FIRST EXPERIENCES WITH AN INCEPTION SUPPORT MODELLER FOR THE BUILDING AND CONSTRUCTION INDUSTRY

An inception support modeller

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Durability of Building Materials and Components 8. (1999) *Edited by M.A. Lacasse and D.J. Vanier*. Institute for Research in Construction, Ottawa ON, K1A 0R6, Canada, pp. 2234-2245.

Abstract

Inception and very early design of complex building and construction projects requires a large number of decisions to be made, considered, rejected, changed, or confirmed. Many views on the project co-exist at the same time, requiring complex communications and access to complicated knowledge covering the complete project and product life cycles.

Balancing the results of this non-monotonic decision taking process is (1) not a trivial task and (2) very important for the project outcome, as most of the product and construction process characteristics (like performance and cost) will largely be fixed. Further optimizations in later design stages will only be marginally possible.

In order to support the inception and very early design of complex construction project we are developing an Inception Support Modeler (ISM) that guides the user through the decision taking process. Decision taking is supported by a combined PDT (Product Data Technology) and KT (Knowledge Technology) approach.

The focus of the current modeler is on the inception of technical buildings, like Power or Process Plant Buildings, Factory Buildings, Hospitals and such. The product model and the knowledge base are developed in co-operation with the Brite-Euram CONCUR project.

The paper reports about the first test case of the ISM. As part of a demonstration in CONCUR, the ISM has been filled with Business Objects and Business Logic concerning the inception of a simple Turbine Building.

Keywords: PDT, CONCUR, Inception, Early design, Knowledge representation, Prototype

1 Introduction

Despite a general agreement about the importance of the first few project stages (various sources estimate that between 70% to 90% of the total cost of the project costs are determined during the first project stages), inception and very early design of building and civil engineering projects is not yet adequately supported by Information, Communication and Knowledge Technology (de Ridder 1994;Mohsini and Davidson 1995; Vanier et al. 1996; Ozsariyildiz and Tolman. 1998).

In the inception and very early design stages of a construction project, the design and engineering team usually develops a number of alternative technical solutions for the facility that might satisfy the Client's needs. These alternative technical solutions are:

- Generally of a global, hierarchical nature,
- Often expressed as variants of existing constructions, for instance: a hospital like the Medical Centre in Amsterdam, but now for say 800 patients, or
- Combining a global hierarchy with variants for parts of the building (a façade like the one used for the Shell building in Rotterdam, but now with a different colour and only 12 stories high).

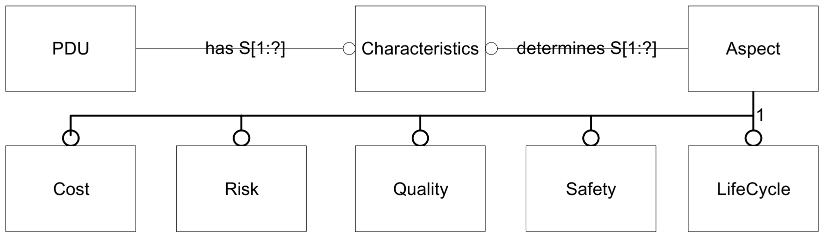
An alternative technical solution, which is required for a business model, eventually consists of a set of existing construction cases and construction products that, put together, provide the spaces for the required functions including: total volume, total floor area, performance requirements, logistical requirements, construction processes etc.

In order to support Inception of complex building projects by ICT and KT we need to define the Business Objects. These Business Objects are the foundations of the general architecture of an information system for inception support. The objects can be used to define a product database structure, but also to define the Business Rules and company workflow, which can provide more concurrent business processes.

2 The theory

Design and construction of building and construction facilities is, from a modelling point of view, very complex. If the business models are chaotic and unstructured, it is impossible to adequately formalise and reuse business objects and rules. Therefore our theory searches an answer to the question "How we can structure the complexity for reuse?" and integrates it with Knowledge Technology. The theory, as been discussed in more detail in earlier papers (Ozsariyildiz. and Tolman 1998; Tolman. and Ozsariyildiz 1998), is based on ideas presented in the General AEC Reference Model (GARM) (Geilingh 1998).

In the GARM, a product (facility) can be represented as a hierarchy of so-called Product Definition Units (PDUs) that covers the required Business Objects. Figure 1 gives a definition of the PDU in Express-G. A PDU can be a whole product, an activity or resource, but also a sub-system, element, component, part, or feature. For our purpose, we extend the scope of the PDU to also include typical project related information about the activities and resources required. PDU now stands for Project Definition Unit (Luiten 1994). The information of a PDU is given as a collection of characteristics. An Aspect determines each characteristics of a PDU. Examples of



Aspects are cost, risk, quality, safety, sustainability and life cycle etc. Definition of a PDU in Express-G (Luiten 1994). A Project Definition Unit has Fig. 1:

Fig. 1: Characteristics that are determined by one or more aspects (cost, sustainability, etc)

The GARM reference model makes a distinction between Business Objects that describe functions and solutions, i.e. Functional Units (FUs) and Technical Solutions (TSs). Each FU can be realised by one or more TSs that can be chosen from a set of alternative Technical Solutions. FUs on the same decomposition level can form one or many 'Interfaces', which in the original model could be modelled with a concept of Ports and End. Selecting a TS from a set of alternative TSs is covered by complex logic which in many occasions involves decisions about choices of TSs for other FUs. For example, the choice between the alternative TSs: Steel Structure, and Prefab Concrete Structure for the FU Structural Frame, will probably influence the choice between the TSs: Pile Foundation, Slab Foundation, or Raft Foundation, for the FU Foundation. Figure 2 illustrates the idea.

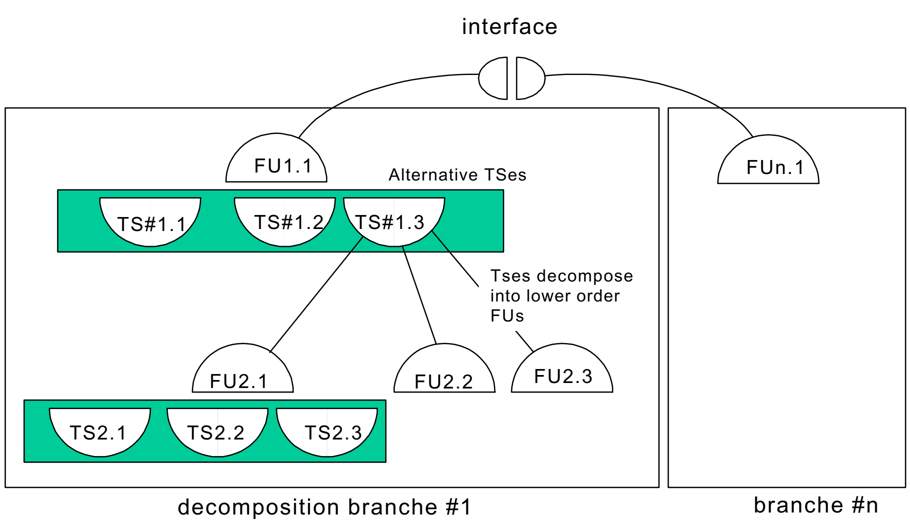


Fig. 2: Impression of an Interface between two FUs (Fu1.1 and FUn.1) in a generic hamburger model

FU1.1 can be realized by each of the three alternative TSs (TS1.1 to TS1.3). As an example FU1.3 is decomposed into lower order FUs, each again with a set of alternative TSs

The Figure 2 also shows Interfaces between FUs on the same decomposition level (FU1.1 and FUn.1). This is done to create the flexibility to change complete sub-trees of higher order Technical Solutions, which is required for a non-monotonic decision and design process.

2.1 Business objects

TU Delft participates in the European Brite-Euram CONCUR Project (CONCUR 1999). Our prior focus in CONCUR is to define inception related Business Objects. The Business Objects covers a higher abstraction level of information that is relevant for the inception support. Those objects, cover not only the product process and project information, but also the business-related issues such as the contract types, the organizational break downs etc.

The CONCUR Project aims to deploy an integrated Inception to Tendering process supported by vendor available tools and models. The main goals of the CONCUR project are,

- to (help to) increase the competitiveness of the European construction industries,
- to develop and employ an electronic format for tendering,
- to shorten time and cost of tendering, while at the same time increasing the tender quality

Inception support plays an important role in the project. The main views on inception and early design are cost and time. In the CONCUR project, we therefore developed a FU-TS decomposition that specifically served the purpose of the inception process. Basically, the idea is that all the relevant cost related objects are included in a Hamburger model, and that a knowledge tool supports the selection and dimensioning of the TSs.

Table 1 below, shows a part of the latest draft of the CONCUR ontology, as a hierarchy of FUs. Level 0 and level 1 covers ballpark or square-meter cost calculations and level 2 and 3 covers the elements that are relevant for conceptual and bill-of-quantities cost calculations.

Table 1: Part of the latest draft of the CONCUR ontology (Technical Building 'Turbine')

Level 0	Level 1	Level 2	Level 3
* New Built Power Plant Project ▪ Fuel ▪ Gas ▪ Thermal ▪ Nuclear			
	* Facility ▪ Turbine	* Zone	* Volume
		* Substructure ▪ Basement ▪ Bed ▪ Suspended	* Pile ▪ Sheet ▪ Replacement ▪ Displacement
			* Foundation ▪ Slab On Grade ▪ Pad ▪ Strip ▪ Raft
		* Superstructure ▪ Shell ▪ Tube ▪ Rigid Frame ▪ Conventional	* Frame ▪ Wall Slab ▪ Column Slab ▪ Column Beam ▪ Portal ▪ Space ▪ Column Cable
			* Roof ▪ Flat ▪ Hipped ▪ Gable ▪ Mansard ▪ Gambrel ▪ Jerkin-head ▪ Space Frame ▪ Folded Plate
			* Facade ▪ Masonry ▪ Cladding ▪ Panel
			Stairway ▪ Masonry ▪ Curved ▪ Spiral ▪ Winding ▪ One-Flight
		* Equipment ▪ Stream Turbine ▪ Gas Turbine	* Boiler
			* Condenser
			* Gas Turbine Unit
			* Generator
			* Stream Turbine Unit

▪ *Technical Solutions* * *Functional Units*

2.2 Business Logic

A typical characteristic of inception decisions is, that there are not much crisp values and algorithmic procedures available. Most of the relevant knowledge is expressed (1) both in rules-of-thumbs and comparison of old cases in fuzzy sets (like a range of cost figures 120$ - 140$) or (2) in fuzzy terms, for instance cheap, or expensive, high-rise, or low-rise buildings etc. and like ballpark square-meter cost calculations, which are formulated from cases (earlier projects). Often the knowledge is not precise, therefore allowance for vagueness and uncertainty should be made especially while assessing risk factors for all abstraction levels of Business Objects. Above all, construction projects are one of a kind projects, which means that we always will have to adapt earlier solutions to new circumstances. So flexibility and adaptability of the knowledge base are primary design considerations.

A typical expert system normally uses a fixed set of rules. In practice the fact list changes continuously, new facts are defined and old ones being removed at all time. However, the percentage of facts that changes per unit of time is generally fairly small. For this reason, we decided not to use the classical expert system technology, and to use a very efficient method known as the Rete (Greek for "net") algorithm (Forgy 1982). The classic paper on the Rete algorithm ("*Rete: A Fast Algorithm for the Many Pattern/ Many Object Pattern Match Problem*") [1] became the basis for a whole generation of fast knowledge base engines such as: OPS5, its descendant ART, and CLIPS (1999). Therefore, in order to be flexible to modify and edit the knowledge base we choose CLIPS as our knowledge engine. The Business Rules and Logic are stored in the project knowledge base. The Business Logic is open so that domain expert can modify the company specific knowledge. At the knowledge level Interfaces store Business Logic and Rules and at the information level it stores dependencies, associations and relations of Business Objects.

2.3 Case study turbine-housing

For 100 Mw power plants or smaller ones, there are two main types of Turbine-Housing available. The first one has only one floor; the second one has two floors, with or without extension (in height). In the Turbine-Housing equipment can be grouped as Back-Pressure turbine (gas), or Condensing-Power turbine (steam). The Gas Turbine requires usually one floor housing and the Steam Turbine requires two floor housing. Sometimes extra height is needed when there is additional equipment in the housing or when the site is narrow. Both housing types may have an intermediate level of steelwork. Housing can be constructed in-situ or prefabricated. Some parts of the building can be reinforced concrete.

Aspects taken into account in this case study are constructability, stability and stiffness.

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[1] *Charles L. Forgy, Artificial Intelligence 19(1982), 17-37*

3 The ISM prototype

The current design and implementation of the Inception Support Modeller (ISM) applies state of the art Product Data Technology (PDT) and KT. The ISM consists of four modules, as shown in Figure 3. The first module, where the GARM (General AEC Reference Model) is being used as a reference model, supports the formulation and capturing of knowledge about the Business Objects. The second module helps the end user, to define the relations and rules between different functions with respect to Business Rules, Business Logic. In addition, this module helps to choose the required alternative Technical Solutions; in other words, helps to create project early specifications for client requirements. The third module is used for verification of the user requirements. The system has a connection to a project database where project inputs are gathered. In addition to that, the system gives advise while choosing alternative TSs to support what-if scenarios. Finally, the forth module visualises the occurrences of the TSs by using a CAD-system or a VRML browser. The end user can change the parameters of various shape descriptions, including those parameters that are covered by other aspects such as economics, lifecycle, durability etc, which are relevant for inception and early design.

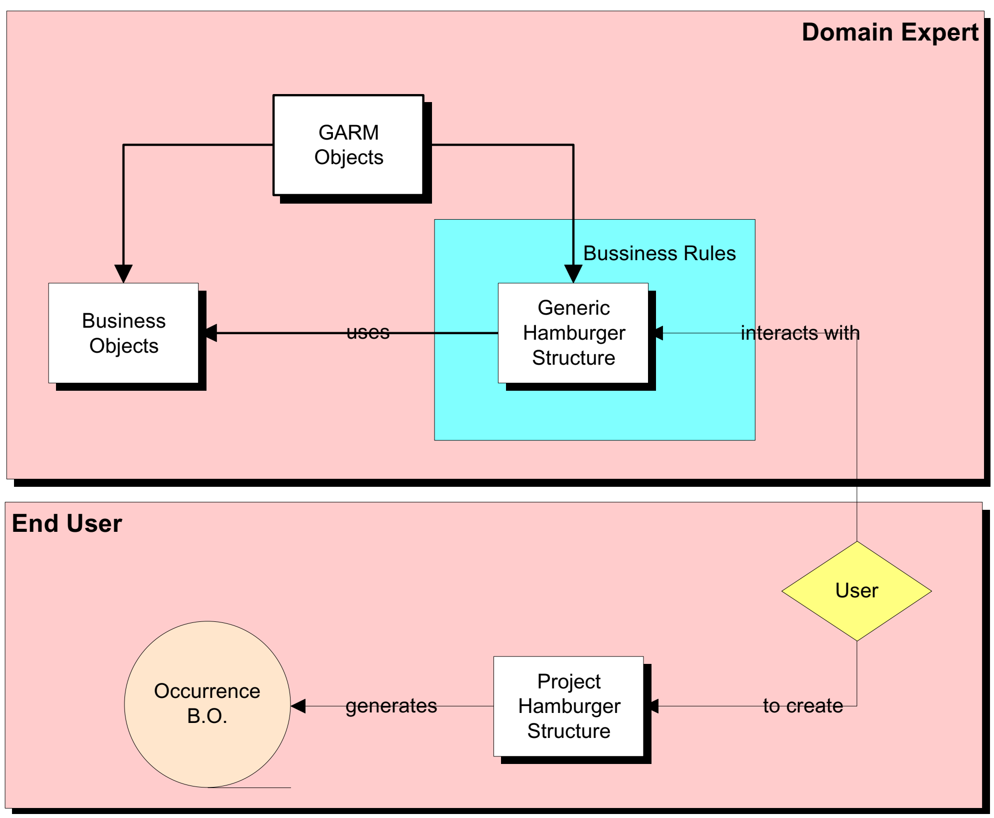

Fig. 3: The GARM Objects are used for generating business objects and business rules

The knowledge is stored in a generic Hamburger Structures in the knowledge base. The end user creates a project specific Hamburger Structure by interacting with the KB. The KB generates the database structure for occurrences of Business Objects.

3.1 The user interface

The prototype ISM uses a simple Windows based point and click user interface that allows the user to quickly enter his data and evaluate the results. The system will at any time allow the user to choose alternative TSs and parameter values anywhere in the project Hamburger tree, so that a non-monotonic decision process can be supported. Figure 4 below shows the current user interface.

The dashed rectangle shows the FUs, TSs, Aspects and Value Domains. The selected FU (Power Plant Project) is automatically linked to a set of aspects that are listed and it is fulfilled by a range of Technical Solutions such as coal, oil, gas and nuclear. Aspects are linked to Value Domains to define the Characteristics of Technical Solutions. The system will update the knowledge base synchronously.

The FU-TS decomposition provides us not only with a structure suitable to capture project knowledge but also supports formalization and re-use of earlier projects as cases. For instance, the FU Pile Group has TSs such as Prefab, In-situ, or Wooden. However, a user can simply express knowledge about a previous project such as: PileGroupInProjectXYZ. By adding the characteristics of this Pile Group the system will update the case base where all past experiences are stored. The user does not need any prior knowledge more than their product knowledge. The system itself is capable of converting product knowledge to matching-rules or meta-rules.

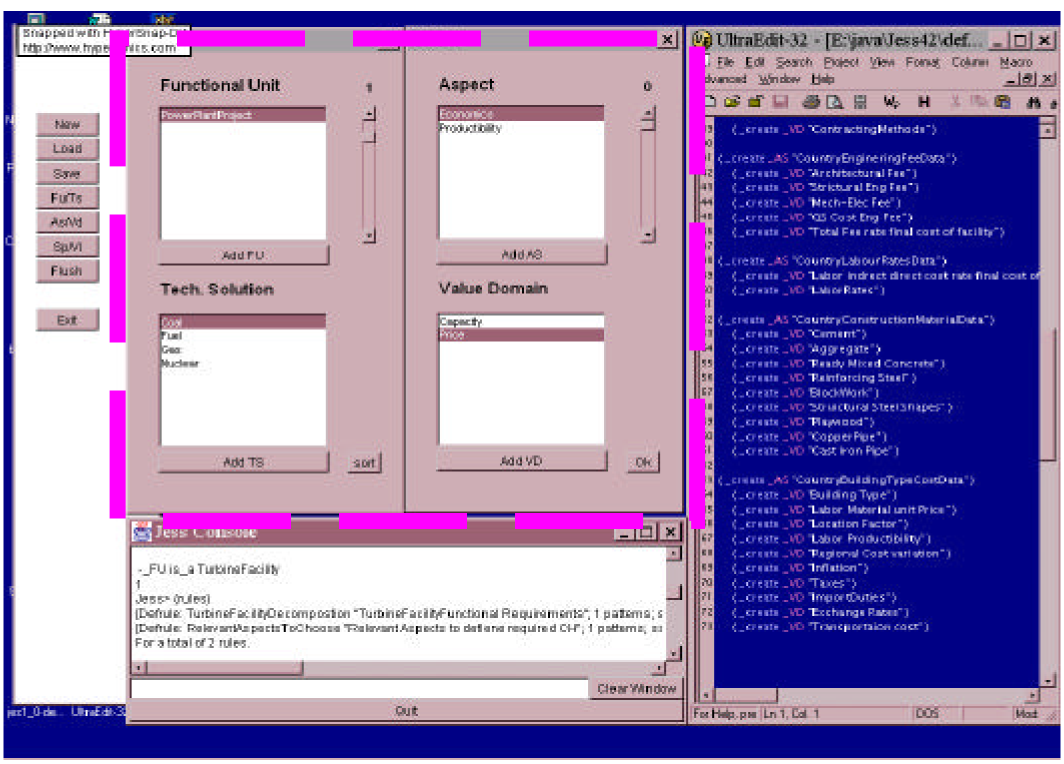

Fig. 4: Picture of the user interface of the inception support modeller (ISM)

The example is the same as in figure 2. By pointing, clicking and adding parameter values, the user provides the information from which the system generates the rules (shown on the right) that are input for the knowledge engine.

3.2 Project KB

The Business Objects, which are structured according to the GARM reference model, are dynamically reflected in the project Knowledge Base. The Functional Units, alternative Technical Solutions and required Characteristics of the Technical Solutions are transferred to the KB as project or product related rules. For instance the Functional Unit "TurbineFacility" can be fulfilled by Technical Solutions Gas, Coal, Fuel and nuclear.

```
defrule TurbineFacilityAlternativeSolutions
        "TurbineFacilityAlternativeSolutions"
          ( _FU ( name "TurbineFacility" ) )
          =>
          ( _create _TS name "Gas")
          ( _create _TS name "Coal")
          ( _create _TS name "Fuel")
          ( _create _TS name "Nuclear")
```

The end user simply chooses one of these solutions, or the system makes suggestions about the best suitable solutions based on the requirements. If the user chooses a TS the system gives the Characteristics of the solution in comparison to the requirements.

Related to all Business Objects every Technical Solution has Characteristics, a Value Domain and a certain Value define Characteristics. For example, if the country is “The Netherlands” then the Characteristic of the country Labour-Productibility-factor is "0.95" and VAT Tax-Rate is "17,5" etc. An other country will have different Characteristic pattern.

```
defrule TurbineFacilityCountry
        " TurbineFacilityCountry Information"
        ( _TS ( name "The Netherlands" ) )
        =>
        ( _create _VD name "Labour-Productibility")
      ( _set _ VD  name "Labour-Productibility"
       (_property value "0.95" ) )
        ( _create _VD name "Tax-Rate")
      ( _set _ VD  name "Tax-Rate"
       (_property value "17,5" ) )
```

```
defrule RelevantAspectsToChoose
          "Relevant Aspects to define required CH"
          (  relevant-aspects  $?aspectList )
          =>
          ( printout t "Relevant Aspect is_a" crlf )
          ( foreach ?aspect $?aspectList
                    ( printout t " - " ?aspect crlf )
                    ;;Define the aspects
                    ( _create _AS name ?aspect )
```

Every Characteristic of the Technical Solutions is defined by an Aspect in such a way that different views on the same product can co-exists. Based on different criteria the user can make his decisions. Aspects are used to define different views on the same product. For a certain type of project, economics can be a valid view and for another type visual aspects can be dominant view.

For complex problems it is important to support upstream and down stream knowledge transfer. Usually project alternatives have different Hamburger structures. In the prototype, decomposition rules can either be written as Functional Unit decomposition or FU-TS decomposition. For example Turbine Facility can have different TSs and if a user sees a risk in the turbine site he can

```
defrule TurbineFacilityFunctionalDecompostion
          "TurbineFacilityFunctional Requirements"
          ( _FU ( name "TurbineFacility" ) )
          =>
          (  _ask "What are the relevant Aspects ?" $? )
          ( assert (relevant-aspects $?) )
          ( _create _FU name "TurbineBuilding")
          ( _create _FU name "TurbineEquipment")
          ( _create _FU name "TurbineSite")
          ( _create _FU name "TurbineService")
          ( _set _FU name "TurbineBuilding"
         (_property level "1" ) )
```

decompose the facility and verify the what-if scenarios.

3.3 The end user

Visualization can be done with Virtual Reality Modeling Language (VRML) for the Internet based support of the early client project specification. The connection is done via IFC file exchange. Figure 5 shows as an example a 3D view of a simplified Steam turbine generator plant which is developed by FORTUM engineering which is collaborating in the CONCUR project. The CAD system is automated with D++[1] software in order to support drafting. The D++ interface supports interaction with the end user. When the decision taking process is complete than the system sends the required information to the central database, or generates IFC 1.51 file as an output IFC files are converted to VRML format. The Client can see and click on the defined item's to get more information about the design. In the future the connection with ISM tool will be online and realized by an http-based client server connection.

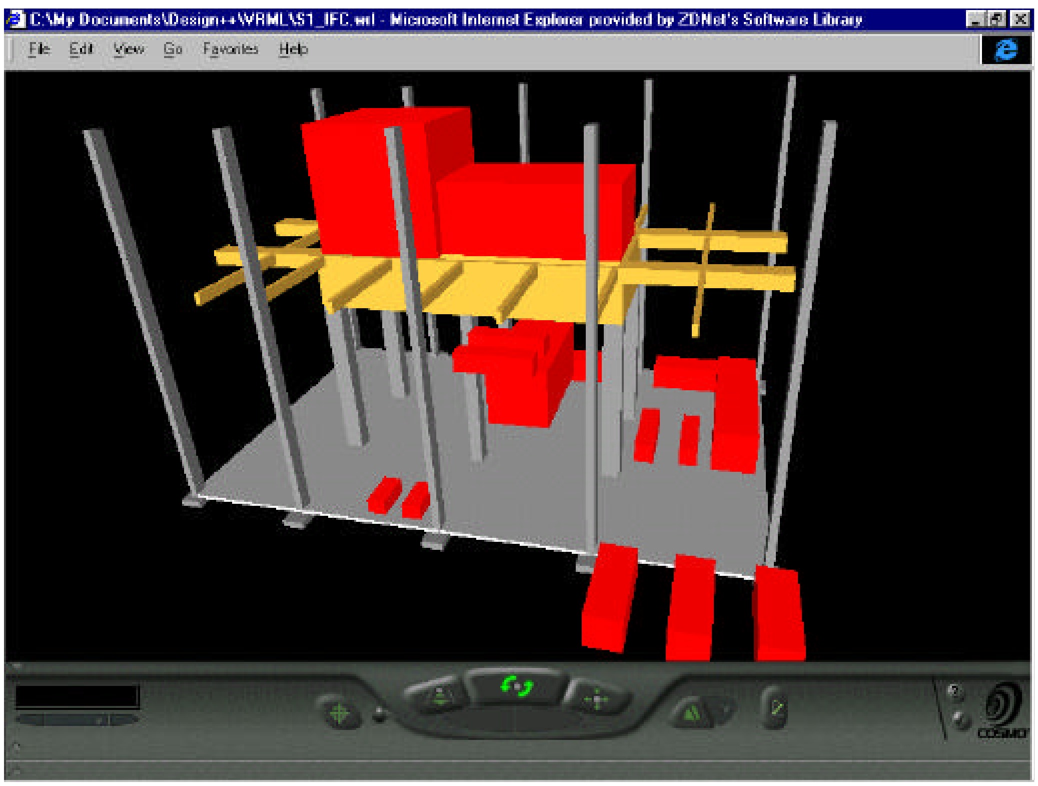

Fig. 5: A Simplified VRML visualization of the steam turbine generator plant generated by FORTUM engineering

At the moment the tool ISM described above has been filled with the generic Hamburger model that is derived from Table I, and the relevant Characteristics and parameter values are being added. Application of the system for simple Turbine Buildings gives encouraging results. However for application on real life cases still more emphases is needed on Business Logic and Rules.

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[1] *Design Power Europe Oy*

4 Conclusions

The Inception Support Modeler (ISM), which is being developed by TU-Delft in co-operation with the Brite-Euram CONCUR project, supports the selection and instantiation process that takes place during the inception and very early design stages. See it as an intelligent checklist, which has knowledge about the things one can chose or cannot chose.

The knowledge gathered in the system as a case study, focuses on the power plant marketing and early building related design, not on power plant equipment. However the system has an open architecture so that knowledge about equipment and its interaction with the building can be easily incorporated. Elaborating the Business Objects and Business Logic will continue for a couple of years. It is our aim that the ISM can be applied to many other project types for instance hospitals, warehouses, factories etc.

Although our experience with the ISM tool is still limited and improvements and extensions are needed, we believe that the basic knowledge structure adopted for inception and very early design is right. Knowledge acquisition can be performed in a structured way and the resulting partitioning of the Knowledge Base is quite understandable and easily extendable. Another good point is the extendibility for the search mechanisms, such as existing cost databases and building component libraries, which seems to work fine.

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