Enterprise Integration of Future Building Design Systems

GODFRIED L.M. AUGENBROE*

ABSTRACT

The paper deals with the project and enterprise environment of integrated building design systems (IBDS), such as the one targeted in the European collaborative research project COMBINE. The research has concentrated on the concept of a set of separate actors, grouped around a common data repository. Its deliverable consists of the first large-sized fully implemented conceptual building model. The actual data exchange is realized by STEP interfaces supported through a COMBINE interface kit. The resulting prototype was demonstrated in a workshop with design practitioners.

The second phase of COMBINE has started recently and will build upon the above deliverables by combining them into an operational system, according to functional specifications derived with the help of practitioners in typical design office settings.

Key Words

information modelling; CAD; building design; design management; enterprise management

INTRODUCTION

Many studies have identified building design as a multi-actor cooperative process which could greatly benefit from IT as the key-enabler of integration of a fragmented industrial process. Among these we mention two studies recently commissioned by the Commission of the European Community (Dupagne, 1991 and Augenbroe and Laret, 1989).

The first one has prepared a building-focus within the ESPRIT-CIME area, whereas the latter defined a new topic, called COMBINE (Computer Models for the Building Industry in Europe) as part of the JOULE programme. ESPRIT (European Strategic Programme for Research and Development in Information Technology) and JOULE (Joint Opportunities for Unconventional or Longer-term Energies) are both large funded R&D programmes, involving international cooperation on a European scale across EC-member states. The COMBINE pilot study and the ensuing call for proposals led to the joint COMBINE project, carried out by 14 partners from 8 countries (Augenbroe, 1992). Its long term goal is the development of a future generation of Intelligent Integrated Building Design Systems (IIBDS).

* *Associate Professor, Faculty of Civil Engineering, Delft University of Technology, Delft, The Netherlands.*

Realistically, the short term goal is to concentrate on integration, rather than "intelligence". The first phase (1990-1992) of the project was thus meant to take a first step towards the development of an IBDS through which the energy, services, functional and other performance characteristics of a planned building can be analyzed.

Through its data-integration emphasis, the research has concentrated on the concept of a set of separate actors, grouped around a common data repository, holding the implemented conceptual building model. The actual data exchange is realized by present PDT (Product Data Technology), which will elaborated in the next sections.

The COMBINE outcome is a prototype which consists basically of a data-exchange infrastructure through which a number of "accidental" design tools are able to communicate, or rather design tools were able to download building data subsets from the central database and store updates, *ie*, the output of a design tool session.

The second phase of COMBINE has started recently. It will build upon the above deliverables by combining them into an operational system, according to functional specifications derived with the help of practitioners in typical design office settings. The targeted project support will require an extensive additional modelling effort "along the enterprise/project axis of the complete integration space". At the start of the project, a number of target building projects will be selected to drive the specification effort. They will also serve to act as field test sites for the resulting IBDS prototype.
The second phase will result in:

- one of the first actual multi-actor IBDS prototypes
- thorough specifications of the type of IBDS's that can be absorbed in practice (*ie*, in real-life enterprise-project settings)
- exploration of necessary features of an IBDS through field testing.

Apart from these issues, we will concentrate on the major contribution that can be made to the overall life-cycle management of IBDS's by embedding these operational systems in "live" modelling environments thus guaranteeing easy and controllable updating *vis a vis* the challenge of introducing the new system in the existing enterprise procedures.

SURVEY OF FIRST DELIVERABLES

The conceptual and software architectures of the "delivered" system of the first phase of the project are shown in Figure 1. It can be viewed as an off-line data exchange system (DES) for a limited number of design tools. The DES prototype consists of a set of design tool prototypes (DTP), logically shared around the common conceptual data model. The Application Interface executes the mapping between the IDM and the aspect model of the design tool.

The six DTP's that are developed address the following tasks:
DTP-1: Construction design of external building elements
DTP-2: HVAC-design
DTP-3: Dimensioning and functional organization of inner spaces
DTP-4: Thermal simulation tool in the late design stage
DTP-5: LT method in the early design stage
DTP-6: Radiator network design.

At this stage of the overall research strategy no attempt is made to include an architectural design actor. This will be one of the targets of the second phase.

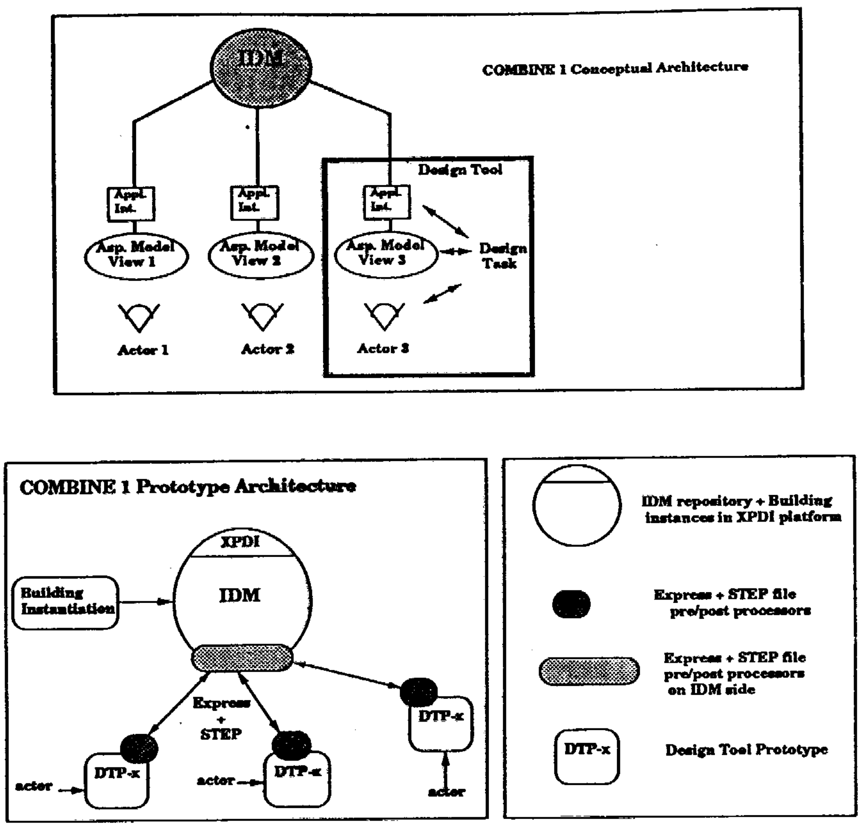

Figure 1. COMBINE1 Prototype Architecture

The data exchange is realised through the following IT-tools:

- a conceptual building model (IDM) that integrates all DTP-actor views.
- implementation of the conceptual IDM on a powerful software platform.
- data exchange facilities through which the DTP's can communicate with the IDM, delivered as a STEP-based interface kit.

The actual communication is accomplished through STEP neutral file (ASCII) exchange.

Conceptual IDM

This is a key-output of the COMBINE-project, as the IDM must enable the integration of all communicating actors. A challenging and time-consuming effort concerning the data modelling and integration of the six actor-views resulted in a generic conceptual building model. NIAM was chosen as the modelling language, supported by dedicated data dictionaries. It should be stated that the present IDM meets only a few of the long-term requirements on ultimate building models; the output reflects the present state of the art.

For easy access to the resulting model, an EXPRESS browser is provided. The browser enables easy navigation between entity definitions, with access to EXPRESS text and dynamic updates of user-defined concepts and creation of new entities. Additional graphical information can be stored with entities, enabling a customized presentation of the model to broad audiences.

IDM Implementation

The implementation of the IDM relied on the XPDI software environment used by the French group in charge of this task (Poyet, 1993). The translation from conceptual schema to the XPDI implementation involves the definition of classes and class-hierarchies, the direct translation of the relationships from the NIAM diagrams and the addition of the implementation structures (frame-slot approach) within the XPDI station.

The following additional activities were carried out:

- development of a XPDI-function for exporting the schema in EXPRESS format and producing STEP-neutral format files for instantiated models, according to subschema-specification in EXPRESS.
- development of the COMSET system (as part of XPDI) which supports rapid definition of NIAM structures. The tool supports NIAM diagram generation, interactive update facilities, and NIAM to EXPRESS translation.

IDM-Data Exchange Facilities

The COMBINE approach is at this stage dominated by the view that DTP's act as "remote" actors, in a heterogeneous (with respect to hardware and software) system of loosely coupled actors. Thus the basic data exchange is accomplished through ASCII file exchange with full adherence to the STEP-standard (off line data integration). The off-line data exchange facility is provided as a development kit enabling external DTP-developers to interface their DTP to the COMBINE IDM.

The interface kit provides:

- an EXPRESS parser delivering C++ software (i.e. class definitions) that together with add mapping software (DTP-specific) forms the mapping module.
- C++ software that handles generic functions that should be available in any mapping module, like import and export of STEP-files.

No generic solution for the DTP-specific mapping (e.g. a mapping language) has been attempted as yet. At this stage every interface development has to code DTP-specific mapping functions from scratch. Depending on the requirements of the DTP, the outcome of the mapping process may be a plain ASCII file, a database or a neutral "object dump" that can be moved to another software environment.

DTP's

The DTP development has generally been done according to the following steps:

Definition

- Define the design-related function that a certain actor can perform and specify a design tool with which to perform it. In the present set-up, there is a one-to-one relation between design-actor and DTP.

Specification

- Define the actor's view of the building, hence specify and formalize it into a formal conceptual model (DTP-View Model), describing the semantical meaning and relations of all input and output concepts in suitable model formats. In the project, NIAM is used as data model and a customized data description form (IODD) is used for adding additional semantics.
- Specify the DTP-functions in a formal way, e.g. relating the DTP-functionality to the overall building design process (external link) and also decomposing the DTP-functions into smaller ones, performed internally, e.g. by embedded evaluation and analysis tools.
- Define the mapping between the integrated IDM (supplied by IDM-conceptual team) and View Model and give feedback to IDM-team on encountered problems. This process enables an iterative refinement of the IDM.
- Make a requirements specification (IT-resources) and specify development approach.

Implementation

Each team has built its DTP in a suitable hardware/software environment of its own choice. No standardization of implementation approaches is required, as heterogeneity across DTP's is one of the starting points.

Each application contains:

- an application interface for two-way data exchange with the IDM, handling the mapping/translation functions. This interface will in most cases be a separate module built with the help of the interface kit, distributed by the IDM team. The standard interface (a minimal option for each DTP) will be based on EXPRESS/STEP file-based data exchange.
- a user interface, giving a design-actor access to and control over the DTP-functions. In most cases the user interface will also allow access to the interface module, eg for data selection.
- the application (run) module itself, which may use existing BPE-modules.

Additionally it may contain:

- a local database to hold the aspect model (in fact, this is the standard approach to the application interface, but without supplying persistence).
- a local knowledge base, designed to support certain intelligent functions.

Prototype Functionality and Demo-workshop

It is useful to distinguish three separate levels of functionality:

- Operational level: this is the level where we show how the data exchange "works", through a common language (IDM) and the data exchange facilities (on IDM and DTP-side).
- Tactical level: this is the level where data exchange operations are built upon the operational sub-level of a set of design actors, to support cooperation among design actors, engaged in a building project.
- Strategic level: Full design support-level with dynamic control support built into the system, along with adequate enterprise integration and adaptability support.

The first phase was intended to produce adequate functions on operational level, *ie*, getting relevant Product Data Technology in place to effectively support the exchange of data in a heterogeneous system. On tactical level moderate goals were reached, in the sense that the demo showed a set of actors exchange data in the context of a simulated project, according to a hardwired pre-defined scenario. The primary aim was to be able to show one support layer of cooperative group work, *ie*, the data exchange layer, in action, be it in a laboratory setting. Full support of the tactical level would have required a much bigger effort, both in the full dynamic modelling of all actors as well as in robust implementation able to support real-life projects. Needless to say that the first phase did not target any additional functions on strategic level. It should be clear that the present COMBINE deliverables are exclusively on data-integration level, thus inherently very limited in their potential of providing dynamic design support. Summarizing, the results of the project concern general facilities for data integration of a set of tools in early building design.

Results in an Enterprise Context

There are a number of restrictions when it comes to the design support functions of the present deliverables:

- No attempt has been made to clearly define a project-setting, e.g. participating actors involved in a specific design task. In other words, the resulting tools were not meant to cover a specific design scenario.
- As a result of this, the resulting suite of tools/actors represents a more or less random selection in an unspecified design process and project environment.

In terms of "semantic coverage" of the IDM, there are strict limitations as well:

- only the data views of all actors are taken into account and integrated in one common central model. Strictly speaking, the present IDM's semantics are confined to the six design tools considered. It is expected however that the common model is sufficiently general to serve other tools from the same disciplines as well.
- extended levels of coverage would have to deal with purpose, intent and other operational issues, associated with the data. Only at these levels one would also be able to provide support and inter-actor control of the dynamic migration and enrichment of data as the design progresses. Support of these levels would obviously, apart from a very rich building model, require data sharing rather than just file exchange.
- ultimately, we target full concurrency support where conflict detection and negotiation-support are adequately supplied.

COMBINE2 TARGET

The extensions of the first phase deliverables in the second phase are primarily towards delivering project support to real life enterprise environments. These extensions will predominantly address issues on tactical level by focusing on a number of project/enterprise environments, identifying the actors in a number of scenario's and configuring the exchange system accordingly. The exchange control offered by the system will be of moderate flexibility, hence functionality on strategic level (assuming flexible, intelligent and eventually concurrent multi-actor control) will not be offered. An abstract view on the extensions that the second phase will cover can be conveyed by using the "integration space" as an abstract space in which integration views exist along four separate orthogonal axes. Figure 2 locates the COMBINE1 deliverable within a limited "project window" in the flat actor-life cycle plane.

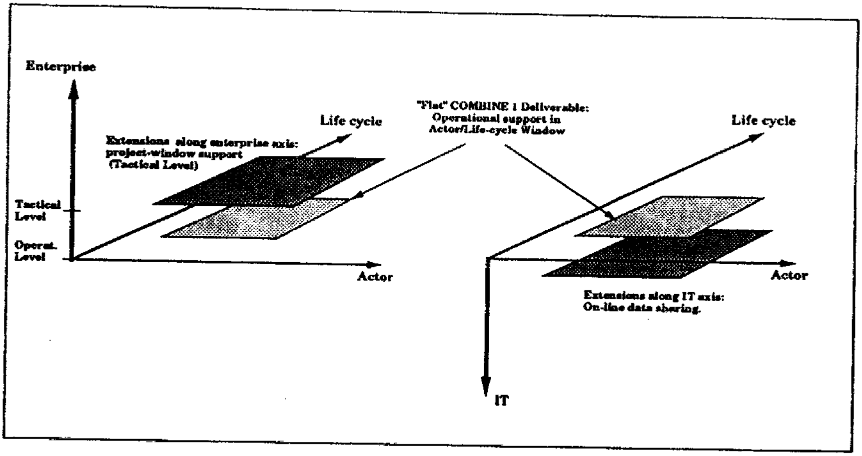

Figure 2. COMBINE Deliverables in Integration Space

A "project window" borders the "playing field" of a number of actors along the Actor-axis and a limited life-cycle span along the second horizontal axis thus identifying the "horizontal" project support range.

Within this limited range different levels of support can be identified, according to the two remaining integration axes:

- enterprise integration: each partner/actor in a building project is part of an enterprise-specific management structure, reflecting among others the one-to-many relationship that exists between enterprise and project.
- IT-integration: this axis covers the panacea of IT tools, methods and architectures. It more or less signifies the level of IT sophistication of the system, both in hardware/software terms as well as in the semantic coverage of the information within the project window.

As Figure 2 suggests, COMBINE2 has chosen to concentrate on enterprise integration and will only moderately seek to extend the present range along the other axes. This is a result of the conviction that building industry has to gain belief in the new technology before they will be prepared to make any significant contribution to PDT by investing in the initial modelling efforts necessary to widen the range in the horizontal plane (the primary short term STEP goals), *eg*, by aiming for industry-wide STEP Application Protocols.

"Vertical" extension in the level of IT-support (axis four) is significant with respect to the type of concurrency of the interaction in horizontal planes, *ie*, between actors. The data integration is usually built on the premise, that the exchanging actors act only on predefined states of the product specification, whereas the semantic coverage in the conceptual model is mostly directed towards (rigid) product description, with little or no design support semantics realizing that the present COMBINE result is thus "flat" with respect to concurrent engineering support, it is helpful to distinguish different levels of concurrency support, that could be targeted in this and the next stages.

Subsequent levels of increased functionality address:

- "on-line data exchange": adding some (minor) level of design support through active sharing of data and behaviour.
- "design support": adding extensive design semantics in the common conceptual model, thus providing design support to a range of design operations (on a "design per view" basis).
- "concurrent design support": adding explicit support for simultaneously operating actors, i.e. explicit interaction support between multiple actor-views.

It is important to note that each additional level requires a leap in the semantics of the information model required to support the operational system. The targeted level in COMBINE2 will be on-line data access to the IDM in an ODB data server environment, paired with standard off-line exchange for those design tools that do not require "direct" interaction. Adequate data exchange tools will be provided following the STEP Data Access Interface Specification (DAIS); suitable mapping mechanisms and control mechanisms will be added to support this level of functionality.

Specification of Suitable "Project Windows"

Figure 3 shows the target of the IBDS-specification done in Task 1 of the project.

Basically we are targeting a number of real-life project environments which will then be used to drive the specification and ensuing configuration of the IBDS-prototypes that will result. At this moment, a number of potential project-windows offered by end-user groups in several countries are being explored together with the enterprise-actors involved.

For any project-window, the IBDS should at least be able to support the following functions.

- Supports a real-life function in building design, *ie*, IBDS functions match a (range of) functions of several actors in building practice in an "actor/life-cycle" window of a building project.
- Constitutes support for a "connected" scenario in that window (this is in fact a constraint for real-life use).

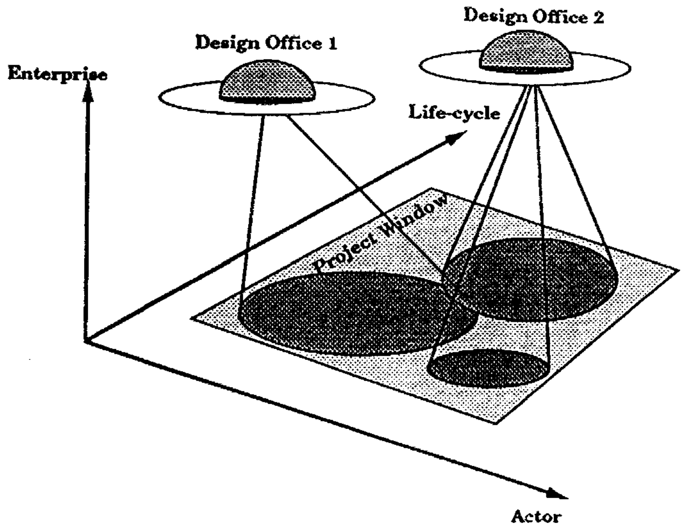

Figure 3. The Search for IBDS-"project-windows"

- Can be tested in an "isolated" environment within a real project. Field testers will have to be able to further adapt the IBDS to make this possible.
- Offers adequate functions to "start up" a project, *ie*, at the front of our time window of the IBDS we must be able to populate the building data base with all information already generated.
- Must offer adequate functions to "export" the project beyond the backend of the IBDS time window.
- The functions offered must stay close to present practice and be based on existing tools. This is related to the emphasis on supplying added functions through integration rather than through new design tools.
- Additional design support (through online actors supported by CAD systems) and data exchange support for "external" evaluation (through off-line actors with STEP interfaces).
- Online actors will supersede all other actors and will in fact control the system.

These specifications will be further specialized and refined to account for the specific actors, functions, tools, project type, time-span of each of the selected project windows. Our development approach reflects this by first developing a generic data exchange system (DES), acting as the "exchange engine" as the kernel for further configuration into an IBDS through adding specific tools, interfaces, etc. These IBDS's will then be subjected to field tests in the real-life project window environment, *ie* in their "natural environment".

Development of IBDS Prototypes

The global software architecture of DES and IBDS prototype is shown in Figure 4. In view of the available resources we are targeting, at most, two CAD-based online actors and upto five off-line actors.

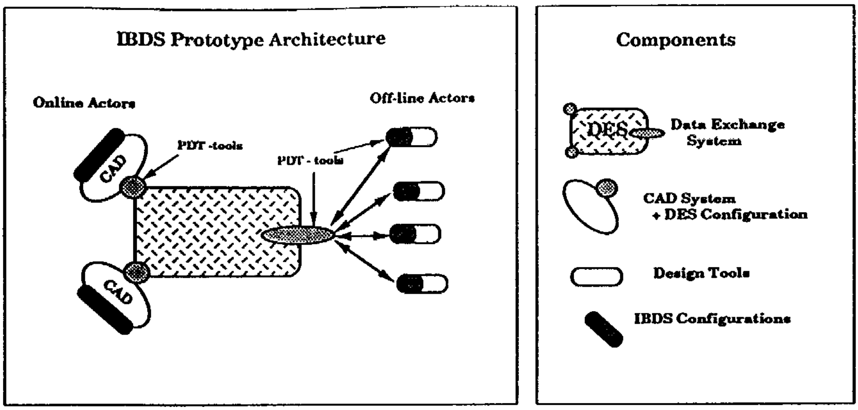

Figure 4. IBDS-architecture

The two online actors could exist of:

- a building modeller, based on a CAD system from one of the main CAD-vendors. A preselected number of layers is online connected to the IDM; other layers are "free drawing" layers, residing between sessions only in the local native format (no support, no integrity control offered on these layers). The configured CAD system must be equipped with functions to take information from other layers to the assigned IDM-layers to start-up a project. In fact this will offer easy integration of the system in existing projects.
- a HVAC design tool, based on another CAD system.

Again, only on preselected layers the configured CAD system acts as a graphical front-end of the IDM. There will be complete integrity control (in the IDM) over the assigned layers in the configured layers of the two online actors, but not concurrently. However, between sessions notifications on affected entities would be posted in configured layers of the other actor.

The off-line actors will concern functions such as of costing, conformance checking, access to product catalogues, performance evaluations, and online document search.

The following deliverables will result:

- a robust Data Exchange System (DES) supporting on-line data sharing with off-the-shelf CAD systems and off-line STEP file exchange with a variety of actors,
- an extended conceptual building model (IDM+); the present IDM will be retailored and stabilized to generically and fully cover energy/HVAC aspects,
- the DES will be built on an ODB implementation of the IDM+,
- several prototypical IBDS tuned to specific project environments consisting of the DES core, configured design tools, and IBDS configurations such as interaction controls, data management, etc.
- experimental facilities on top of the IBDS, exploring future extended design support functionality.

ENTERPRISE INTEGRATION

The COMBINE project is making an effort to develop new building design systems that have a credible potential to be absorbed into practice. Through the inherent integrated nature of the next generation of these systems their introduction will impact intra and inter-enterprise working procedures and project management protocols. It is because of this, that enterprise integration needs to be addressed in an overall enterprise-wide management context. Up until now the integration effort was solely the enterprise-responsibility, whereas inevitable modifications and project-specific tailoring of tools required tedious and time-consuming negotiations with the system developer. Usually a migration path from present procedures to the new system-enabled "integrated procedures" was not clearly visible at the start, nor were there adequate ways to manage this transition. Not seldom, during this process firms had to reverse the transition as a result of unexpected process-bottlenecks or lack of management tools over the new information flows. It is difficult to imagine how present procedures will be able to accommodate the introduction of the next generation of integrated design systems, as they will involve a multitude of departments (actors) within an enterprise and even across enterprise borders.

It is helpful to make a distinction between different levels of enterprise functions in order to grasp the type of barriers that must be removed in order to ensure the most efficient use of new integrated technology.

- Operational level: on this (shopfloor) level, significant progress is being made in terms of standards (*eg* STEP) and tools from software vendors. As far as the building industry is concerned, COMBINE seeks to play the role of intermediate between emerging PDT and the supply of PDT-based tools to industry.
- Tactical level: on this level we should be looking at enterprise-oriented support within a project window, which could span the whole of the project (as far as the enterprise is concerned) or only part of it. In the latter case the

pre- and post life of the project, as well as actors outside of the window must be able to communicate across the edges of our project window. On this level we must be able to provide full project control, at least within the project window of the IBDS. Moreover, some form of protocol must be offered to manage and control the external project life-time and external actor involvements. Within the project window the multi-actor process requires adequate support for collaborative group work procedures.

- Strategic level: we must realize that new information systems change the way that members of an organization think about and organize their work. In fact, we must think of future systems as yet another business function, adding another "entity" to the strategic information model of the enterprise, rather than just a shopfloor tool (Syvertsen, 1992).

Meeting the Challenges of the Future

Although there is no clear view as yet where the STEP-standardization effort will eventually lead us, it has incited an ongoing and exciting international effort to advance PDT as a whole. Notably the ISO-STEP effort (Danner, 1990) and related projects *eg*, ESPRIT-CIME projects have enlarged the scope of tools on operational level at a remarkable pace. Recent coordination efforts in Europe like PDTAG (PDTAG Newsletter, 1993) are worth mentioning here. Much can be expected of the recently started ESPRIT-CIME project PISA (Gielingh, 1993) which strives for an advancement of PDT in supplying general "integration services" based on integration-methodologies along with implementation-tools, that seem to go beyond the present ISO-STEP approach.

In spite of this remarkable progress one must also acknowledge that the focus is still primarily on data exchange, with some increasing focus on project support on the basis of design and manufacturing process modelling attempts. We argue that some of these attempts fail to acknowledge the need for advanced modelling formalisms, in order to be able to capture an adequate level of semantics (IT-axis in Figure 3) and thus fail to deliver support beyond data exchange, due to lack of modelling power. An exciting prospect is the EDM-approach (Eastman et al, 1992) which can capture the semantics related to generating building information in a design context. Fully capturing all additional semantics involved with cooperative multi-actor design (full tactical level support) will pose additional challenges in trying to cover the temporal, transactional concurrency aspects to their full extent.

Meanwhile, the need for adequate MSE's (Modelling Support Environments) and rapid prototyping tools is recognized. Good examples of how an MSE and rapid prototyping can be combined into one environment are PMShell (Luijten et al, 1992) and XPDI (Poyet, 1993). Both tools are used in the COMBINE project; with their built-in PDT-support they are very well suited to bridge the gap from operational level to configurations on real-life project support level.

Finally, we conclude that the conscienceness regarding the ultimate challenges with respect to enterprise integration is increasing. This is reflected by the emergence of enterprise-wide modelling tools with facilities to embed operational shopfloor systems. Most notably we mention the n-dim approach (Levy et al, 1993) from Carnegie Mellon University and METIS (METIS, 1992) which is a commercial system.

CONCLUSION

In the paper the introduction of the next generation of IIBDS's in enterprises has been discussed by distinguishing three different levels of integration in company organizations. We have taken COMBINE's approach, being one of the leading international efforts into IIBDS, as an example. It is explained that the present phase of the project will target IBDS prototypes on tactical enterprise-level through the definition of adequate "project-windows"; it will build upon state-of-the art operational PDT tools emerging on the market. It is recognized that no system will find any acceptance in real-life circumstances if a smooth integration into a project environment cannot be guaranteed. At this stage of development we target smooth introduction of IBDS's, operating within a project window.

COMBINE's contribution to R&D and building practice will for now consist of:

- one of the first actual multi-actor systems in building design, thereby situating itself in the translation range between PDT and practice. This is a necessary step to prepare enterprise for future systems.
- it will make a thorough specification of the type of IBDS's, that can be absorbed in practice and provide support on tactical level.
- exploration of necessary features of future IIBDS's through field testing.

For future stages of COMBINE and IIBDS reserach in general, it is argued that the main long term challenges concern increased levels of semantic coverage and their conceptual modelling tool support. Enterprise-Integration of tools on strategic level will be the ultimate challenge as it requires, on top of the previous, "live" enterprise-wide modelling environments in which IIBDS's can be embedded, guaranteeing full control, management and updating facilities. That these environments must be able to support group work is self-evident.

References

Augenbroe, G and Laret, L (1989), *COMBINE pilot study report*. CEC-JOULE Report.

Augenbroe, G (1992), Integrated Building Performance evaluation in the early design stages. *Building and Environment*, Vol 27, 2, pp 149-161.

COMBINE Consortium (1992), *COMBINE Seminar Report*. Stuttgart, 20 November 1992.

Danner, W F (1990), *A proposed integration framework for STEP*. NIST, US Dept of Commerce.

Dupagne, A (1991), *Computer Integrated Building*, Strategic Final Report, CEC-ESPRIT Expl. Action no. 5604.

Eastman, C M, Scott, C C and Hisham, A (1993), System architecture for computer integration of design and construction knowledge. To be published in: *Automation Based Creative Design: Current issues in Computers & Architecture*, A. Tzonis and I. White (eds).

Gielingh, W (1993), *PISA Framework*. In PISA Workshop Report, Paris, 27-28 January.

Levy, Sean, Eswaran Subrahmanian, Suresh Konda, Robert Coyne, Arthur Westerberg and Yoram Reich (1993), *An overview of the n-dim environment*. EDRC-05-65-93. Carnegie Mellon University.

Luijten, Bart, Bart Luiten, Peter Willems, Peter Kuiper, Werner de Bruijn and Frits Tolman (1992), *A collection of PMShell papers*. Report BI-92-087, TNO Building and Construction Research, The Netherlands.

METIS (1992), *Information and process modelling handbooks*, METIS, A.S., Horten, Norway.

PDTAG Newsletter, 1993, *Product Data Technology Advisory Group*, ESPRIT-CIME.

Poyet, P (1993), *XPDI Manual*. CSTB, Sophia Antipolis.

Syvertsen, T (1992), The building industry at a crossroad. Some critical issues at the threshold of the information age. *Symposium on Building Systems Automation-Integration*, Dallas, June 10-12.