INVESTIGATIONS IN THE BICT PROJECT OF STATE-OF-THE-ART ICT FOR INDUSTRIALIZATION OF HOUSE BUILDING PROCESSES

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ABSTRACT: The research presented here is part of a project named BICT, "Evaluation of benefits of ICT for the industrialization of project and product processes in the construction industry". Its overall objective is to establish a mutual understanding between the construction industry and R&D actors of the needs and possibilities of ICT. The project is a cooperative effort between Swedish and French researchers and industry representatives within the EraBuild program. It includes an investigation of the processes and ICT tools in a representative house building project, together with a study of the State-of-the-Art of ICT for immediate, short and medium term uptake.

This paper presents the main results of the State-of-the-Art study with specific focus on:
- *Visualization and coordination using digital mock-ups of 3D models;*
- *Model based quantity take-off;*
- *Integration of applications for product design;*
- *Reuse of experience based knowledge.*

The presented study concludes that the use of integrated 3D applications must be introduced early in the project lifecycle in order to pave the way for the use of object-oriented information in downstream processes. This requires common standards for 3D based deliveries developed in cooperation between industry and R&D actors through joint analyses of actual information management both in industrialised partnering-like processes, and fully industrial building processes.

KEYWORDS: construction processes, house building, industrialization, ICT, digital mock-ups, model based quantity take-off, integration of applications.

1 INTRODUCTION

The European Construction Technology Platform (ECTP) has recently published a Strategic Research Agenda for the European Construction Sector with the objective of achieving a sustainable and competitive construction sector in Europe by 2030. It declares the "Transformation of the Construction Sector" to be a strategic research area to assist in achieving these goals. Information and communication technology, ICT, is generally agreed to be essential in this transformation to empower the new paradigm of a knowledge based Construction Sector.

In spite of successful European and national R&D programs in later years, actors within the construction industry experience a gap between the R&D-results and current needs and benefits of ICT in the sector. Many research and development projects have been technology-driven, resulting in applications and data standards, expected to be useful. Projects that set out to develop systems or applications based on process and product analyses of actual industry practice are less frequent.

The research presented here is part of a project named BICT, "Evaluation of benefits of ICT for the industrialization of project and product processes in the construction industry". Its overall objective is to establish a mutual understanding between academia and industry of the needs and possibilities of ICT for industrialization of the construction industry. The project is a cooperative effort between Swedish and French researchers and industry representatives, and is financed within the EraBuild program. Through the French participants the project builds on results from the Strat-CON project within the same program.

The project includes an investigation of processes and ICT tools in a representative Swedish house building project, together with a study of State-of-the-Art of ICT for immediate, short and medium term uptake in areas considered of strategic importance. Based on the case study of the house-building project, specific ICT-related development areas were identified as being potentially beneficial for improved productivity and quality within multi-storey house building, and were further analysed in the survey and workshops. The development areas are Computer aided design, Virtual reality, Interoperability, Cooperation and ICT-policies, Integrated product definition, Use of systems products, Quantity take-off, and Reuse of experience (Molnar et al 2007).

The State-of the-Art investigation made a deeper analysis of four of these strategic development areas: a 3D model based design process, integrated product definition, quantity take-off, and reuse of experience. The investigation has focused on typical applications for immediate and short term uptake in the construction industry, and recommendations for development of applications for a medium term perspective to reach the ICT-development goals in the ECTP research agenda.

2 DIGITAL MOCK-UPS AND QUANTITY TAKE-OFF USING 3D

2.1 *Digital mock-ups*

Today's object-oriented 3D CAD systems can be applied for much more than the generation of drawings. However, the potential of these systems is often not fully utilized and application is limited to generating and exchanging traditional documents, such as 2D drawings, in a digital format. This section will outline two applications of object-oriented 3D CAD systems for immediate uptake by the industry that exemplifies the use of 3D CAD beyond generation of traditional documents.

A digital mock-up (DMU) is a collection of 3D CAD models which are positioned in a 3D environment (i.e., a 3D space) to represent the geometry of the product to be constructed. This technology has been used and refined for years in the automotive and manufacturing industry and the rapid developments of gaming technology have driven prices down.

Today, several commercial low-cost VR packages are available such as NavisWork, WalkInside, Ceco Visual, Common Point etc, that can import and visualize multiple 3D CAD models and 4D simulations in an integrated and user-friendly non-CAD environment. These products are starting to be used in real construction projects and the following benefits have been demonstrated (Jongeling 2006; Woksepp 2006):

- The process of acquiring a building permit process becomes much faster. Visualisation of the overall design improves communication and clarification, resulting in less complaints and misunderstandings of the layout and effects on neighbouring environment.
- The sale process improves in early stages of the project. Selective price tags on attractive flats can easily be determined by the developer. Potential customers can get a visual impression of the layout and the view from the flat before they sign the contract.
- Digital mock-ups and clash detection between architectural, structural and installation 3D designs leads to fewer collisions and hence, less re-work at the construction site. Also the coordination work between different design teams becomes much more efficient.
- Visualizing the construction process (4D), improves the planning and layout of the construction site and facilitates the communication of the planning during the construction process.
- Combining 4D models with location-based scheduling techniques that are based on model-based quantities from 3D models, is an effective instrument to ensure a continuous and reliable work-flow on the construction site with less waste as a result.

For the successful implementation of 3D and DMUs in construction projects the following recommendations are given:

- 3D modelling must be introduced early in the process if the full potential is to be achieved. Also, the effort of creating a DMU is less in the beginning since the early models are not detailed.
- The different design teams (Architects, Structural, HVAC) must agree on 3D modelling principles such as the use of a common coordinate system, the level of detail of the models imported to the DMU, grouping of objects, naming convention for objects and files, common file formats, etc., to simplify the design integration in the detailed design phase.
- A concurrent engineering approach is recommended where the design is incrementally refined, see figure 1.
- A project information officer (PIO) as suggested by Froese (2004) is recommended to be appointed by the project management. The PIO has the responsibility of (1) setting up requirements for the modelling work by different design teams, (2) ensuring that delivered models follow these rules, (3) creation of the DMU from the delivered models from the different disciplines (4) management and distribution of DMUs to users in the project and (5) education of (potential) model users.

The PIO can possibly facilitate the uptake and successful use of digital mock-ups in projects and relieve the design- and project manager from tasks that they are not used to perform. Also he/she can successively transfer the required skills to these managers.

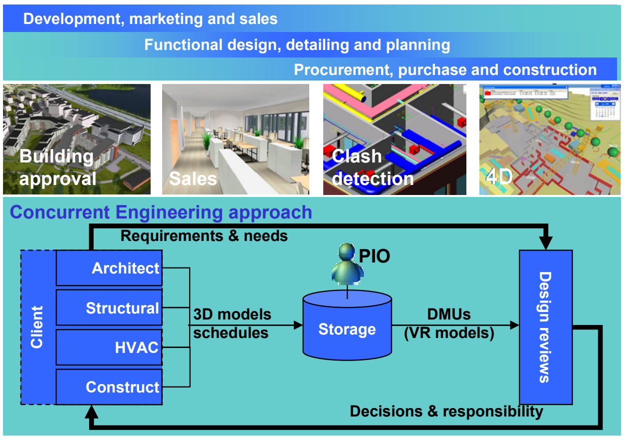

Figure 1. A concurrent engineering approach refining the design incrementally starting early in the development phase throughout the detailed design and construction phase of the project.

2.2 *Model based quantity take-off*

The case study project by Molnár et al, (2007), shows that quantities are calculated more than 20 times for cost-estimation purposes, material procurement, material call orders, production planning, etc. Quantity take-off currently involves a number of manual measurements on drawings, listing of quantities in spreadsheets, grouping of similar items and a number of additional tasks, each requiring manual, repetitive and error-prone operations. The quantity take-off and cost estimation processes are important parts of a project and improving these processes by using object oriented 3D CAD models is a much discussed application. There are a number of different types of model-based quantity take-offs and cost estimations, depending on the phase of the project, level of detail of the 3D CAD model, the type of the 3D CAD model and the selected method and software applications.

The following types of model-based quantity take-offs and cost estimations can be identified and are already used in the construction industry by a number of companies:

- Early quantity take-offs are made for cost estimations based on key figures from similar or completed projects. The purpose of these are to obtain an approximation of the total project costs, a basis for the space-use program, key figures for LCC design, etc. 3D models that are used for these purposes are often modeled by an architect and represent building volumes and a possible disposition of the building floor area.
- Quantity take-off and cost-estimation for the selection of the building types, divisions and construction methods (e.g. cast-in-place concrete, prefabricated concrete, steel, etc.) are made by using 3D models from mostly architects and structural engineers on a so-called general design-level. Building components can be identified in the general design, but the connection and interface between these components is not detailed at this stage. The models contain floor areas, material quantities, types and quantities of building objects, such as total length of bearing walls, weight of steel structure, window area, etc.
- Detailed 3D design models include technical solutions for and specifications of building components and connections between these components. Quantity take-off at this level results in detailed specifications for production planning and procurement.
- During construction 3D models are used to plan and control the work on site, by extracting quantities for specific work packages of production work. 3D models are also used for Supply Chain Management to keep track of material deliveries and to call material orders to site.

Important requirements for 3D model based quantity take-off and cost estimation are the definition of the different levels of detail of objects in the models, the definition of meta data (i.e., using attributes) for these objects that corresponds with the cost-estimation systems and the quality or correctness of the model contents. Much of this work can be facilitated by using different types of object libraries that correspond to different types of cost-estimations and that help the modelers to use the right objects definitions, including meta data, such as so-called code-accounts used in cost-estimation systems.

The delivery of model-based quantities for cost estimation purposes raises a number of questions, of which many are centered around responsibility and liability issues. 3D models, when properly applied, can speed up the quantity take-off and cost estimation process considerably and can improve the quality of the estimation process. However, it is relatively easy, and therefore a potential risk, to work with inconsistent or incomplete models, or to work with differences in definitions and versions between libraries used for modeling and cost-estimation purposes, etc. Clear rules and routines are required to minimize the risk of such errors. The PIO has an important role to play in a model based quantity and cost-estimation process. The PIO has the technical know-how to ensure that the right object libraries are used for the different project phases and different types of models. In addition, the PIO has the skills to check the model based data delivery from the various models on completeness, consistency, versioning, etc.

Delivering model-based quantities is a new and unknown role for many designers and consultants, and many fear to be held liable for erroneous data delivery. Delivering the right data requires establishing working methods, training, a learning period and trust in the tools, but above all it requires trust in the common use of the 3D models for these purposes by all stakeholders in a project. This puts requirements on the set up of the project environment, in terms of cooperation models, contractual forms (e.g., partnering) and remuneration models (e.g., incentives).

3 APPLICATION INTEGRATION; FROM FUNCTIONAL TO TECHNICAL SOLUTIONS

3.1 *Applications for integrated information management*

Traditionally, IT-applications used within construction were developed to solve tasks which earlier were carried out manually, e.g. calculation, estimation, drawing, and documentation. The majority of applications within the building process are still of a stand-alone nature and have no relation to other applications or other tasks and working methods. The fragmented building process has not encouraged the development of interoperability of these applications.

The BICT-project has studied the use of ICT applications in the building process for a normal, recently built block of flats in Sweden (living space of 3500 m^2, turnkey contract). The result is reported in (Molnár et al 2007). The great majority of applications used in this project are stand-alone applications, e.g., Word, Excel, AutoCad or Acrobat, resulting in unintelligent documents. As a result many input data must be manually entered into the system several times. One advanced electronic document management (EDM) system was used, but only a small amount of its functionality was applied (the drawing archive). The property manager gets a CD from this EDM system when taking over the real-estate unit. An e-commerce place on the Internet has been used for minor purchases of working materials, etc. Quantity take-offs and cost estimates (MAP, www.map.se) have been connected to time schedules (PlanCon, www.consultec.se) in order to rationalize and avoid multiple inputs of data.

In order to investigate the possibilities of integrated information management in a normal house building project using state of the art applications we have interviewed four developers. The applications studied are Lindab ADT Tools (www.lindab.com) Impact Precast (impact.strusoft.com), Energilotsen (the “Energy Pilot”, www.energilotsen.nu) and Tekla Structures (www.tekla.com). These applications are either newly developed or old applications with new functionality.

The structure and purpose of Lindab ADT Tools and Impact Precast are almost the same although they handle different building components. The two programmes integrate the work and the computer systems of the architect, the structural engineer as well as the building material supplier. But while Impact Precast integrates different concrete element suppliers, building components and building systems, Lindab ADT Tools is specifically developed only for Lindab's own profile system. This makes Impact Precast a neutral and more generally usable application for a structural engineer. Energilotsen is a different kind of application. It guides actors to make qualified energy related design decisions and simulations/calculations with different applications adapted to each actor. Energilotsen claims to be an overall solution to energy consumption calculations, both according to collaboration between different actors and the design of the buildings' energy performance as the process goes on. Tekla Structures has great ambitions. The application aims to integrate different parts and different actors in the building process by the use of a building information model.

A comparison between these four applications according to the surplus value that can be achieved, compared to stand-alone applications, yields the following results:

- all applications use object oriented 3D models
- all applications try to combine and render different actors in the building process more effective, where output data from one of the actors is input data to the next actor
- all applications reduce the number of times data is entered into the process
- all applications have possibilities for extensions and collaboration with other applications like open API, IFC- and XML-connections, database structure, etc.

3.2 *The load-bearing wall example*

We have investigated whether there was any integration of the applications used in the case project described above. The only case was a minor connection between the MAP application (quantity take-offs and cost estimates) and the PlanCon application (time schedules).

The design of a load-bearing exterior wall could be used as an example for how the four applications described above could have been used. Impact Precast (an additional application for ADT) could have been used to design and specify the concrete element walls. Lindab ADT Tools (an additional application for AutoCad) could preferably have been used for designing the steel stud walls, provided that Lindab was the supplier of the steel profiles. Energilotsen may be an excellent aid when consideration is taken of the new EU-energy terms. Tekla could have been used as a general product-modelling application with integrating other actors and applications. The object properties of Impact Precast and Lindab ADT Tools are stored in a dwg file while the Energilotsen applications (Vipweb and VIP+) use native file formats. But by using export formats one could connect to Tekla's BIM model using IFC files. The uncertainty about using the IFC format will probably mean that all needed object properties are not transmitted to Tekla. Manual interaction would be necessary in order to complement the properties. Once getting all the necessary information into Tekla one could use it to communicate with related applications for cost estimations, time scheduling etc.

4 REUSE OF EXPERIENCE BASED KNOWLEDGE

4.1 *Knowledge management*

Scientific questions of reuse of experience based knowledge are handled within the field of Knowledge Management (KM) defined as: "the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage" (Webb 1998). The purpose of KM is to increase a company's value creating capacity (Egbu 2004). Other drivers for KM in construction are the need to encourage continuous improvement, disseminate best practices, respond to customers quickly, reduce work, and develop new products and services (Carrillo and Chinowsky 2006).

Three kinds of knowledge are critical to an organisation, *technological knowledge* covering products and processes, *organisational knowledge* about the organisation and its operations, and *network knowledge*, which is inherent in the alliances and relationships that exist between the entities within the organisation and its networks, including suppliers, subcontractors, clients, consultants, and universities (Siemieniuch and Sinclair 2004).

In order to develop, the organisation needs to establish a favourable climate to innovation by committing resources, allowing autonomy, tolerating failure and providing opportunities for promotion and other incentives (Tatum 1987). In order to learn, an organisation must also have a learning strategy, flexible structure, blame-free culture, shared vision, promotion of knowledge creation and dissemination, and team working (Siemieniuch and Sinclair 2004).

Based on studies of best practice in the US and UK construction industries, Carillo and Chinowsky (2006) have identified the following barriers to efficient KM: lack of time, lack of standard work processes, insufficient funding, lack of management support, employee resistance to sharing, not invented here syndrome, and poor IT infrastructure. A survey in the BICT project mentioned in setion 3.1 gave the following explanations concerning the limited reuse of experience in multi-storey house-building projects (Molnár et al 2007):

- Lack of distinct product and process ownership in construction companies
- Poor knowledge when it comes to a structured description of building systems and processes
- Fragmentary process, often with new teams in every project.

Favourable conditions to learning from experience occur by joint control of the processes, e.g. through *strategic partnering*. See Table 1. Other possibilities to learn from experience develop from repeated use of building systems and components. The most advanced possibilities arise from using both mechanisms, as in fully industrialised building.

Table 1. Prerequisites of product and process control for learning from experience.

Control of technical platform		Separated	Shared
Control of process	Separated	Limited incentives to learning	Product based learning
	Shared	Process based learning	Product and process based learning

4.2 *Methods and solutions for reuse of experience*

Documentation of experience based knowledge may be 1) ICT-centric or 2) human resource management, HRM-centric (Carillo and Chinowsky 2006). The ICT-centric strategy is directed towards information management and communication using databases, project networks and collaborative tools. The HRM-centric strategy focuses on the establishment of a learning organisation, creation of networks, and identifies and disseminates lessons learned on previous projects, addresses organisational culture, etc.

In the investigated house building project mentioned in section 3.1 there was no attempt to use ICT for the purpose of collecting or distributing experience based information. However, the project consisted of 8 separate buildings erected consecutively, enabling HRM-centric reuse of process and product experience in this specific project.

Case studies of companies implementing systems for reuse of experience based knowledge, e.g. (Tan et al 2006), conclude that it is essential that experience based information can be created, stored, disseminated and used in a manner that is natural to project work and does not increase existing costs or tasks in a way that seems unnecessary or bureaucratic. Lessons learned should be documented at specific process stages, by a responsible person together with members of project groups, using specific templates and check lists, be included in the project report, and placed in a knowledge database on the Intranet.

Experienced based information may be handled by Groupware systems which enable and support teamwork. Groupware solutions handle unstructured information from various sources and include: workflow (task scheduling), multimedia document management, email, conferencing and shared scheduling of appointments. Groupware helps manage and track the project life cycle throughout its various stages (Rezgui 2001). Data warehousing solutions handle structured information by extracting data from a variety of distributed systems into a central repository. This is still in a stage of implementation and experimentation in the construction sector (ibid).

The development of strategies for experience based knowledge management should not focus solely on document based information, but must include personal meetings, seminars, video conferencing etc., to allow verbal and perceptual communication. A specific function as Project Knowledge Manager, PKM, is needed in a company that wants to implement experience based knowledge management.

5 CONSTRUCTION ICT IN A MEDIUM TERM PERSPECTIVE

5.1 *A global vision*

The medium term perspective for industrialization of the building industry, especially the house-building sector, is envisaged through a deeper integration of engineering and manufacturing, especially providing (potentially ambient) services at “interfaces” between the various processes (and involved actors) along the whole life cycle of the building, see Fig. 2. This will push flexibility in construction processes at an extreme with building components available as manufactured components, while at the same time transforming industrialization as a customer-responsive integrated product/component achievement system, with as many degrees of customisation as possible for the manufactured components.

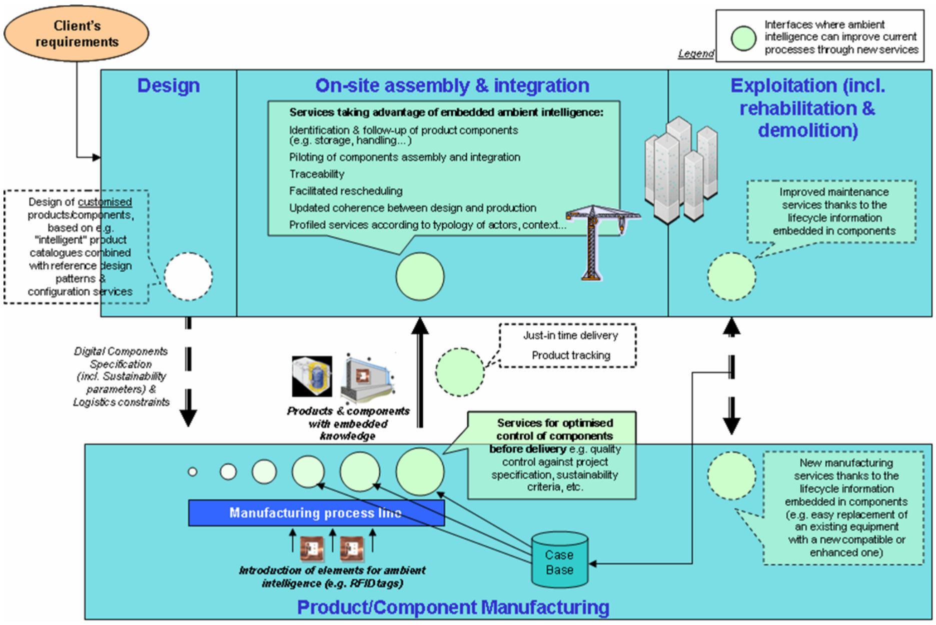

Figure 2. Industrialization of the house-building industry through integration of engineering and manufacturing, providing services at “interfaces” between building life-cycle processes.

Such a vision can be structured according to the following targets:

- Industrialized production has to be combined with individual design solutions of customized products/components: this means that, based on e.g. "intelligent" product catalogues (from manufacturers) combined with reference design patterns (available in some standard libraries, should they be proprietary or open), the design may be customized according to the client's requirements thanks to configuration services. This should lead to a growing world of pre-defined solutions providing options for customised configurations for specific situations, managed by future CAD systems.
- Before the manufacturing phase, a preparation phase is to be considered, that deals with developed planning/scheduling, cost estimation, potential instructions/-decisions for management of external constraints, control and follow-up of activities, initial identification of potential re-use of technical solutions, etc.. The idea is that the design phase provides as output for the next phases a structured description of the overall product concept and its related (sub-)parts, under the form of trees or networks of objects with clear characteristics (e.g. property sets) and interfaces: such objects should be instantiated from the so-called BIMs that, developed with a comprehensive methodology, are to be the grounding for future management of the Buiding lifecycle.
- From the design phase, providing "virtual" customised components (under some form of fully object-oriented specifications, with all types of parameters and constraints), the physical component is fabricated according to manufacturing-level production methods in factory and on site. Factory production in the future is likely to adhere to manufacturing methods adopted from other industries, enhanced by innovative services for optimised control of components before delivery e.g. quality control against project specification, sustainability criteria, etc.. All along the production line, the component under fabrication may embed information that is used at time of manufacturing, with innovative measurement techniques for assessment and quality control of materials on the production line and before arrival at the construction site.
- The component is then shipped with embedded knowledge to the Construction site (logistics may rely on just-in-time technique and product tracking to optimise delivery). On-site assembly methods make further use of component embedded knowledge, of high-precision positioning of components as well as intelligent machinery, and on real-time availability of digital site models accessible to site personnel via wearable terminals connecting to corporate information networks. It is worth noticing that some of the components maybe pre-assembled (or even pre-produced) in small mobile factories at or close to site or during transport, just like ventilation ducts, HVAC-assemblies etc.. Dedicated services have to be developed, relying on generalized use of embedded information and ambient technologies.
- Eventually final products (houses, buildings, etc.) may benefit from improved maintenance services that will use the lifecycle information embedded in the various components of the product, and will rely on specific software in charge of achieving globalised control or applying global strategy (according to well identified set of combined rules and constraints) for the operation and maintenance of the product. The information embedded everywhere in the final product may also be used (e.g. at time of refurbishment) to provide base cases for definition of new components adapting themselves according to the environment formed by the existing house or building.

To achieve such a comprehensive vision of future engineering / manufacturing, it is required to develop both new models and applications relying on up-to-date ICT (see next section). Realizing an integration of engineering, manufacturing and construction is the only tangible answer to ultimate industrialisation of the Construction sector: it will sustain the idea of a building or house no more being a long-lasting but inert object, but indeed being a living object and besides providing real services. This notion of "service" also induces a notion of measure (and therefore indicators and referentials), so as to assess the capacity of the building to provide with the required level of service(s), through the potential conformity of each of its components to be checked all along the whole life-cycle: this should allow to avoid future situations where, for instance, initially estimated energy performance of a building and the real performance noted in use is dramatically different.

5.2 *Recommendations for future R&D targeting industrialisation*

Recommendations in this section, targeting potential ICT-development goals, do not claim to be comprehensive or exhaustive: they are based on current investigations in terms of future R&D in Construction ICT (e.g. undertaken in the EraBuild Strat-CON project), the proposed global vision in section 5.1, and make the link with the more specific areas that have been introduced in the previous sections of this paper. The table below provides an overview of some key points targeting the ICT side supporting such future industrialisation:

Table 2. Key points of ICT support for future industrialization.

INTEGRATION OF APPLICATIONS - STAGES FROM FUNCTIONS TO TECHNICAL SOLUTIONS	*REUSE OF EXPERIENCE BASED KNOWLEDGE*
• **IFC & BIM development**: this includes formalised development of the Core and Property sets to guarantee continuous evolution of structured BIMs supporting digital mock-ups and processes above it. • **Ontologies & Standardised classification schemes**: identification of key concepts, semantic description of products and their characteristics, enabling EU-wide semantic search of product information over the Internet. Ontologies should target lifecycle phases or topics (e.g. facilities management), and mechanisms should be	• **Advanced/distributed CMS** *(Content Management System)***:** Dedicated solution, providing advanced services (profile and context based information push for instance). These solutions will also rely on open common agreed standards to exchange knowledge across different CMS. • **Open framework for data/ knowledge sharing:** Generalising the previous bullet, development of platforms and services dedicated to knowledge sharing in inter-organisational environments based on user profiling, and push of adapted/relevant information to each profile. These should ide-

built to allow for interoperability and mapping between these ontologies when and where needed. BIMs & ontologies should allow assessment and quality control of materials and components. • **Mobile applications, e.g. RFID, integrating “adapted knowledge processing”**: RFID technology automating the critical task of documenting the delivery and receipt of uniquely tagged construction materials and equipment.RFID technology tracking tagged items in the construction process, all the way from fabrication through installation and Quality Assessment monitoring. • **Integration of design, production & assembly**: this implies the elaboration of new processes relying on BIMs and ontologies to integrate model-based design, specification of manufactures products and components (through e-catalogues), and Customer oriented configuration of manufactured components. The objective is to develop a new approach at the construction site integrating a generalized use of ambient and semantic knowledge technologies (especially RFID technologies) to ensure optimisation of manufacturing, integration, resource management and quality control.	ally be transparent to the users and be accessible by different applications and search services. Furthermore, they should provide relevant groupware functionality at an industry (e.g. network of experts) level. They should allow to deal with both ICT-centric and HRM-centric aspects of experience based knowledge documentation. • **Knowledge /best practices repository:** Methods and tools for the identification, capture, consolidation, and dissemination of best practices, and tools that enable the search and retrieval of past experiences, good (to-do) and bad (not-to-do). • **Knowledge mining and semantic search:** Development of searching methods to facilitate and extend information search and retrieval of knowledge. Searching capabilities may be extended to non textual content (multimedia formats), along with tools and application components for managing the business logic, and rules from different information sources and applications.

6 CONCLUSIONS

The use of 3D applications and digital mock-ups must start early in the processes requiring development of common delivery standards. Central to the uptake of model based information is its practical applicability for quantity take-up. Project management must take an active responsibility for ICT-based information management, e.g. through the dedicated role of Project Information Officer. There are already several kinds of 3D based applications ready for uptake as soon as the circumstances for their use are clarified. Examples of applications concern: geometrical modelling, energy calculations, resource specification, and production control. The reuse of experience based knowledge is central to the development of any industry, and promoted in partnering-like processes, and where product development is an important competitive factor. Organisations must establish a favourable climate for innovation and learning. Knowledge management solutions must be both ICT-centric and human centric. In a medium term view these developments could serve both industrialised and fully industrial building processes, characterised by integration of engineering and manufacturing, with applications servicing the interfaces of the various processes. Important development areas are interoperability; BIM; shared semantics for design, production and facilities management; knowledge management; and mobile applications. Developments in these areas require cooperation of industry and R&D in joint analyses of information management in practice.

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