DATA EXCHANGE IN DESIGN/REALISATION PROCESS IN BUILDING TRADE, AN EXPERIMENTATION WITH WOOD-FRAME PANELS

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Abstract

Exchange of computerized data is today at the centre of interest for most of trade partners and authorities of standardization. The aim is to set up continuous and cooperative processes of exchange, without "re-modeling" or loosing information.

The paper presents our research on building modeling at design stage and its application to data exchange during the design/construction process. An experimentation about data transfer between two software is presented. The first one realizes the design process according to the developed data model (arTec[1]). The second one is a trade software for the design of wood-frame panels (Woodpecker[2]).

1. Introduction

The current AEC industry is comprised of diverse disciplines. Each using its own processes and terminology to accomplish a common goal which is the realization of a building. Over the last 15 years, use of CAD tools in the building trade evolves through different main stages. During the eighties, tools are developed to meet the particular requirements of the partners in order to increase productivity. Furthermore, data exchanges between the diverse disciplines are limited to graphical data, without any semantical description. It often leads to “re-model ” information, because it is not adapted to the own terminology of the diverse users. Then, during the nineties, productivity means integrating the different processes into a single one from design to realization. The hardware and software technology improvments and the several works on standardization make possible this interoperability. We go from data exchange file format problems to a logic of data sharing, which involves semantical description of design objects.

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[1] Architecture Technology. A data model developed at the CRAI, France, 1992.
[2] Woodpecker, developed by CastorProduct society, Gerardmer, France.

1.1 BUILDING MODELING

The design / construction process can be approached through different aspects, which reveal the great segmentation of the process and the difficulty to model it in a continuous way.

- *different partners and multiple views* : client, architect, engineer, etc. Each one performs a specific role and has one or several views of the building. They have different primary interests for the same project and use a different description of the building [1]**.** It is difficult to find a standard semantic description. The same building component can have various definitions when used by different trades, with their specific practices and ways of working.
- *independent participants and interpretation of information* : during the life cycle of a building, the different participants are not part of the same organization. Even they work in a cooperative way, information is contained in different sources. Building programs, drawings, cost estimates, etc, are all independently stored in different formats. Information is then converted, interpreted, and modified, which often leads to "redesign".
- *use of CAD software* : over the last 15 years, it has evolved through different stages : drawing with lines, creating elements based on lines, grouping elements into templates for repetitive drawings, connecting text attributes to templates, and connecting templates to relational data bases to retrieve needed non-graphic information. In all cases, the graphic representation was separate and independent of the non-graphic data storage and affected exchange formats definition.

Modeling the building along the life cycle needs developing conceptual models which specify data to describe work along its life cycle, where each partner identifies his specific information. These models must also support data transfers preserving the "building design objects" features.

1.2 ISO SPECIFICATION OF BUILDING CONSTRUCTION

The objective of standardization is to provide a neutral mechanism able to describe product data throughout the life cycle of a product, independently of any particular system. The nature of this description makes it suitable for neutral file exchange, and makes up a basis for implementing and sharing product databases.

ISO technical committee for industrial automation systems and integration proposes two models [2] : a product model (static), and a process model (dynamic). The product model (product object) identifies all the entities and relationships which constitute the object. It is organised around three concepts : facilitie (ex:factory), physical part (ex : wall) and space (ex:premise), described by their properties (shape, size, thermal properties, etc). The process model describes the life cycle of the building (inception, design, production, use, decommissionning). Object design evolves through states, with the instanciation of its attributes, with different values along the process [3].

The standard STEP[3] provides the ressources and methods for describing data related to the products used in the design/realization process , as a basis for CAD editors. It is organised as a series of parts : geometric and topological representation (part 42), product explicit shape representation (part 225), product life cycle (part 208), etc.

This standardization brings a new approach of the building life cycle modelling. Common ressources aim to increase interoperability between AEC sectors. These generic ressources are then specialized to the partner needs, to develop application tools. However, we think that there is a lack in the model of ISO about the state chaining in the product life cycle. It is specified as a set of states, each one of them is clearly defined. But the mechanism with which a product evolves from a state to another is not specified. Though, design activity consists of transforming the building along the process. Choose a material, calculate pemissible load of a bearing structure, etc are design actions. We can consider that it is not important in data exchange because we transfer static states of the project, but standardization is also elaborated for CAD editing, which performs design activity.

1.3 A MODEL FOR AIDED TECHNICAL DESIGN

Objective is to draw up the building technical design process according to technical definition of the building, and to the products which compose the building elements, with their "making use of" rules. The arTec model fits into the "rational anticipation stage"[4] of the building life cycle. Through levels of design, information is progressively transformed from an abstract and geometrical state to a technical defined state, by a mechanism using design operations [3].

We aim to identify generic paradigms in order to define technically the information and cover a great number of building elements (walls, floors, etc) and the most common constructive technologies (concrete, wood, steel, etc) as a shared basis usable by several partners.

The paper is organized into two main sections. In Section 2, we present the concepts that the building data model is based upon. We emphasize on integration of technical features in building description.Then, we describe design operations used to evolve through the design/construction process. In Section 3, we describe an experience of data exchange between our prototype and a trade software for wood-frame panel design,

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[3] STandard for Exchange of Product model data, ISO norm 10303.
[4] The design process begins when the project reaches a sufficient definition level to be transferred by conventionnal figuration tools.

using own formats of exchange. We propose finally to use the neutral format of STEP as another way to bring semantical features of building design objects.

2. arTec building data model

2.1 CONCEPTS

We describe the technical design process of a project using :

- *design objects* (physical parts) : there are all the components of the building (walls, floors, windows, columns, beams, etc). ArTec design objects have a geometrical representation and are described by a set of semantical attributes (function, material, etc) at each level of design. We introduce relations between physical parts as virtual design objects, necessary to model the evolution of information through the building life cycle (for example : choosing a technical solution at the junction of two walls must be modelled and described) .
- *design levels* : the work evolves during the process through levels of design : volumic level (spatial figures), logical level (technical choices) and elementization level (decomposition into products, realization documents) [4]. Design objects evolve from a level to another, with progressive technical semantization, using design operations.
- *design operations* : design operations settle the transition from a state to another [5] and define semantically the design objects. These operations, which are described later, are primitives and can be combined to define complex operations.

2.2 PROCESS MODELLING WITH LEVELS OF DESIGN

We use object oriented methods to represent the model [6]. We think it is partially adapted to model the building structure. We can represent the design objects by classes, with concepts as composition (a building is composed of physical parts), sort of (a wall, a window, a beam are "sort of" physical part). However, we have more difficulty to describe relations between design objects. We must represent a relation as a class which contains references of the objects relied. Furthermore, we cannot model object evolution along the life cycle, by transforming it from a class to another, corresponding to the design levels of arTec. In order to specify the dynamic evolution of the building, we have introduced the concept of generalization/specialization by *alternative* [7]. The same entity can change its caracteristics and has differents states through it's life cycle.

2.2.1 arTec object representation

The model is organised around object classes (*Figure 1*). Each physical part is an " object class", defined by a set of geometrical and technical attributes.

We distinguish planar and linear entities according to their geometrical representation, by modelling their boundaries. The planar entities are modelled with a profile[5], the linear entities with an axis (two points). In both of them, boundaries brings technical information. We consider that several technical problems are arised and resolved at the boundaries of the design objects.

Relations between physical parts are of two kinds : chaining and positionning. Chaining links design objects which have common boundaries. It is graphically represented by connectors[6]. Positionning is a topologic relation which means for instance that two walls are parrallel or belong to the same network.

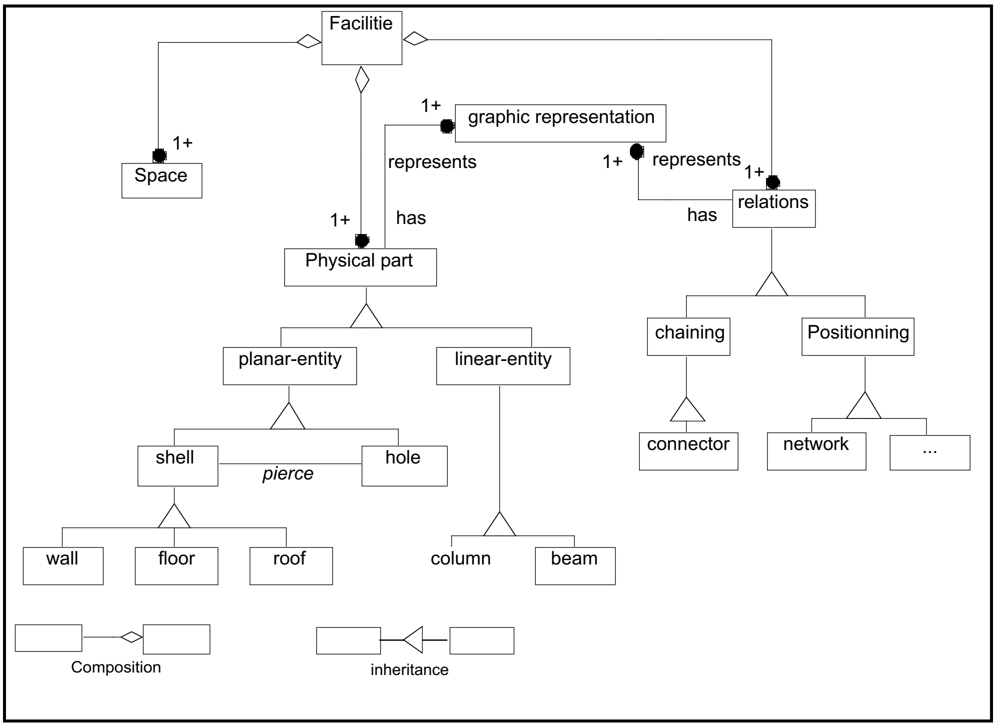

Figure 1: arTec model : design objects and relations.[7]

[5] A set of outlines representing the object boundaries. Each outline is a set of segments.
[6] Graphic representationof technical unspecification between objects.
[7] The diagram is designed with OMT method (Object modelling technic, J.Rumbaugh 1991)

2.2.2 arTec object through levels of design
ArTec object is alternatively at a functionnal stage (volumic), technological stage (logic) or technical description stage (elementization). Three classes are defined (*Figure* 2).

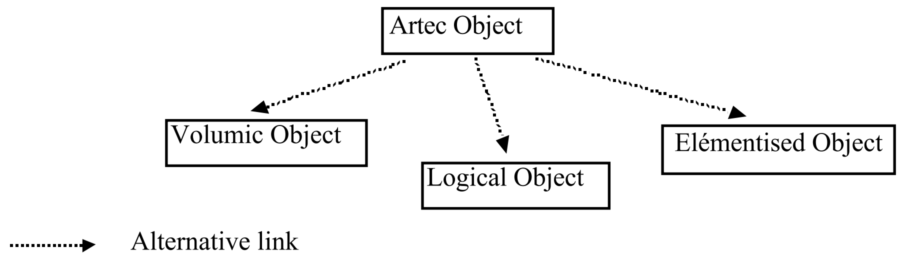

Figure 2: three levels of design.

Attributes have different levels of incertainty, following to levels of design. Uncertainty decreases as we progress through the design process (ex:wall thickness is given arbitrary at the volumic level (20 cm), and precised at logical level when a technology is chosen (16cm).

2.3 TECHNICAL DESIGN OPERATIONS

We have identified basic operations to define technically the building :

- object creation : models a designed object (wall, column, roof, etc) with shape, size and function attributes attached.
- technological instanciation : affects to a design object a technology (wood, steel, concrete, etc).
- association : links two or several design objects of the same class (wall-wall) or of different classes (wall-floor). It is represented by a connector for chaining relations and by a network or an axis for positionning relations.
- splitting-up : cuts a design object into several ones of the same class. Design objects obtained save the properties of the object cut.
- merging : two design objects of the same class are joined. The result is a design object of the same type, saving properties of the objects merged.
- re-sizing : modifies design object size (thickness, section, length, etc). It consists of moving object boundaries (point, segment).
- re-positionning : modifies object design position. It can be a combination of translation and rotation.

- re-formalizing : modifies object design shape. We can transform round section of a column into a square one.
- boundary caracterization : affects to design object boundaries technical caracterization according to the technology chosen.

Design operations are not only geometric ones. They attach semantic features to objects. When a wall is split-up, the result objects have a common boundary which brings joint information.

These generic operations are specialized to each physical part (resizing a wall or a column is not the same operation). Design operations allow feed-back mechanism. The design - realization process is not linear and top-down. A technical option at the logical level can involve to change entity properties and go back to the volumic level.

2.4 DATA TRANSFER AT EACH LEVEL OF DESIGN

ArTec gives a greater place to design-construction viewpoint. It doesn't perform all the views necessary to building design like structural design, thermal design, etc. Nevertheless, it can provide information needed by applications for other views at a given state in the design process. Each level defines a coherent state of constraint satisfaction. Information about the building can be extracted to be used by another partner (ex : structural engineer must calculate the section of posts). ArTec can retrieve data to carry on the technical design.

3. Experimentation : data exchange between arTec and Woodpecker

Data transfer is carried out between the application which performs the arTec data model and Woodpecker software, which realizes the "building product composition technic"[8] of wood-frame panels. According to arTec model, Woodpecker performs the elementization level. Experimentation is realized on walls and windows, which are common to both of these applications.

3.1 SOFTWARE DESCRIPTION

3.1.1 arTec prototype

We have developped the prototype with Autolisp language on Autocad software, mainly used as a graphical interface. Walls are defined at the volumic level by a set of

[8] Calepinage in french

outlines : an outside one and a set of inside ones, representing holes. Outline is a closed set of coplanar segments, which represent wall boundaries. Thickness is the sum of two half ones on both sides of the outline. As all the arTec entities, the wall has an identifier which is the same along the process. The graphical entity generated in Autocad is represented in a 3D system coordinates relative to the wall entity.

3.1.2 Woodpecker Prototype

Woodpecker is a trade software running on Macintosh system. Walls are wood-frame panels defined in 2D system coordinates according to vertical panel plane. For each panel, origin (0,0) of the system is at the down left on the outside face of the panel. Panels are modelled with simple geometric primitives (rectangles, triangles, trapeziums) or their association. Technical caracteristic on boundaries are specified, in order to design the wood-frame solution.

3.1.3 Data exchange

ArTec data project is stored in the own format of the prototype, in ASCII mode. A program converts arTec format into Woodpecker format. This procedure avoids the panel geometrical modelling stage in Woodpecker.

3.2 AN EXAMPLE OF MODELLING PROCESS

The following project illustrates the process : modelling the volumic design objects, defining them at the logical level, transferring data to Woodpecker for panel design.

3.2.1 Modelling the project at the volumic level

The project is modelled (*Figure 3*) and default thickness (20 cm) is assigned to all the walls. Connectors are represented automatically when the system meets wall common boundaries.

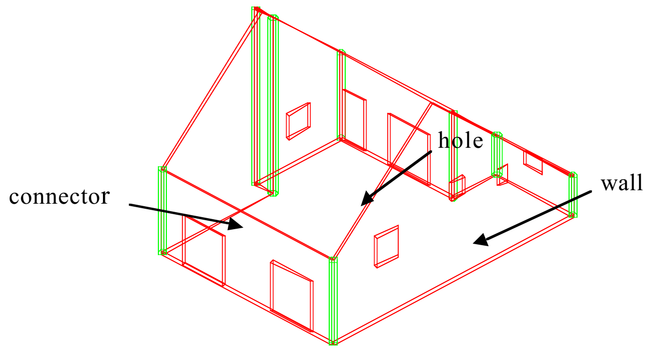

Figure 3 : Building at volumic level.

3.2.2 Project instanciation at logical level

The " wood-frame panels " technology is assigned to all the components of the project, which implies automatic operation of thickness resizing (16 cm) according to the technology constraints.

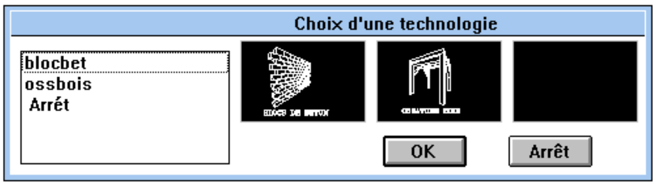

Figure 4 : technology instanciation operation.

3.2.3 Chaining resolution

All the connectors are resolved by choosing a technical solution to the junction of the walls (Figure 5). This operation implies resizing and repositionning the walls (these operations are made automatically).

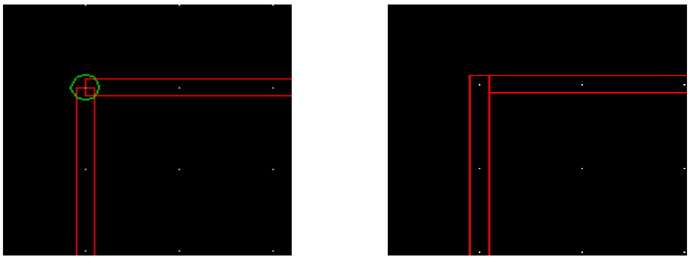

Figure 5: connector resolution.

3.2.4 Boundary caracterization

Object boundaries are defined in the geometrical representation of the physical part. Technical caracterization operation consists of choosing a boundary type (*Figure 6*) and attach it as an attribute to the boundary (described as a segment in the wall) (*Figure* 7).We have added to the prototype the caracteristics used in Woodpecker to define panel boundaries.

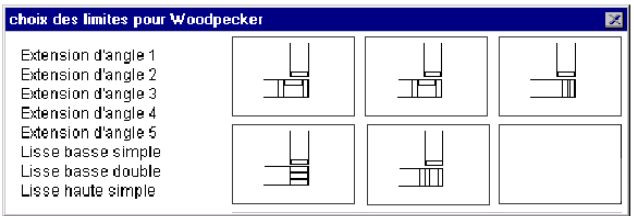

Figure 6 : choosing boundary caracteristics for the wall.

In wood-frame technology, choosing an angle extension type is important to settle cladding.

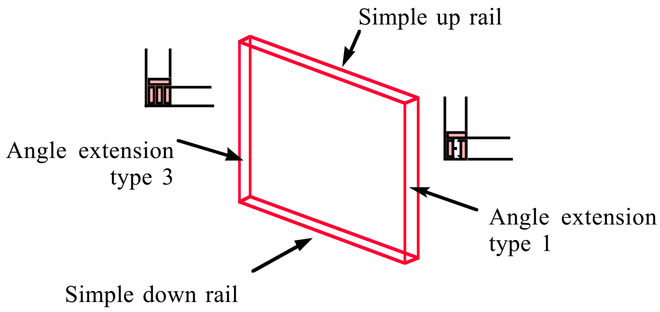

Figure 7: wall boundary caracterization operation.

3.2.5 Wall cutting for prefabrication

Wood-frame panels are prefabricated in a workshop and transported to building site to be assembled. Panels which have too large dimensions or a complex shape, are decomposed into simpler ones, in order to facilitate prefabrication and transport. This activity is performed by a combination of design operations (ex : *Figure 8*) : splitting-up (1) into two panels, window repositionning (2) and boundary joint caracterization(3).

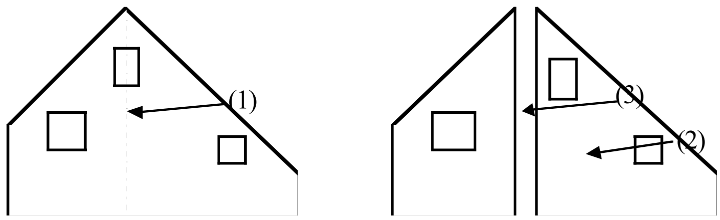

Figure 8 : an example of design operations.

3.2.6 Data transfer to Woodpecker

Data project has been saved in arTec format and translated in Woodpecker format. Object is described by its geometry and technical caracteristics of its boundaries.File format is written as follows :

```
PAV                                /*object type : wall, floor, window, ...*/
num             8                  /*  identifier*/
thickness  10.0            /* in cm*/
carc            wall               /*load-bearing wall or enclosure*/
points
        num     coord              /*num : point identifier*/
        1       x y z              /*coord : wall system coordinates */
```

lims				*/* boundary list */*	
	num	*np1*	*np2*	*nol*	*carl*
	1	*1*	*2*	*9*	*LBS (simple down smooth)*
	...				

/ num : boundary identifier; np1,np2 : identifiers of segment points; nol : identifier of chaining connector; LBS : technical caracteristic*/*

holes		
	17 18	*/* list of hole identifiesr */*
tech	*"wood-frame-panels"*	*/*technology attribute*/*

3.2.7 Realization of the wood-frame panels

Each wall is designed separately. Technical solution is designed according to the boundary types specified in arTec. Working drawings (*Figure 9*), wood quantities (classified according to section and length) are determined. Computerized data is then used by an automatic machine for wood conversion. Panels are realized in workshop and finally assembled in building site.

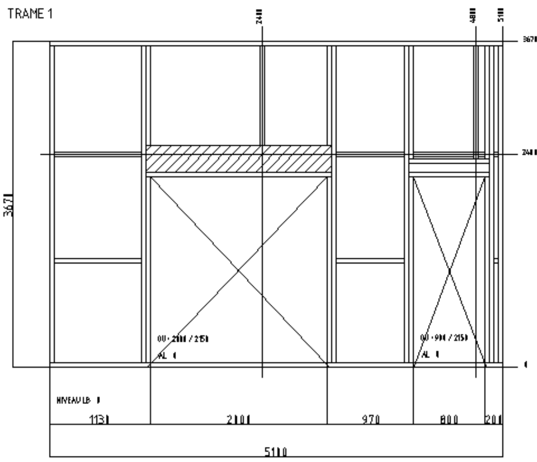

Figure 9 : working drawing for a panel.

3.2.8 Assessments

Data exchange experimentation proves that design-realization process can be continuous and cooperative. Design operations perform this evolution. However, two problems emerge. The first one concerns panel orientation for distinguishing inside and outside, which is important for cladding design. The solution proposed is to attach a *normal* vector to wall profile, oriented towards outside. The second one is the expression of designer wishes. There is a kind of information that cannot be expressed with data (ex : particular section of a wood pieces) which is not chosen at the logical level. We propose to add in the file exchange format a commentary field where the designer can express his particular requirements and wishes.

3.3 DATA EXCHANGE USING STEP

We said in the first section (section 1.2) that there is a lack in both of ISO and STEP to model transformation from a state to another in the life cycle of the building. In data exchange, we don't need to transfer the history of designed objects, describing the object and all the operations performed to reach a given state. We need to transfer static state of objects. If it is necessary to go back and modify the object, task must be performed by the related application. Data is exchanged at a given state in the building design process. So, STEP format of exchange (part 21) seems relevant, since it can bring semantical features in the design object description. It also avoids to write a format converter adapted to each exchange.

4. References

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