents can reproduce themselves, both by cloning and by collaboration. If the vendor has a particularly interesting offer for a substitute component that might serve the same purpose much cheaper, then this offer can consult the design specifications and propose the appropriate design changes to the end user. These examples are just a few of examples of the intended applications of the innovative new concept. Here, documents are considered as context sensitive documents with 'self-knowledge', that: (1) are able to update their multimedia content if needed, (2) translate and present their content in different languages, both human and computer languages, (3) use different multimedia techniques and devices for presentation and information processing, and (4) behave differently in different contexts. A document is a semantic container for the definition, representation and presentation of streams of information and knowledge, resulting in a responsive and autonomous type of documents.

The next innovation of innovative new concept lies in how implicit knowledge (or experiences) within the documents is handled. Although some implicit knowledge is available within traditional documents, the implicit knowledge and experiences of a traditional document are lost when the process comes to an end and the document is archived. The proposed document makes this knowledge (i.e. document's knowledge of itself) and experiences gained during the document life cycle explicit. These can then be reused, shared and exchanged in the BC eWork environments of other projects.

5 Reference projects

Four references projects are used in order to demonstrate the possibility and feasibility of the innovative new concept that can be applied to the BC eWork environment. Specifically the attention is paid to the type of applications in these projects to emphasize the broader meaning of the innovative new concept of building document where explicit and clear distinction is made with the traditional definition of documents.

5.1 BC Virtual Knowledge Network

Developing new knowledge management strategies has become an integral part of the short and long-term policies of the academic institutes. Recently in the Netherlands, a lot of efforts have been put into developing new strategies for improving the 'knowledge transfer' between the academic institutions and the industry. However, there is still a gap between the high-level policy-making and the development of low-level ICT and knowledge instruments that needs to be bridged. In fact, the implementation of the high-level policies is hampered by constraints imposed by both the existing knowledge infrastructures at the academic institutions as well as the available solutions provided by the software industry. However, most of the knowledge resources of academic institutions exist on hard-drives and in personal files of individual researchers. Only a part of these knowledge resources is available through traditional communication channels such as on-line libraries or databases and to some extent through non-interlinked (personal or group) web pages. Increasingly academic institutions are implementing portal solutions within their organizations, in order to interconnect the non-interlinked personal or group web pages. Although these portal solutions indeed provide mechanisms for connecting non-interlinked web pages of individual researchers or research groups, they do not provide adequate mechanisms or tools for connecting to on-line libraries or databases and hard drives of individual researchers. As a result, most of the available knowledge resources at the academic institutions are locked up in *islands* across the organization. In addition, the available knowledge resources are not accessible by the industry at all. Based on these observations, the faculty of Civil Engineering and Geosciences at the University of Technology in Delft initiated a research and development project for the improvement of the 'knowledge sharing and transfer' between the university and the BC industry in 2004.[9] This project, entitled 'A Virtual Knowledge Network (VKN) for the BC Industry', aims at providing an ICT infrastructure that not only facilitates the knowledge sharing between universities and the BC industry stakeholders but can also make knowledge available to individual companies on a project basis.

In the VKN, computers are not regarded anymore as single isolated devices but as entry points into a global network that are able to exchange and share knowledge. In VKN terms, each individual computer represents a node in a network that consists of personal nodes, group (or community) nodes and super nodes. Each different node is interconnected, allowing a two-way knowledge transfer with one or more other nodes through the physical communication infrastructure of the Internet. In most cases, super-nodes are network nodes that are established and maintained by large research institutions. In fact, they form the backbone of the network. The other nodes are network nodes that are established and main-

9 Dado, E. et al (2005). Exploring Enabling Technologies for a Virtual Knowledge Network for the Building and Construction Industry, Proceedings AEC2005 Conference, Netherlands

tained by individual researcher(s) (groups) or individual staff (or groups) of the BC companies. Figure 2 shows the top-level view of the proposed VKN.

The proposed innovative building document concept could support a number of the intended abilities of a VKN:

- The ability of making knowledge resources accessible for other users
- The ability of presenting knowledge resources in different forms (multiple knowledge representations e.g. 3D, 4D, tabular, statistics, text, figures etc.)
- The ability for making distributed knowledge resources (i.e. stored in traditional libraries, databases and web pages) in one specific domain that is accessible in a more centralized manner (knowledge merging)
- The ability for making computerized models accessible for others and the ability of integrating different complementary models (model integration)
- The ability to offer interactive training and learning courses
- The ability to perform virtual tests and experiments that are traditionally done in laboratories
- The ability to use research models for predicting the material properties of concrete materials
- The ability to promote products and services (exploiting knowledge and information on a commercial basis)
- The ability to collaborate with other end-users on a project-to-project basis, including functions for human-to-human interactions (collaboration)
- The ability to access knowledge resources by means of advanced searching and indexing functions combined with user-friendly interfaces, including functions for searching individual researchers (or research groups) and knowledge resources, based on standardized profile templates (advanced searching and indexing)[10 11]

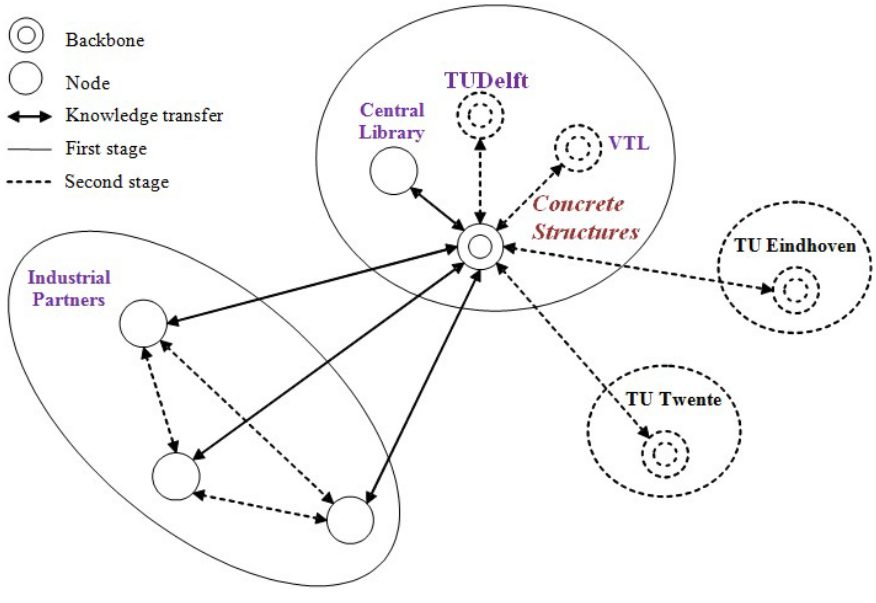

Figure 2 The top-level view of the VKN that is a network of super nodes (established by universities and other research institutions) and (industrial) group nodes (personal nodes are not shown). Each of the nodes can be interconnected with one or more other nodes. The ability of the VKN to support the two-way knowledge transfer between the (super) nodes is planned for the third phase of the project. In the first phase of the project, only the development of the super node and the one-way knowledge transfer between the university and the industry is planned. The node representing the section Concrete Structures will be further elaborated as a show case.

10 Koenders, et al (2004). The Re(Use) of Knowledge for Academics and Industry, Proceedings 4ICCPM conference

11 Dado, E. et al (2005). ibid

In fact, the VKN represents a BC eWork environment populated with documents that are seen as semantic-based and context-aware cognitive systems to acquire, organise, process, share and (re)use complex, dynamic information and knowledge. One of the innovations of the new document concept discussed earlier is that it integrates existing and emerging technologies into one concept. For example, in integrating content and context models for example provides documents the capability of presenting multimedia content to the end user in relation to its respective use context. Combining intelligent agents with process, information and knowledge models not only allows for reasoning about the outside world but also about the user's role and activities. The current lack of integration of technologies and standards hampers the development of the VKN. Noticeably, the innovative new concept could provide a solution to this problem.

5.2 BC virtual testing environments

Virtual testing is rapidly emerging as a key technology in the BC industry. Although some applications for virtual testing of construction products have been reported by a number of researchers,[12 to 16] most efforts have been put into the development of virtual testing environments (VTEs) for composite (mostly cement-based) materials in mostly an academic (educational) setting.[17] In this respect, virtual testing is mostly defined as a concept of making use of high performance computers in conjunction with scientific simulation models to predict the properties and/or behaviour of composite materials. A physical test or laboratory experiment is essential for verifying or validating scientific simulation models. However new areas of engineering analysis have emerged as a result of the application of advanced computer-based modelling techniques that have changed the roles of scientific simulation models and the physical test and laboratory experiments on construction materials and building products. Rather than trying to prove whether a calculation or simulation is correct, the focus is put on learning how to use available test data in order to 'improve' the accuracy of existing scientific simulation models.[18] From a more practical perspective VTEs also can provide a solution for the increasing regulations from national governments and the EU concerning quality, safety and environmental properties of construction products..

From an ICT perspective, most approaches of VTEs are based on the idea of a VTE as a web-based interface providing access to a 'virtual testing laboratory', to physical laboratory equipment and accompanying materials (often referred to as remote laboratories) and/or access to scientific simulation models. According the idea of the innovative new concept, a VTE is no longer regarded as isolated web-based, but as a set of integrated software and hardware components and standards that, used together, form a distributed and collaborative eWork environment for testing construction materials and building products. In fact, a VTE could be also one of the nodes of a VKN. An example of a VTE that has been designed and implemented according to these ideas is the VTE for cement-based materials developed by the Concrete Structures at the faculty of Civil Engineering and Geosciences at the University of Technology in Delft.[19 20 21]

A more recent project regarding VTEs is the European ECWins project. The European labels of conformity, known as CE markings, are a guarantee for quality and safety of BC products that are produced and sold throughout the Euro-

12 Kuester, F. & **Hutchinson, T.** (2007). A virtualized laboratory for earthquake engineering education, ASEE Journal of Engineering Education, 15:14

13 Hallbach, E. (2007). Development of Simulator for Modelling Robotic Earthmoving Operations, Master thesis, Lulea University of Technology, Finland

14 Ghaboussi, J. et al (2002). Real-Time Soil Modelling for machine-Medium Interaction in Virtual Reality, Proceedings of the 8th International Symposium on Numerical Methods in Geomechanics, Italy

15 Cervenka, J. & **Branis, P.** (2002). Virtual testing laboratory on the Web, Proceedings of the Fourth European Conference on Product and Process Modelling in the Building and Related Industries, Slovenia

16 Nagy, Z. et al (2008). The impact of remote and virtual laboratories in engineering education: A Workshop, Proceedings International conference on innovation, good practice and research in engineering education, United Kingdom

17 Dado, E. et al (2009).Theory and Applications of Virtual Testing Environments in Civil Engineering, International Journal of Design Sciences and Technology, 16:2.

18 Doebling, S. et al (2001). Validation of Transient Structural Dynamics Simulations: An Example, Proceedings Third International Conference on Sensitivity Analysis of Model Output, Spain

19 Dado, E. et al

(2009).ibid

20 Dado, E. et al (2009). Virtual Testing Environments for Composite Materials and Components in Civil Engineering, Proceedings CC2009 Conference, Portugal

21 Dado, E. et al (2010). Towards an advanced virtual testing environment for concrete materials, Proceedings MS2010 conference, Spain

22 ECWINS Consortium (2007). The Road to Standardized Window Production, Collective Research Projects for SMEs, Vol. 3, European Union

23 Surmeli, A. et al (2008). Deliverable 5.2; Sub models for CE-performance characteristics, ECWINS; COLL-CT-2006-030490

pean Union. According to the CE conformity standards, all building and construction products (for instance beams, columns, doors, windows, etc.) have to undergo a series of performance tests - mostly performed in laboratories of certificated (research) institutes - before they can be sold on the EU market. For example, windows manufactures have to carry out physical testing of properties of each window type in order to obtain CE-Conformity. However, it is very difficult for SMEs to provide all the necessary testing for their window types. The formal requirements of the standard can be put in practice easier by large industrial manufacturers. Without any support by their Associations, the SMEs depend on industrial suppliers. Based on these observations, the ECWINS R&D project was proposed comprising 30 partners from 8 different EU member states (supported by the 6th Framework Programme in 2004). The technical objectives of the ECWINS project were:[22]

- To develop a CE-Assessment Model that calculates most of the CE-performance characteristics whereby 'physical testing will be minimized". With this model new and individual window designs with CE marking will be become possible for SMEs.
- To develop a European Window Interface Model that assesses the applicability of CE-marked windows in specific building projects in the EU. With this model local produced windows can be designed in this way that they can be built into facades in most of the EU countries.

In order to develop an 'Integrated' CE-Assessment Model, two types of computational models are distinguished. The first one is the explicit models which are used to capture calculation procedures for the main window performances: Thermal Performance, Acoustics Performance, Resistance to Wind Load, Load Bearing Capacity of Safety Devices, Air Tightness and Water Permeability. Figure 3 shows the calculation model for the window performance 'Resistance to wind load'. The second one is the implicit model, which provides the integration of the explicit models together with manufacturer product specifications and old test results (from test institutes or certification bodies) and creates integrated output, i.e. creates CE assessment Output (CE mark) for windows and doors. The implicit model will first check if there is a similar window actually which has been tested, if it is been tested it will not use the calculation procedures, but will display the previous test data. If the similar product does not exist the selected calculation procedures will be used for evaluation.[23]

The virtual testing of construction materials and building products that are not supported by appropriate calculation methods have to be dealt with using reliable technologies using the aforementioned knowledge base. A similarity search can usually help identifying comparable specifications of materials and products (whole or parts) in order to establish a good probability for replacing the need for physical testing. The knowledge base will grow in content and scope that will consequently increase the degree of reliability of results. The greater challenge that still is in need of further research is what to do in the absence of a calculation method or similar data.

Arguably the VTE can promote dynamic collaboration for quick analysis of technical difficulties and will profoundly and effectively contribute to the knowledge enhancement. A VTE lends itself to a more productive and efficient

environment, capable of anticipating future technological and production needs as well as being a huge confidence builder for the BC industry market place of the future. In this regard all VTE elements are in fact documents in a broader meaning operating within the BC eWork environment.

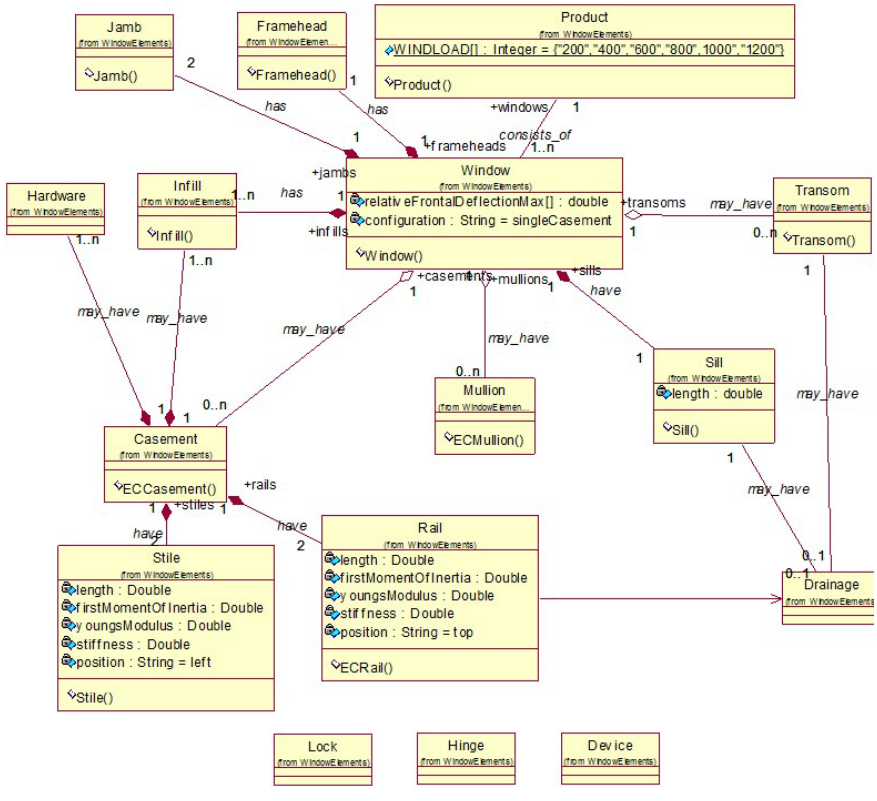

Figure 3 Calculation model for measuring the window performance 'Resistance to wind load' (most object attributes are hidden)

5.2 BC eCommerce environments

The results of the European eConstruct project have (partly) formed the basis of the ideas for the proposed innovative document concept. The main objective of eConstruct was to contribute to the development of an eCommerce information infrastructure for the European BC industry. The eConstruct project addresses one of BC important problems, i.e. the migration of the traditional (European) BC industry into the electronic future where collaboration and e-Business are state of the art. In the future Builders become e-Builders using the Internet technology to work, to communicate, to collaborate and to test building products. EConstruct's objective is realised by developing an XML vocabulary, called bcXML, which not only supports meaningful communication between European project partners, but also supports national languages and classification systems. Figure 4 shows the bcXML architecture. The bcXML architecture contains three components: (1) bcXML Meta-Schema, (2) Transaction Schema and (3) bcTaxonomy. The bcXML Meta-Schema holds the generic language information upon which the bcXML DTD/XSD is built.

24 Dado, E. (2002). ICT-Enabled Communication and Co-corporation in Large-Scale On-Site Construction Projects, PhD-Thesis, Delft University of Technology, Netherlands

25 Rees, van, R. (2007). New instruments for dynamic BC: computer as partner in construction, PhD-Thesis, Delft University of Technology, Netherlands

The Transaction Schema defines how information is communicated between partners and is partly based on ebXML. EbXML is an international initiative established by UN/CEFACT and OASIS, which provides a XML-based infrastructure for e-Business communication. The bcTaxonomy holds the objects (as instance of the bcXML Meta-Schema), such as a beams, columns, doors, windows etc., which provide the semantics for meaningful communication.

eConstruct, as a two-year European project did not establish an information infrastructure for the European BC industry itself, but showed the way. The final demonstration was convincing, in the sense that a full e-Commerce scenario was played through: existing catalogues of building products were converted to a semantics-based model in an on-line catalogue server and the taxonomy server allowed multi-lingual browsing, searching and visualisation. Figure 5 shows a screenshot from the final demonstration.

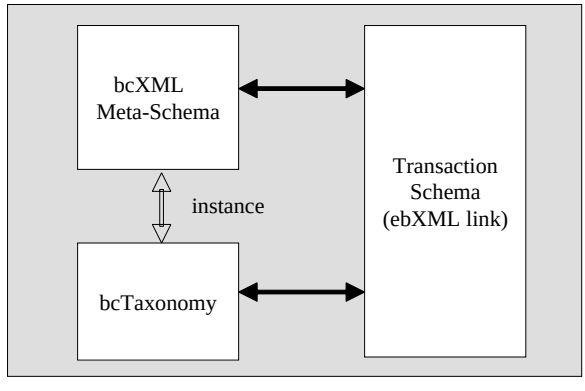

Figure 4 The bcXML architecture[24]

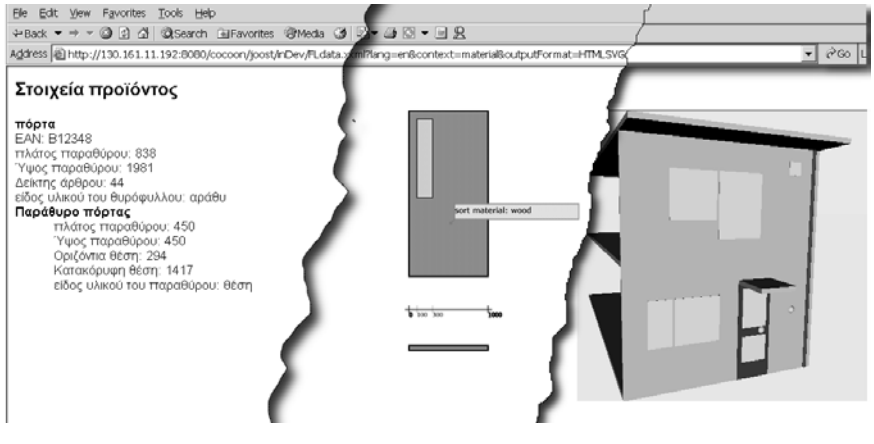

Figure 5 Screenshot from the eConstruct final demonstration showing bcXML multilingualism and visualisation.[25]

Looking at the outcomes of the eConstruct in respect to the innovative new concept for BC eWork environments and VTEs we can conclude that developing vocabularies based on Internet technology is a good idea. XML and the standards for the semantic web such as OWL and RDF provide widely accepted standards upon which building product vocabularies can be built which does re-

quire huge standardisation efforts. Multilingualism is an important feature but the eConstruct project showed that due to the national differences the creation of multi-lingual vocabularies is difficult but not impossible. In general we can conclude that the XML-based Internet provides the necessary base for the required migration of the BC industry but moreover it could facilitate the development of BC eWork environments, especially when it is integrated with agent technology and built upon results from UN/OASIS, eConstruct, IAI (ifcXML) and other R&D projects.

5.4 Human-Design interaction the BC eWork environment

The research project attempts to materialize the concept by separating humans from back-end systems and populating the gap with the innovative new document concept in a BC eWork environment.[26] These documents are intended to allow for high-level *design* interaction rather than low-level precise *human-machine* interaction. Illustrative is a designer who requests a draftsman to produce a professional drawing based on a sketch and a brief verbal explanation; in this case, the draftsman could (not meant disrespectfully) be regarded as an efficient, high level interface between the designer and the necessary backend systems. Therefore the intelligent documents are minimally expected to be skilled in the widely accepted visual and auditory communication standards in order to interact with the human perceptual physical world.

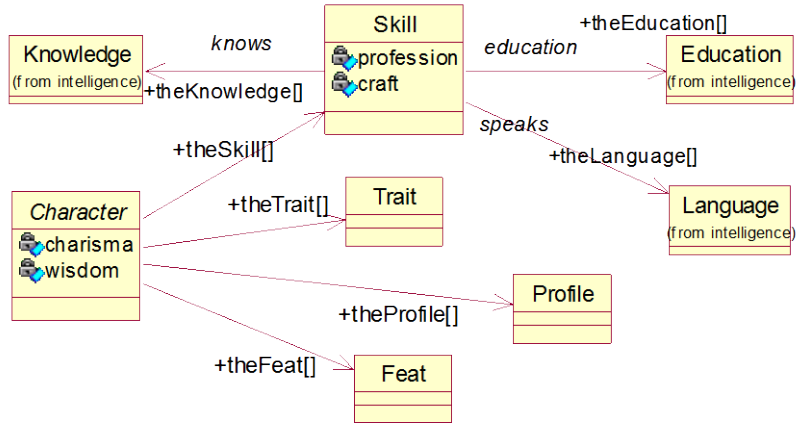

Figure 6 Knowledge and artificial character

The most profound advantage of this loose coupling approach is that information exchange issues can - without reprogramming each problem instance - be handled on a natural visual and audio level; this includes interaction with various other (skilled) intelligent documents, humans, existing computer systems' visual interfaces regardless of their applied inner technology or brand, phone calls, paper documents and such. The down side is obviously that high level interaction frequently comes at the cost of accuracy and speed decreases; however the authors are convinced that this can be tackled with the intelligent documents' ability to continuously discuss results, anticipate where needed and to use or create low-level systems that check or take over repetitive tasks to ensure integrity.

26 Ruitenbeek, M. van de (expected publication 2011). Human(oid)- Design interaction for AEC actors, PhD Thesis, Delft University of Technology, Delft, The Netherlands

Inspired by information handling in the BC industry and developments in cognitive science, this research elaborates on seed centred thinking, situation unfolding and embodied levels of computation in order to achieve the mentioned skills. Basically it regards stimuli as individual seeds that root, expose, unfold and respond with respect to the governing circumstances very similar to DNA and proteins. DNA exceeds the lowest level of decomposition; rather it is a highly compressed reference to the seed itself, its parents, its historical development and potentials. Similarly the seemingly small elements in designs often dictate the entire system breakdown structure.

The intention is to assign documents in the BC eWork environment character, charisma, and wisdom (Figure 6). The character holds the information about the physical properties such as trait, feat, and profile. In addition, the character has a set of skills related to the agent's profession. The skills are a set of languages it understands and uses, and the capability to learn and educate itself. Furthermore, it performs a certain intelligence that knows what knowledge it has. The document is capable of understanding natural languages and is capable of making dialogues about certain subjects. The future may hold more application documents performing virtual partners in the BC eWork environment processes.

6 Conclusions and discussion

In this paper the feasibility of an innovative new document-oriented concept for BC eWork environments has been discussed. Starting point for this discussion was the observation that current document models neglect a large variety of real-life aspects of document-based working. In order to overcome the current bottlenecks within the existing document-based BC eWork environments we stated that the formal electronic representation of a document has to be extended and enhanced with all capabilities required for supporting a document-based BC eWork environment. We introduced the innovative new concept of proactive, mutually interrogative, ambient, adaptive and responsive documents that are self-aware, user-aware, knowledge-aware, process-aware, control-aware and content-/context-aware. Within the innovative new concept, documents are regarded as semantic-based and context-aware 'cognitive' systems to acquire, organise, process, share and (re)use complex, dynamic information and knowledge. This cognitive system will be distributed among associated documents of the environment and is able to interact, exchange information and perform tasks. Furthermore, this cognitive system is able to evolve (by learning, adapting and improving) in order to achieve a level of autonomy and performance in activities requiring context-specific (situation or task) information and knowledge. This environment aims to maximise automation of the complete information and knowledge life cycle and to achieve semantic interoperability between actors/stakeholders in multi-disciplinary processes.

From a technology pint we view we stated that the technology to develop such documents is largely available and include a number of enabling and emerging technologies such as cognitive reasoning, semantic web, XML technology, web services, integrated web platforms, artificial intelligence and soft computing, document services, mobile technology and text/multimedia recognition. The biggest scientific challenge lies in the integration of these different – but complementary – technologies into one single concept. Therefore the innovative new

concept relies extensively on existing European and international information, knowledge and infrastructure standards. The integration of technology based on these wide-accepted standards provides an integrated low-cost ICT infrastructure upon which organisations can be its own eWork environment. Four reference projects showed the feasibility of such integrated approach supporting the innovative new concept.

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