THE COMBINE PROJECT: A GLOBAL ASSESSMENT

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ABSTRACT

The outcome of the EU funded COMBINE project will be assessed. The objectives of COMBINE (Computer Models for the Building Industry in Europe) are to deliver the first examples of a future generation of intelligent integrated building design systems to engineering design practices, with the emphasis on the energy and HVAC disciplines. The objective is accomplished by embedding proven IT solutions for data integration in a system architecture that enables the information exchange among the members of a building design team.

An overview of the approach of the 70 man years effort between 1990 and 1995 by a consortium of 11 R&D institutions across Europe is presented..

A global assessment of the overall approach and the use of available product data technology that have led to three prototypes of integrated building design systems is given.

INTRODUCTION

COMBINE targets the development of future intelligent integrated building design systems (IIBDS) through which the energy, services and other performance characteristics of a planned building can be analyzed. This is accomplished through the use of standardized IT solutions for data integration and as such on application of emerging STEP technology [ISO-STEP, 1992].

The research concentrates on establishing a data infrastructure and tools for managing the information exchange in a building design team, with emphasis on the energy HVAC consultant. The aim is to enable better and more efficiently designed buildings, especially from an energy and HVAC perspective.

COMBINE's goals are not to add to information technology as such; rather it targets efficient use of advanced Product Data Technology (PDT) in the building industry and show its potential to the end user community.

The first phase of COMBINE (1990-1992) has concentrated on data integration based on the concept of a set of separate actors shared around a central common data repository [Augenbroe, 1993]. It's deliverables comprise the first large conceptual building model and a standard STEP interface kit supporting STEP neutral file exchange. Six design tool prototypes were developed to demonstrate the concepts. A final workshop and seminar held in Stuttgart in November 1992 marked the end of the first phase.

The second phase built upon the above deliverables by combining them into an oper-

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ational integrated building design system (IBDS) according to functional specifications resulting from particular building project-partner settings in practice. These specifications are drawn up in close collaboration with local end users who will also act as field testers of the deliverables in follow up activities.

The extension of the suite of interacting design tools is based on a configuration of existing tools in the areas of costing, HVAC-CAD, component databases, daylighting and energy, CEC standards and building regulations. Additionally, off-the-shelf and widely used architectural CAD tools are incorporated.

Whereas extended intelligent design support features and coverage of concurrency issues were not within the scope of the project, the resulting IBDS prototype is configured to support robust multi-actor data exchange in specific engineering design office-settings.

Some added features of future IIBDS's are explored in a separate prototype, e.g. by enabling enhanced scheduling control through a Black Board.

The results comprise an extended conceptual building model. The first prototypes of a future generation of IIBDS's based on available information technology have resulted. Important feedback from practice will now be gathered by doing field testing in several "project windows" conducted in several countries.

Improved design processes leading to improved energy efficiency will be demonstrated on-site by the field test partners in their own real life practice environment.

Reiteration of COMBINE objectives

The COMBINE initiative emanated from a JOULE Workshop centered around the theme of "Future energy modelling" held in 1988.

One of the important outcomes of this Workshop was the statement that the energy reduction potential will ultimately be dependent on three R&D tracks, (i) the expansion of our knowledge about physical processes as the basis of energy saving technologies, (ii) the harnessing of this knowledge in tools for the skilled building services engineer, and (iii) the enhancement of the use of these tools at the right moment and with the right information.

It is in the latter that COMBINE has found its mission. If successful, it will enable the energy and HVAC discipline to play the essential role it deserves in the important stages of design.

It is important to realise that any progress in the area of more energy efficient building will have to be based on advances in all three areas. Better tools without proper design integration use potential won't do the job for you. Neither will integrated data infrastructures if the right set of disciplinary tools is not available or not properly integrated.

The COMBINE main objective is to create an integrated design environment that enables the interfacing of state-of-the-art HVAC/energy tools in design scenarios with multiple "actors".

The ultimate goal is to enable the HVAC/energy expert to exort his expertise in the vital decisions taken along such a scenario, leading not only to more efficiently designed but also to more energy-efficient buildings.

A LAYER TAXONOMY FOR INTEGRATED SYSTEMS

The objectives stated in the first section are very challenging. They combine advanced R&D in the areas of simulation, integration technologies, CAD, multi-actor design systems.
We can group these areas under the headings of "cooperative engineering" (CE) and "product data technology" (PDT). The latter comprises all recent efforts in the area of complete product descriptions (product models), exchange of product data and standards to support data exchange, notably the ISO-STEP standard [ISO-STEP, 1992].
COMBINE's approach is not to add to the fields of PDT or CE as such but rather enable and promote efficient use of these technologies by the energy/HVAC disciplines.

Figure 1 shows five layers that should be present in any type of multi-actor integrated system in order to meet its basic requirements. Each layer builds on the ones below it. Functions in a layer enabled by the functions offered in the layers beneath it.

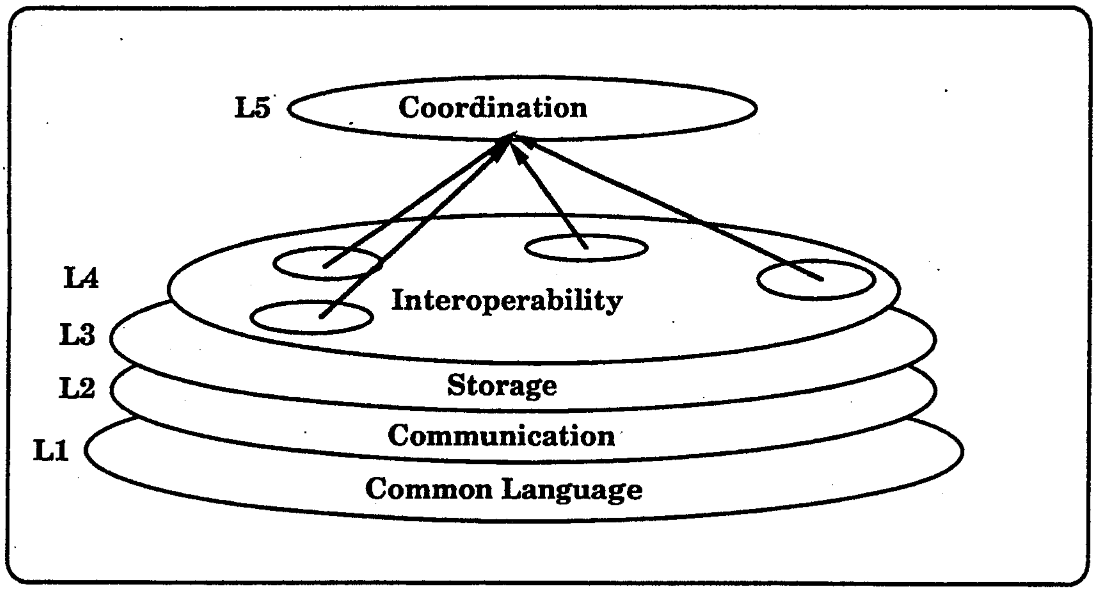

Fig. 1. Distinguishable layers in integrated design systems.

A closer look reveals which key functions should be supplied by each layer.

L1: *Common language*
This is the bottom layer which is essential to any type of meaningful exchange. It represents the knowledge in the universe of discourse in a formal manner; it comprises a superset of the semantic content of the information that actors want to

exchange with the system (hence with each other). Many suitable knowledge representations exist. The choice is strongly dependent on the depth of the semantic coverage and scope of the covered domain. Moreover, the type of formal representation is also strongly linked to the choice of exchange paradigm (layer L2).
Another aspect that has to be faced is the level of explicit actor view support. As each actor has a distinct view (i.e. HVAC or structural engineering view) the common language could take two different approaches:

- explicit representations of each view, keeping track of all relevant (i.e. within the scope definition) interrelations between views.
- no explicit representation of views. Initially, all actor views contribute to the definition of a common language. The resulting common "model" is supposed to be complete in the sense that each particular view can be mapped to/from it.

A final and crucial aspect in the definition of a common language is the "harmonisation through modularity" principle. For instance ISO-STEP has developed the AP-strategy for their particular type of (shallow) knowledge representation.

L2: *Communication*

In this layer we can distinguish a variety of physical connectivities (network, diskette), communication protocols (on/off-line, OLE, CORBA, native) and messaging paradigms (exchange of states, exchange of operation, atomic messages ......).
A vital decision is in the allowance and system support for actor to actor communication in contrast with actor to system communication only, i.e. no support for particular addressees in the communication.

L3: *Storage*

Although the first two layers enable meaningful exchange of information, they by no means suffice to support a design process. Explicit and persistent storage of the state(s) of design is an essential requirement.
The following aspects of the storage determine it's functionality in a design process: versioning, audit trail, public/private versions, actor definable locking, explicit view storage.

L4: *Interoperability*

One is quick to realise that the delivery of building data as input to performance evaluation tools and the subsequent return of performance calculation results back to the database becomes rather meaningless if there is no real design support. Such support requires that it enables evolutionary design scenarios with feedback loops and incremental design refinements. Moreover, the interactive use of CAD systems (e.g. shape design) in conjunction with other tools like materialisation, costing, requirements checking and performance analysis is an essential requirement.
This poses extreme constraints on the way that different tools are allowed to operate on the central building data in order to guarantee consistency and integrity of all data.
This layer provides the functions to execute the actual information exchange and evolution of states in a multi actor design process.
It is in this layer that the "team performance" of the system is determined.
The functions located at this layer are obviously restricted by the support levels in

The functions located at this layer are obviously restricted by the support levels in layers 1, 2 and 3. For instance, in the absence of explicit knowledge of inter-actor activity in layer 1, lack of online or interruptible communication in layer 2, or lack of flexible locking in layer 3, the interoperability support will be severally hampered.

L5: *Coordination*

Data exchange without a controlled purpose and interaction scenario will lead to chaos. One may be able to "understand" and "interpret" all messages but one has no control over "who should be doing what and at what time and for what purpose".
The coordination layer provides the means to "drive" the system towards defined design-objectives. It contains the ingredients to supervise actor activities and schedule events, and manage the work flow. It can employ different project management paradigms (reactive, monitoring, pro-active, autonomous, etc).
The coordination layer should add the project specific and design office specific context to the generic layers beneath it.

The following section will show what components the COMBINE project has provided in each of the five layers.

THE COMBINE APPROACH

Figure 2 indicates how the COMBINE project approach each of the five layers.

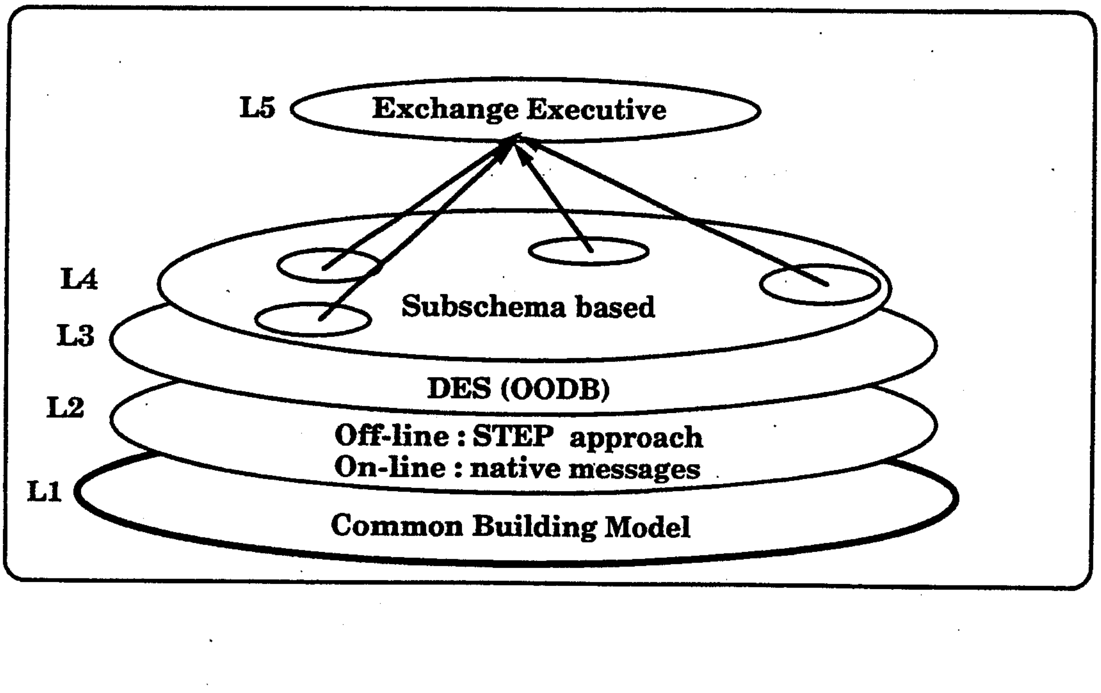

Fig. 2. COMBINE Components

L1: *Common Building Model*
Based on 12 actor views in the field of architectural design with energy and HVAC as primary scope, an integration exercise led to a common building model. EXPRESS was used as knowledge representation language.
The scope of the model caters for the tools that make up a realistic part of a building design process (encompassed by a so-called "Project-Window"):

- thermal/energy/comfort simulation
- HVAC design with HVAC CAD support
- lighting design
- shape design and space layout with architectural CAD support
- cost estimation
- building regulation checking
- component database access for HVAC and fabric components
- on-line document browsing

The approach to semantic coverage represents state of the art product modelling where the emphasis is on capturing (static) product description using simple entity-relationship type of model as basic knowledge representation.

L2: *Two Data Exchange mechanisms: on-line/off-line*
A distinction is made between on-line and off-line tools. All performance evaluation tools are regarded as off-line tools, whereas the CAD applications operate as on-line tools. Off-line tools use ISO-STEP neutral files for the communication between the central building model and the application.
The instances in STEP files are passed and mapped to local entities on input at the start or a design tool session and the reverse takes place when the session ends. Off-line tools thus exchange static product descriptions with a central repository.
On-line tools have a native interaction with the central building model; they can both exchange entity instances with the central repository as well as activate operations on the model in the repository.

L3: *A data storage component.*
This component keeps a coherent description of the designed building in a central persistent storage location. The component acts as a central repository, keeping track of versions and is able to update a design according to the new information supplied by one of the actors.

L4: *Interoperability through (specialised) subschemas*
COMBINE has managed to develop a basic, but crude, interoperability support mechanism based on subschemas for design tools. The granularity of interoperability is chosen to be at design tool function (DTF-level). Each design tool (CAD applications included) has a range of specific DTF's that are predefined and used as the basic granular activities in a design scenario. Each DTF is associated with a subschema of the complete building model.
A subschema may contain any (valid) subset of entities and subset of relationships of the complete building model. The validity of a subschema is ensured by sticking to certain rules when stripping the building model to subschema proportions. Explaining those rules is beyond the scope of this paper.
A subschema can be further "specialised" by adding tighter cardinality constraints,

add or remove optionality constraints and add clauses which act as a query and thus reduce the set of instances that fit the subschema. The latter serves to limit the building instances to those that make sense to a particular DTF.
In an exploratory effort this approach is augmented by an additional interoperability mechanism for direct actor to actor exchange through predicates.

L5: *Project Supervision Module*
COMBINE has addressed the issue of project supervision and developed a so-called "Exchange Executive" module. It can be fed with sequences of actions (scenarios) that a certain project demands and along the way it is able to detect what results are affected by design modifications so that it requests the redoing of certain evaluations. The granularity of a scenario is again DTF.
All actors, DTF's, constraints with respect to transitions between DTF's are formally modelled using a new adapted form of Petri-Nets. Each DTF in the model has it's in and output subschemas (L4) associated with it. this serves to detect overlaps between DTF's (disallowing concurrent use) and also enables to maintain a list of DTF's that have to be reinvoked because a downstream DTF has changed its input.

The five basic "mechanisms" introduced above, are supported in an implementation into operational IBDS's.

IMPLEMENTATION ARCHITECTURE

Figure 3 shows the implementation architecture of the COMBINE IBDS.

COMBINE IBDS Implementation Architecture

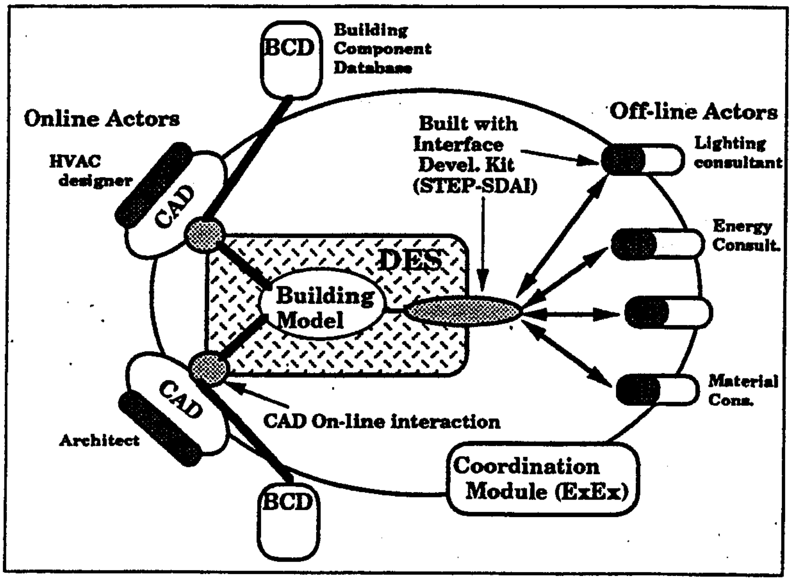

Fig. 3. IBDS Implementation architecture

The figure shows where the components identified in the five different layers are integrated in the architecture.
The conceptual model is developed in EXPRESS and parsed to C++ classes that initiate the implementation schema in a commercial OODB, the kernel of the data exchange system (DES).
The data exchange toolkit for building STEP interfaces for the design tools is SDAI compliant and consists of a parsing, mapping and viewing/selection module.
The mapping between subschema and design tool entities is performed in a DTF-specific mapping module which has to be C++ coded.
The DES is equipped with a generic (late bound) STEP file read an write module, based on predefined subschemas.
The on-line interaction is maintained for three specific CAD tools involving (early bound) methods in OODB clients. The range of design functions supported in this fashion is minimal, as only a proof of concept was targeted.
The IBDS configurations fully support heterogeneous multi-platform use of design tools whereas communication may take place both off-line (ASCII files) as through message structures over a local area network. This set up is an important feature as no particular software or hardware are pre-supposed at the actor sites. Only through this open communication architecture it is possible to enable the multiple on site configuration envisaged as follow-ups of COMBINE.

DELIVERABLES

The COMBINE project has made an effort to develop new building design systems that have a credibility potential to be absorbed into practice.
The following deliverables are available:

- conceptual building model with broad coverage of energy, HVAC and related aspects and a rich topology. The model is fully operational in a C++ environment.
- generic data exchange facilities in the form of 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.
- two prototypical IBDS's tuned to specific project environments consisting of the DES core, configured design tools and other IBDS configurations such as interaction controls, data management, etc.
- exploration of enhanced extended intelligent support in an experimental IIBDS.

Through these deliverables, COMBINE seeks to play the role of intermediate between emerging product data technology and the supply of tools that use (but hide) this technology in the setting of the energy/HVAC and architectural firms.

At the final seminar/workshop of the project (COMBINE '95) the IBDS prototypes have been shown "in action" in a number of realistic multi-actor design scenarios which contain active roles for the energy/HVAC consultants in the energy-relevant decision making process.

ASSESSMENT

A critical assessment of the support for the five mechanisms in the present IBDS prototypes shows that the three bottom levels deliver the basic data exchange needs in a robust dependable way. Moreover, they are generic and thus form the consolidated kernel of any future COMBINE IBDS configuration.

The remaining two mechanisms supplied in L4 and L5 (Interoperability and Coordination) represent advanced pioneered solutions. They will have to be matured and consolidated in follow-ups. They represent the project and partner specific configurations of an IBDS. This makes it very important that further work on these components will be done in close harmony with practitioners and guided by on-site testing.

Major after-COMBINE work must provide these two mechanisms in a rich way and add extensive configuration capabilities.

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