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Title:

Virtual Buildings (VB) and Tools to Manage Construction Process Operations

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Abstract: *Previous and current research and commercial activities within the virtual building area indicate that models are being developed to test and simulate different aspects of the building, but never being used to manage construction projects.*

This paper formulates visions and outlines solutions for how building process data can be used to represent and co-ordinate meta level digital virtual building models, generate construction site process models, capture as-built data from construction process, and handle external supplier information. A crucial part of the VB is the Project Management System (PMS), which is designed to manage the information input/output of the proposed virtual building and external processes. The PMS is outlined and specified in the paper according to functionality, part of user environment, and structure and underlying digital representations. The outlined framework will include IT-tools as temporal databases, semantic web technology and emerging web services.

The PMS will support practical integration of partly redundant building product and process descriptions, improve capturing of as-built data to raise quality of the construction process and subsequent building use and maintenance, contribute to development of unified high (meta) level building process descriptions, and support project experience capturing and re-use.

Keywords: *Virtual buildings, project management, temporal data, knowledge management, semantic web*

Background

This project is intended to help to fill a gap in the research of existing and emerging IT. It addresses information generation and use on construction site and workface in particular where the construction 'product' is being produced and where information is needed to deliver a high quality product, safely within the set time and budget. In this context, the overall aim of this research is to re-engineer the management of information needed by and generated by construction site through the utilisation of the virtual building concept and to develop the technology needed.

Models describing the building (product) are slowly developed oscillating between low and high degree of formalisation for some decades now, from the Cambridge BDS system to today's system based on object oriented and parametric models. Temporal aspects are though only sparsely taking into account. Virtual Building (VB) models are in its infancy of development though highly supported by introduction of operational standards like IFC <http://iaiweb.lbl.gov>, emerging possibilities to efficiently model temporal aspects (Snodgras, 1999) and use of Internet based distributed handling of models, applications, and meta data.. (See also web services <http://www.w3.org/2002/ws>, and semantic web <http://www.w3.org/2001/sw/>).

Visions are presented on how physical reality is connected to a virtual building model. Primary focus is on support of construction process and capture of as-built information for later use in O&M and building usage. A Virtual building model containing building product temporal and meta data will support a Product Management System (PMS) in capture, storage and supply of building process data. One area will be scanning technologies linked to digital models, i.e. scanning psychical entities of the product under construction and assemble detailed 3D as-built model. This will be super imposed on the as-planned model and progress will be calculated according the evaluation of the two models. Another way of automatically integrating actual and digital buildings is through embedded technologies and GPS systems. A number of issues, focused upon in this paper, arise regarding the proposed PMS relations to building product models and application sub models, process models and temporal aspects.

Relevant industry activities and research projects

Substantial research efforts have been exerted in the area of IT applications in the construction phase of the building process industry

Technology / *Function*	3D CAD/VR	4D CAD	GPS/Laser	Neural Network/GA	Fuzzy Logic	Database Management	Knowledge-based/AI	Internet Applications	Multimedia Applications	Digital	Portable/Wireless	Robot/	EDM/Bar Code
Scope Management													
Contract Administration							1	1					
Change Management						1	2						
Delay/Claim Management									2				
Cost Management													
Estimating/Budgeting				1		1	1						
Cost Monitoring/Control	1			1		1							
Resource Use/Control	1			3		3		1	1		1		2
Time Management													
Work Package Definition						2							
Scheduling	2	3	1	1		2	1						
Progress Monitoring/Control	2		1	1		2	1	2	2		1		
Work Management													
Site Layout/Temporary Facility Management	4	1		3	1	2	1						
Workflow/Path Control	1		3			1	1						
Process Simulation	3					1			2				
Work-Face Instruction and control				Gap in the Research									
Construction Operation	4		8	1	1		3		1	2		5	
Work Inspection/Approval								1			2		
Procurement/Logistics	1					2	3	1					
Documentation	2		4			3		2					2
Communication	2	1				2		7			1		
Quality Management	2		4			2	1		1		2	1	1
Safety Management	3		2			1	2						
Risk Management							1						

Figure 1. Function-technology matrix for identifying gap in research in construction IT (Sriprasert, E. and Dawood, N., 2001a). The number in each cell represents the number of related papers.

An extensive literature review on this subject has been carried out by Sriprasert, E. and Dawood, N., 2001, and a summary table of the findings is presented in Figure 1. This has been assembled from 74 papers published in the past 6 years. It shows that recent research mainly focuses on the supply of management and control information in favour of high-level managers or planners. None of the papers considers what information site mangers at the work-face actually need in order to perform the most important function of construction the actual building and managing the project. There is, therefore, a tangible research gap in this area.

In addition to the overview in figure 1 we also give reference to some recent relevant research.

(Karhu, 2001) presents a new generic construction process modelling method, GEPM. GEPM that uses object-oriented principles, and has borrowed features, such as activity, task, and temporal dependency, from methods like IDEF0 and scheduling.

In (Burku et.al., 2001) a vision is discussed for utilising advanced sensors and integrated project models at construction sites for active project control. Focus is on advances in embedded sensing, laser scanning and wearable computer technologies. An overall central AEC is outlined containing Design/Product model, As-built Model, Schedule/process model and a Design/Spec. model.

The introduction of IFC based objects gives us more freedom to efficiently build and handle a building product model also for capture of as-built data and use in subsiding use, operations and maintenance phase of the building life time. IFC can partly handle time dependent properties.

The authors are currently involved with a number of R&D projects in the areas of IT applications to the building processes and the idea is to built on these projects to deliver the VB initiative.

The Virtual Construction Site (VIRCON) project is about developing a methodology and Decision Support System (enabler) for evaluation, visualisation and optimisation of construction schedules, see (Dawood, et al 2001). The project has delivered a number of tools (VIRCON Database, SPACEMAN, ProVis, AreaMan, PlanMan), see (Dawood et al, 2001) and (Dawood et al, 2002), to optimise schedules and products and processes. The VIRCON tackles strategic issues about construction schedules and space allocation and some of the VIRCON tools are discussed in separate papers in this conference.

LEWIS (Lean Enterprise Web Information System) is about re-engineering workforce information where actual production is being performed on construction sites and provide tools to capture and process construction site information, (Sriprasert & Dawood 2001b). The project argues that once construction schedules are rehearsed and the supply chain is in place, the next stage is to communicate these schedules with the Forman and construction Ganges at the workforce. This project proposes a framework to generate clearer execution plans, which is based on well-defined work packages using lean databases and visualisation technologies. It is anticipated that delays and rework caused by informal and unclear instructions will be lessened which, in turn, will lead to improvement of on-site productivity and quality.

The EU DIVERCITY project, Distributed Virtual Workspace for enhancing Communication within the Construction Industry, aims to develop a "shared virtual construction workspace" that will allow construction companies to conduct client briefing, design reviews, simulate what if scenarios, test constructability of buildings with time dimensions taken into account, and communicate and co-ordinate design activities between teams. (Christiansson et.al., 2001), (Fernando et.al., 2001).

We will also mention some further software development initiatives that are of relevance for building a PMS. The Solibri system that enables a IFC based product model to be checked according to user specified constraints <http://www.solibri.com/>. VirtualSTEP 4D Planner Navigator planner <http://www.virtualstep.com/> and Visual Project Manager from Genisys <http://www.genisystems.com/vpm.html> for integration of Cad drawings and Microsoft Project files.

An overview of current work on implementing IFC in applications are found at Building Lifecycle Operable Software (BLIS) <http://www.blis-project.org/> and <http://www.bauwesen.fh-muenchen.de/iai/ImplementationOverview.htm>

The Project Management System, PMS, in context

PMS properties

We mean that it is now fruitful to design and implement a project management framework taking into account the ongoing standardisation efforts such as International Standardisation Classes (IFC), Extensible Markup Language (XML), and Resource Description Framework (RDF) also taking into account existing building classification schemes. In addition to this we also mean that it now is convenient to start implementing operational temporal databases as an extension to Structured Query Language (SQL). We also find a growing interest to develop systems that support project management information exchange using standards like IFC (Froese, 2001).

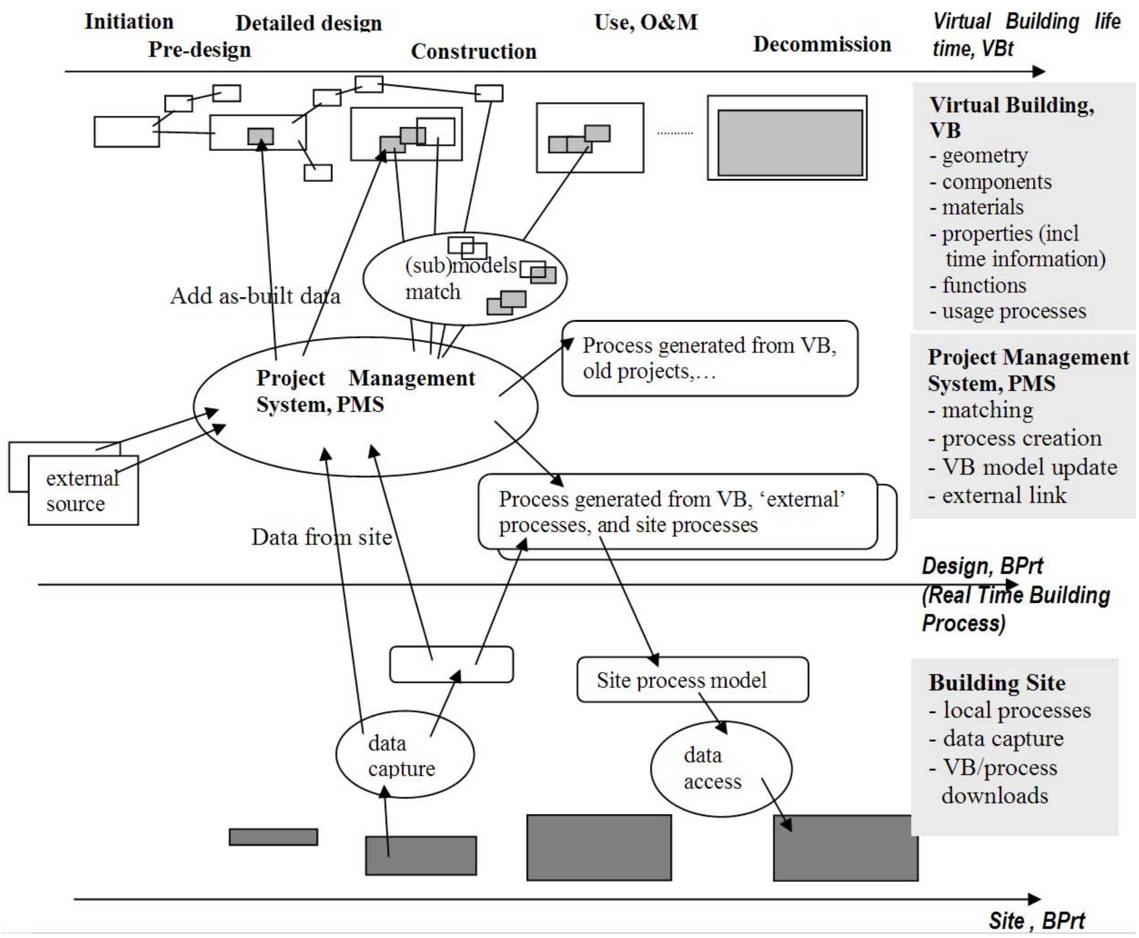

Figure 2. The Project Management System (PMS) will integrate Virtual Building models, Site Process models, and external information containers. It will also manage matching and updating of the VB sub models as well co-ordination with building site activities. BPrt = Building Process real time, VBt = Virtual Building time to describe time points in life of Virtual Building (sub)models.

PMS, see figure 2, will support integration of properties of Virtual Building models, and site process models especially on meta data level. The main properties of the PMS will be

- capture as-built time marked information in the constantly improved virtual building model;
- handle time dependent data efficiently (intervals/periods not only instant time points);
- offer new services for the construction site;
- handle a non-redundant meta description (model) of the building process including time marked virtual building data;

- handle co-ordination, matching and updating procedures for virtual building and site process sub models;
- provide interaction through a digital Process Manager (PCM);
- provide a adapted distributed User Environments (EU)

Certain emphasis will be on

- constitute a framework for integration on project management level integrating applications and building process models using XML formalism and existing exchange formats like Simple Object Access Protocol (SOAP) in a peer-to-peer fashion (see also the DIVERCITY < http://www.e-divercity.com/> and IFC Model Server projects < http://cic.vtt.fi/projects/ifcsvr/>);
- contain a meta data description (data dictionary, XML, RDF name spaces) for project management support allowing access to information in different representations (IFC models, documents, drawings, multimedia information);
- provide rich web-based multimedia interfaces to underlying models and applications (virtual workspaces, interactive 3D models, space and time browsing facilities, meta search mechanisms)

Figure 2 shows overall the relation between models that are used to describe the design artefact (the Virtual Building), the Project Management System (PMS), and models that support the activities at the construction site.

Virtual building Model

The virtual building contains all documentation of the building including drawings, models, documents etc. It will normally contain redundant information and temporal information describing discipline models and sub models of the building over time (Christiansson, 1999). The virtual building should:

- support design activities, construction planning, constructability, O&M
- provide data to construction site process models
- be augmented with as-built information as construction proceeds
- capture valid time (related to building process events) within building project and between projects
- support existing and upcoming types of organisation in the construction industry

Construction site Model

The construction site is where construction managers convert resources (materials, men, machines, money, information, specification, regulation, etc) and method statement into activities and these activities will produce the final product under a given management and control system. In order to have a meaningful construction site model and to use such a model for the control process a clear dependency and interactions between process (resources and activities) product models should be established. Resources outputs, productivity, cash-flow, costing, transactions should be all modelled. It is proposed to have a project-centric database that uses IFC/Uniclass to model and structure the information.

Construction site model should have a element of ‘valid’ and ‘transaction’ time (see 'Temporal Databse Implementations' below) so that actual construction can be controlled and monitored. Construction site model will be able to handle redundant data that can be used for knowledge extraction and usage for future projects.

Project Management Model

Project management by definition is the process of planning, organising and controlling construction processes and activities. The main functions of the PMS will be: release plans and schedules to the construction site (and more specific to workface), undertake constraints based schedules by comparing ‘available’ against ‘needed’ resources, capture construction progress through embedded and scanning technologies, update schedules and calculating progress. One important aspect of the PMS will be the real-time calculation of cash flow and cost of construction operations. It is envisaged that intelligent systems (could be in a form of knowledge base systems or agents) will be developed and integrated in PMS to perform the functions outlined above.

User Environment - UE

The user environment provides virtual workspaces (VW) where we should be able to handle the building artefact from idea, design, and construction to usage, maintenance, demolition and recycling. We will thus include all the traditional activities like client briefing, design, and construction simulation in the

VW activities, see also (Christiansson 2001). The Virtual Workspace should thus be able to contain, describe or reference to:

- building *organizations and management processes*;
- the building (*virtual building*, VB) and it's components;
- production systems and *construction* activities;
- *usage and maintenance* of the building artefact;
- *user models* that will highly influence computer interfaces and collaboration styles;
- *ICT tools* especially those that are new and unfamiliar to the process participants;
- new types of *services* and linked building applications;
- VW *administration* processes.

An efficient user environment is a central issue of the PMS and it must be designed in close collaboration with end users. In this process it is extremely important to bridge the gap between the user requirements specifications and the actual interface design and implementation of the underlying operational models of the distributed virtual workspace system (see also Christiansson et al. 2001).

Design and Implementation of Data Models

The design and implementation of the Project Management System, PMS, raises some fundamental questions

- how can we introduce temporal parameters as an integral part of the system?
- how can a virtual building meta data model be implemented?
- how can we implement knowledge management procedures in the system?

Fortunately recent advances within the knowledge representation research domain and standardisation efforts within Internet based information handling have opened up for creative design of systems taking into account the raised questions. We refer to temporal databases, structured information handling using use eXtensible Markup Language (XML) and Resource Description Framework (RDF) formalism, and semantic web technology.

Knowledge Representation issues

Building product and process models have over time been implemented using a wide variety of knowledge representations. We mention

- relational databases;
- analogue representations (photos, video, hand drawn sketches);
- vector and bit mapped graphics;
- objects;
- rules and predicate logic in knowledge based expert systems;
- hypertext (manly in web based environments);
- decision tables.

The building industry unlike many other sectors work on products and within processes that are hard to formalise yielding models with overlapping information stored in large integrated models containing redundant information. Most products are fabricated in short (or one item) series in projects of limited duration (not organised in a permanent organisation/company with standardised procedures, concepts, and products).

We have above commented on virtual building models. These models will to higher degree contain formalised components usable in national and global building context. This is due to a global market and expanding use of electronic commerce and Internet based e-business portals. Digital infrastructures gives opportunities for digital catalogues and distribution of building components that can easily be incorporated in (attached to) building product and process models. Digital representations can also be incorporated in the physical component itself e.g. with information about its identity, properties and maintenance instructions.

The fact though remains. We will have to deal with a combination of overlapping knowledge representations with possibilities for high level meta models containing non-redundant building product and process models.

We will also see a rebirth of implementation of more or less intelligent behaviour of systems due to favourable scale effects (access to huge amounts of information) caused by global standardised Internet services.

Temporal Database Implementations

From (Christiansson, 1999)

With temporal data introduced into the Virtual Building (VB) new opportunities arises:

- we can store snapshots of different building processes (e.g. alternative designs) and *backtrack* to make a re-design or re-simulation with changed requirements (regeneration of the VB);
- it should be easier to document and retrieve *causal connections* over *time* and *space* in the VB;
- storage of *lines of reasoning* and possibilities for analyses of their relations;
- improved possibilities for efficient updating of VB model with *as-built data;*
- effective use of the time parameters in the *life time documentation* of building behaviour;

Temporal extension to traditional relational database systems, see also (Snodgras, 1999) and (Böhlen & Jensen S., 1997), enables us to handle queries like 'how many resources have we used over different time periods at different building locations?', 'when and how many carpenters were engaged at the same location at different time periods/tie points?'. These types of questions are very difficult to handle in conventional databases but will help us to capture experiences for better planning of resource allocation and to make complex time dependent queries. We will be forced to handle both so *called valid times* (times related to events at construction site, virtual building states and design activities) and so called *transaction times* i.e. when the supporting systems were actually augmented and updated). These aspects can be handled separately or in a mixed mode in bitemporal tables in the database part of the PMS.

Semantic Web properties

The Resource Description Framework (RDF) - developed by the World-Wide Web Consortium (W3C) - provides a framework for metadata interoperability across different Internet based resource description communities <http://www.w3.org/RDF/>, (RDF, 1999). The significant benefit that RDF brings is that it will allow the resource description communities to primarily focus on the issues of semantics rather than the syntax and structure of metadata. The semantic webs (Berners-Lee, et al., 2001) will use eXtensible Markup Language (XML) <http://www.w3.org/XML/>, RDF, and Ontologies (with taxonomy and a set of inference rules) as basic building substances. See also (Christiansson, 1998). Products like the Ontobroker (Fensel et al., 1999) are appearing that comprises languages and tools, which allow us to semantically mark-up content on web pages and let the user semantically query the WWW taking advantage of semantic inferences. We envision that it will be feasible to define high level concepts and semantics to be incorporated in the PMS to match and handle building process sub models.

Discussion and Conclusions

The paper puts forward a vision on how existing and emerging technologies can be used to develop a framework that will integrate and further develop virtual buildings (VB), construction site models, and project management systems (PMS). Focus is on handling of temporal and meta level data using temporal databases and the semantic web formalisms. The PMS that will be accessible for users through virtual workspaces will have knowledge management capabilities to handle VB sub models matching and update with respect to as-built data, and handle information flow to and from construction site.

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