A COMPUTER-AIDED EVALUATION SYSTEM FOR INTEGRATING DESIGN- AND ORDERING-PRINCIPLES INTO PRODUCT MODELS

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Abstract: It is true that the commercial applications used in architectural offices have mainly focused on CAD as a drafting tool, although the primary functions of computers in architecture have been changed from the computer-aided drafting to its 2D or 3D graphic representation and in recent years to the collaborative design among different specialists, such as architects, engineers, construction managers, acoustical experts, and so on. There are still few computer-aided tools to help a designer in selecting the best suited design strategies, in particular satisfying the design aesthetics, and in connecting the design up to the collaboration. This paper shows how the design- and ordering-principles can be joined into a CAAD system and how the data of the applied design can be integrated into product modeling environment, providing the appropriate solution to the upcoming needs of the construction industry.

Keywords: Design- and Ordering-Principles, Collaborative Design, Product Model, IFC2x, Integration, CAAD.

1. INTRODUCTION

The building-industry is suffering from the high total-costs of its structurally non-dimensional products, which are relatively minimally automated, less computer-aided and, now as before, highly manual-labour orientated; these are wage-intensive products.

Efforts to improve qualities of an architectural design and simultaneously to reduce building- and completion-costs through comprehensive mechanical and computational technology have met with little success in the past, as has been the case in other branches of the economy.

Construction using computerised design-programs has great advantages in the two branches: design and construction in architecture. In the design aspect, the computational programs not only empower our imagination, but also provide opportunities for verisimilitude to support decision-making and for shortening planning-phases. In the construction aspect, this also has a lot of advantages, such as shorter building-time, greater precision (higher security standards for walls, greater strength in concrete), continuous machine capacity, resistance to the weather, dry construction-sites, the solving of complex details and surface cleaning by stationary saw- and planning-apparatus.

Along with this a problem arises: new elements in mechanically-prepared construction often appear unformed, due to soulless machinery. In other words, building, too, should meet aesthetic expectations.

Technology-guided construction has so far been unable to do justice to customers' needs concerning appropriate aesthetic form. Thus, this paper proposes an evaluating system that evaluates and advises on design qualities of architecture, using analytical design- and ordering-principles from traditional theories for the optimization of the architectural design from the aesthetic perspective. At this point, it must be assumed that the creative design, which depends on a human's own spiritual capability, lies with the designer himself.

Designs proposed by this system include optimum design qualities in terms of a traditional architectural theory, and new one which can be in future connected to product models. To do this, the definition of information about building elements is accomplished by using the neutral format EXPRESS-G, the graphical counterpart of EXPRESS [1], for such application systems.

2. PRODUCTION MODEL IN THE CONSTRUCTION

2.1 Overview of Product Model

It is widely accepted that the quality and efficiency of the design process in the AEC (Architecture, Engineering and Construction) domain can be improved only through increasing automation of the design and construction process. The key to success in achieving automation is seen as the integration of the information processing required by the various disciplines involved at the various stages of the design process; that is also the basis for collaboration. To do the collaborative work associated with each field, the communication aspect should be understood at least.

In order to enable this communication among actors, for example, in the construction process, the data in each process have to be formally defined and standardized. In general, most of this issue is concerned with the exchange of project data. As there are many different CAD-systems and each CAD-software has its own internal description, we encounter difficulties when we try to transfer design data from one CAD system to another. In order to solve these problems, studies have been conducted since the beginning of the 1980s. These studies used the neutral-format files, such as IGES (Initial Graphics Exchange Specification) and DXF (Drawing eXchange Format). IGES has been evolving for over twenty years and has become a reliable and widely used format. However, it has serious limitations; it is restricted to partial geometry and annotation but does include structure and relationships. DXF is an Autodesk proprietary format that has been adopted by the construction industry. Similar to the case of IGES, DXF is not suitable for transferring partial geometry because of its lack of precision. As the next generation of IGES, the STEP (Standard for the Exchange of Product Model Data) is the international effort by ISO at trying to combine the different national activities in a single international standard.

2.2 STEP (Standard for the Exchange of Product Model Data)

STEP was born in December of 1983, when the International Standards Organization (ISO) formed the TC184/SC4 committee. STEP is an international effort to produce high-level standards for exchanging product information that support technical information exchange and communication within industries. STEP is targeted at the exchange of data describing a product between Computer Aided X (X = CAD, CAM, CAE, etc.) systems [2]. STEP product models are rich, structured, object-based data models of industrial products. They are generally designed to provide fairly complete, cross-application descriptions of product data, and the modeling methodologies for defining them are extensive and formal.

One of the best reasons of the success of STEP is the standardized EXPRESS language, which allows a complete and unambiguous description of information related to different conceptual components of a product. EXPRESS allows the designer to describe the data structure of the objects of his application, especially through the concept of entity describing a class of objects [3]. EXPRESS-G is a graphical notation for schemas defined in EXPRESS.

2.3 IFC (Industry Foundation Classes)

IFC is an information standard for the building industry, encompassing AEC/FM (Facility Management) domains. This standard is being developed by IAI (International Alliance for Interoperability) [4] whose mission is to define, publish and promote specifications for IFC as a basis for project information sharing in the building industry.

The IFC concept is based on the idea that objects are brought into an integrated model. These objects are defined in order to support the whole lifecycle of facility development from inception through design, documentation and construction, then facility management and finally to demolition and or disposal. The principal benefit of IFC is their object description – not only does the IFC protocol preserve the full geometric description in 3D, but it also knows its location and relationships, as well as all the properties or parameters of each object such as finish, serial number, material description, etc.

Part 11 of STEP, and the ISO EXPRESS language (STEP-11) have been adopted by IFC to describe its model. Thus, the IFC data model corresponds with the STEP standard and consequently contributes to the evolution that permits the exchange of building data between different programs. Unlike STEP, evolution is not planned for a norm, but aims at direct application in the industry. For example, the IFC has a much broader scope than AP 225 of the STEP. Work on the IFC model development has led to various releases of the model; IFC R1.0, IFC R1.5, IFC R1.5.1, IFC R2.0 and the release of IFC R2x. The current release (IFC2x) is focused on the design stages, but there is already support for facility management, and future releases will include thermal analysis etc. A subset of IFC is shown in Fig.1. It illustrates some of the entity definitions and relationships related to building elements, such as the decomposition structure, sub-types and associations with other objects [5].

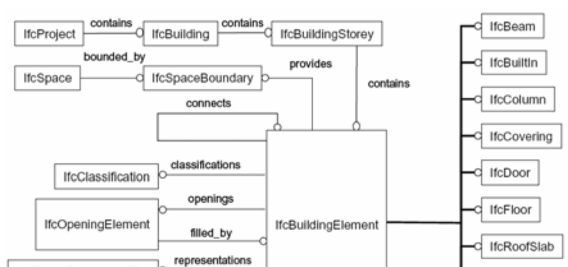

Figure 1. An interpretation of IFC, showing a subset with focus on the IfcBuildingElement

3. SCHEMA AND PROCESS OF THE SYSTEM

3.1 Conceptual Schema of the System in Product Model

The conceptual schema that plays a basic role in product models describes the process of the information about an architectural façade, which is needed for applying design- and ordering-principles to product models. A schematic view is shown in Fig.2:

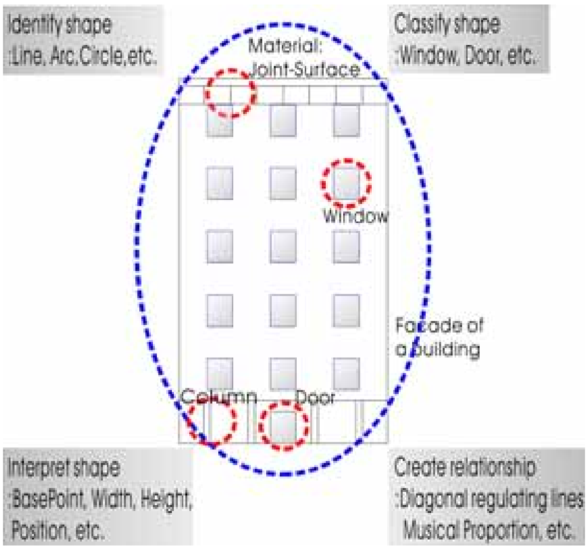

Figure 2. Conceptual schema of a façade

Four major sources of the information about a façade are described in Fig.2. These consist of:

- identifying shape: line, arch, circle, etc.
- classifying shape: window, door, column, façade, material of surface, etc.
- interpreting shape: base-point, position, width, height, etc.
- creating relationship: diagonal regulating lines, musical proportion, etc.

For implementation in a product model, each shape has to be defined and found in a drawing first. In general, a shape consists of a set of lines and curves which are usually connected. When each of the elements of a shape has been identified, it then has to be classified, in order to be recognizable by a computer by its own name, such as a window, a door, a column, etc. The interpretation of a shape is considered as the process that shifts the semantic content of the drawing to a higher level. Normally, this phase is one of main goals of IFC2x, and is the key to implementation of the application system in an object-orientated CAD-system; here, different aspects of an object are analyzed and stored as parametric values. When all elements of a façade have been recognized, their relationships can be analyzed and proposed by implementation of the AutoLISP. Thus, the design is "qualified", according to the optimum design- and ordering-principles.

3.2 Process for Development of the System

A process model provides a description of tasks needing to be undertaken. It defines all of the required tasks within the process and puts them in a logical sequence. The following process diagram illustrates the required scope of specification development for applying the architectural design- and ordering-principles to CAAD systems in the framework of a product model.

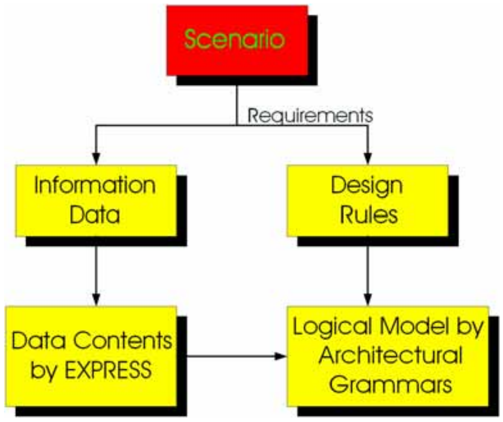

Figure 3. Process diagram of the product model

In this diagram, "Information Data" and "Data Contents" can be described with EXPRESS or EXPRESS-G, which give the fundamental information about a façade. In these phases, general entities, attributes and relationships between a building and its elements are defined. In the case of a building façade that will be examined, the hierarchical decomposition can be divided into structural layers, openings, surfaces and columns; the columns are described as optional attributes. These components of the façade can be defined with EXPRESS-G, as the following Fig.4:

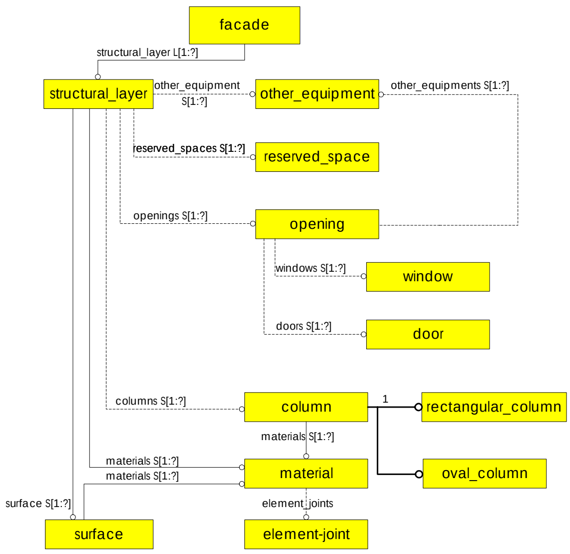

Figure 4. Overall EXPRESS-G diagram of the façade

This schema in Fig.4 contains physical parts of the façade that are related to each other element, which allows input of information about a façade in applications for design- and ordering-principles.

"Design Rules" and "Logical Model by Architectural Grammars" in Fig.3 are described in the following chapter 4.

3.3 Program Mechanism in the System

The programming language employed in AutoCAD is AutoLISP. As this language retains most of the general LISP (LIST Processing Language)-functions, it is a symbolic manipulation-based, interpreted language that provides a simple mechanism for adding commands to AutoCAD [6]. For example, this interactive programming language in AutoCAD allows users to program external applications, using the AutoCAD drawing generation and manipulation functions for 2D geometry, 3D wire-frame structures and 3D curved surfaces. Therefore, customizing AutoCAD into a more useful tool for a particular application for users can be carried out using AutoLISP programs. The AutoLISP program is normally written by "text editors" and then is saved as "text only" with the ".lsp" extension; i.e. rhythm.lsp. The main programming language of the proposed system in this work is AutoLISP. The system demonstrated here operates in MS-Windows XP and in the AutoCAD 2000 environment.

The choice of AutoLISP in this work has been made for several reasons: this author's amount of experience with both AutoLISP and AutoCAD; the reliable graphic control/output in AutoCAD and the worldwide usage of this system in architectural offices.

4. DESIGN RULE AND APPLICATION EXAMPLE

4.1 Design- and Ordering-Rule and Product Model in the System

Architectural theories in western architecture have been considered as a basis for answering the fundamental questions of architectonics: proportion, symmetry, color, harmony and so on. Among those the design- and ordering-principles are significant, since it affects the aesthetic evaluation of human's visual perception. In particular, the specific formal ordering-system, such as proportions, axes, grids, symmetries, etc., can help to maintain unity, to avoid chaos and then to achieve harmony in an architectural design.
In this paper, only the subsystem about rhythmic arrangement of windows among many design- and ordering-rules is described because of the limited pages. In general, rhythm in architecture is divided into two categories: even and odd rhythm. A very common symmetry is even rhythm such as 3, 5 or 7 time [7]. Above all, the use of 3, 5, 7 time is of greatest importance in the grouping of buildings. 3, 5, 7 time rhythm brings together and gives focus, thereby creating a considerably stronger impression of a form, moreso than 4, 6, 8 time rhythm, which continually threatens to break down into two or more parts; the latter permits a gap to exist within a maximum of two seqences of elements, for the creation of an axis of symmetry.
In short, odd rhythm, such as 3, 5 or 7 time, always has the power to determine symmetry through its center axis. This element "rhythm" alone can not achieve unity in a design. However, it contributes significantly to empowering the existing ordering principle. Representative kinds of different symmetrical time-rhythms in architecture are described in Fig.5:

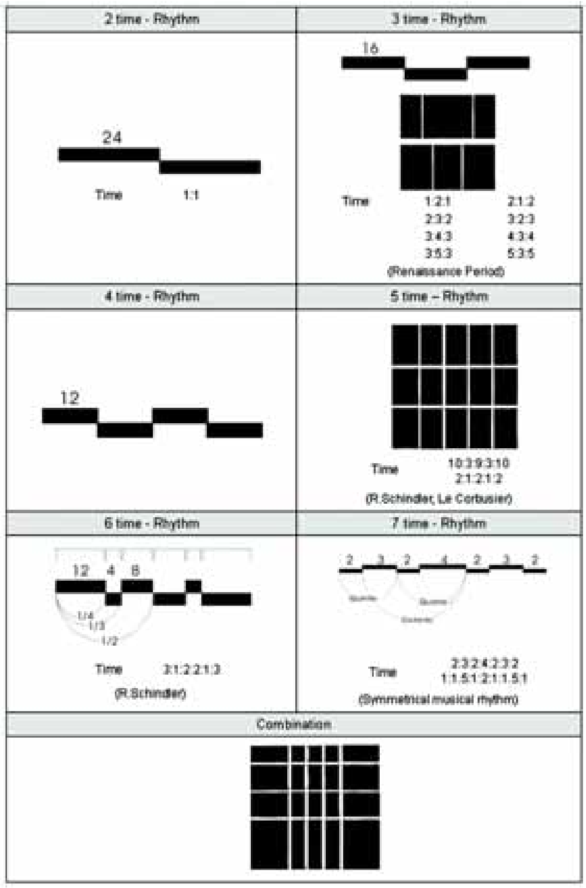

Figure 5. Different symmetrical time-rhythms

These time-rhythms as a design rule can be applied to the arrangement of building windows in a CAAD system. The base shape for implementation of the system is illustrated as following Fig.6.

In Fig.6, each relationship, A:B:C:D:E, on a façade can be calculated automatically through the computer, according to the mentioned symmetrical time-rhythms. For implementation of the system in a product model, a lot of information about this façade and its parts are needed, such as the length (L) and the height (H) of the building, each length (l) and height (h) of windows, distance (W1) from the building's edge to the edge window.

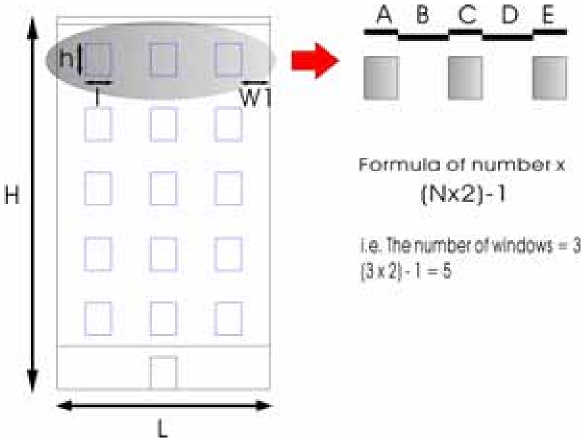

Figure 6. Basic shape for implementation of the system

The definition and value of this needed information are referenced from the already defined Ifc2x-model. The requisite entities for the symmetrical time-rhythms in the product model are as follows:

- TotalHeight of the Building: IfcQuantitiyLength
- TotalWidth of the Building: it can be measured from IfcQuantityArea
- OverallHeight of a Window: IfcPositiveLengthMeasure in the IfcWindow
- OverallWidth of a Window: IfcPositiveLengthMeasure in the IfcWindow
- Placement: IfcObjectPlacement (referenced entity: IfcLocalPlacement)
- Distance between Windows: it can be derived from the position of each juxtaposed window

The most definitions of entities of the façade correspond to the IFC2x. However, some entities were as yet undefined in IFC2x. These can be measured or derived from the existed IFC model, or can be newly defined.

4.2 Examples

The generated AutoLISP file can be loaded into AutoCAD. Then, the user uses "(rhythm)" in the command prompt to invoke the AutoLISP program to achieve harmonious arrangement of windows, which is based on the symmetrical time-rhythms.
While the AutoLISP program file is running, the command window of the AutoCAD asks the user for entering each needed value. The numerical value entered by the user is calculated automatically in this system, and the computer gives the user a number of design alternatives that are based on the time rhythm principle.

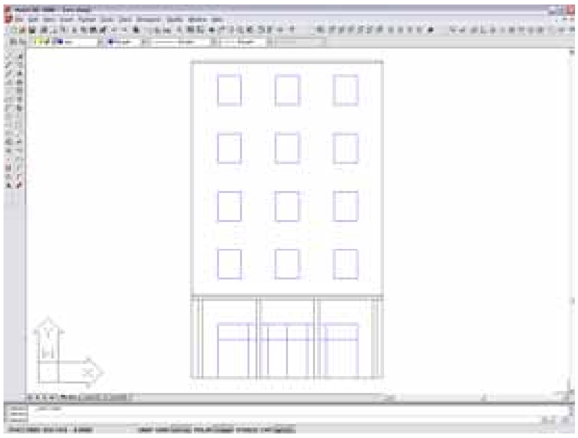

Figure 7. Original drawing of building façade

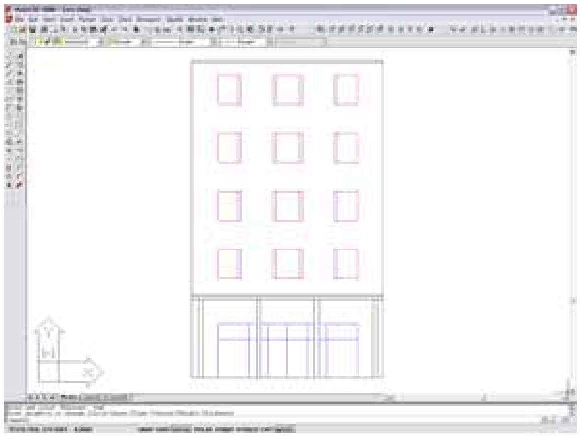

Figure 8. Design alternative that is advised by the computer

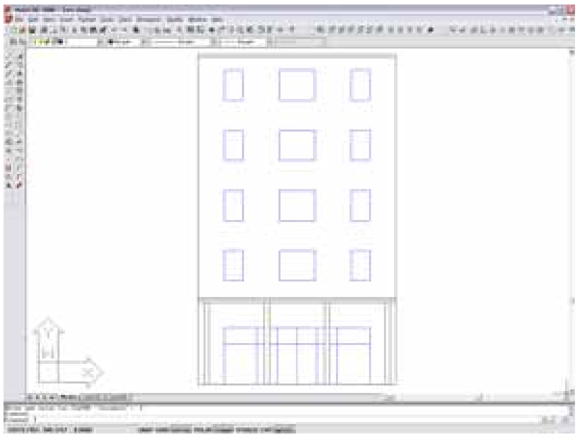

Figure 9. Final design based on the symmetrical time-rhythm

Fig.8 shows the screenshot of an alternative design among different ones which are advised by the system on the arrangement of windows.
The user can choose his preferred rhythmic relationship from those shown on the screen, according to his own design experience, as shown in Fig.9.

This system can be used as soon as it is needed and simultaneously the user can obtain some design advice from his own computer for a quality assessment of the particular design qualities.

5. CONCLUSION

As shown in the previous examples, the application system is applied to explain and develop aesthetic qualities of a design. Designs proposed by this system include optimum designs, which are based on the design- and ordering-principles, and on new ones which can be in future connected to a product model. The simple, visual rules used to develop designs are meant to explain how the designs are improved. Some problems are encountered during these tests. This proposed system has not been developed under the object-based CAD system, so that there are only series of lines, when any elements such as windows, doors, walls and roofs, are drawn in the existing CAD system; when one draws the outline of a shape, the drawing is always a line. This means that users must select each line that encloses an element in order to examine the relationship, for instance, between windows on a façade when implementing this system; the value of an element must be also chosen by users, clicking the mouse or entering the value on the screen.

However, the world's big CAD vendors, such as Autodesk, Graphisoft and Nemetschek, have recently started to offer object-based software, including the IFC2x model. They offer powerful CAD capabilities and significant building-design tools; e.g. when we add openings to a wall in this CAD software, the wall automatically adjusts itself to accommodate the openings and adds end-caps where needed. If we move the wall, the openings move with it. If we remove an opening from a wall, the wall repairs itself in the space where the opening was located. Therefore, the proposed system could be better enhanced, if it were developed using object-based CAD systems; it would neither need to select each element nor to click the length and height of an element.

REFERENCES

[1] Schenck, D. and Wilson, P., *Information Modeling – the EXPRESS Way*, Oxford University Press., p. 25, 1994.

[2] Wilson, P., *STEP and EXPRESS*, http://deslab.mit.edu/DesignLab/dicpm/step.html, 2004.

[3] Junge, R., "The VEGA Platform – IT for the Virtual Enterprise", *CAAD Futures 1997*, p. 596, 1997.

[4] IAI 1996, *IFC Project Model Specification. Ver.0.94*, Industry Alliance for Interoperability, 1996.

[5] For a complete understanding of IFC, the reader is encouraged by refer to the following website: http://www.iai-international.org/iai_international/

[6] Sommer, W., *AutoCAD 2000 - Kompendium*, Markt & Technik Verlag., pp. 1030-1034, 1999.

[7] Wienands, R., *Grundlagen der Gestaltung zu Bau und Stadtbau*, Birkhäuser., pp. 105-114, 1985.