THE LACK OF INTEROPERABILITY IN 2D DESIGN– A STUDY IN DESIGN OFFICES IN BRAZIL

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SUMMARY*: A lack of interoperability represents a significant problem (not only in Brazil) in many productive sectors and is still not explored in building design. In order to investigate the problems relating to information exchange, principally data interoperability, a survey was conducted in design offices in the south of Brazil, to identify the problems and quantify the losses due to problem with the lack of interoperability. This survey indicated an average percentage of losses in the design process of approximately 22%. In order to generate information starting from Computer Aided Design (CAD), and as a way to improve the communication between the partners, a study on the use of the Industry Foundation Classes (IFC) as a standard for transferring data between design modalities (architectural, structural, hydraulic and electric) was carried out. An application of syntactic conversion of attributes of the IFC to XML was then used as a way to assess the viability of technical integration and to transfer information to a web environment. The prototype demonstrates the viability of the technical integration of information in design to agents of design modalities involved in design processes.*

KEYWORDS*: IFC classes, Information exchanges, interoperability, CAD, technical integration, communication.*

1. OPTIMIZING THE USE OF IT IN THE BUILDING SECTOR IN BRAZIL

Many researchers around the world acknowledge that the use of information technology in construction results in modifications and improvements in the production process of the sector. The current period in emerging countries, such as Brazil, is still incipient in relation to the use of IT resources and the dissemination of innovative tools.

Although it is important to show that IT innovations in the Construction Industry are possible and increasingly present, some problems persist, such as a lack of integration and the problems regarding information exchange between agents in the construction process, as well as deficient information systems. All of these have been reported in the literature as obstacles to the growth of IT use in research in Brazil (Cintra 2000, Souza 1997, Barros 1996, Gomes and Morgado 1996, Fruet and Formoso 1993).

The building industry in Brazil is characterized as a fragmented industry because of the lack of companies to significantly influence the production chain, as having a series of small business companies, and as having serious difficulties in aggregating information relating to the sector, due to a dispersion of data and the similarity of the participating agents. This problem is observed in relation to the workflow of the participants in the production chain, but it is a consequence of what occurs internally in each company. The flow of information among departments, projects, and sectors, in general, occurs in a dispersed way and often with no control of the data flow.

The question of information exchange is a point that can indicate the level of success in the use of current computational tools. It is common knowledge in the sector that the definition of standard terminology contributes to the codification of the products and processes, allowing its use in text languages, through the web, generating the possibility for automated transfer of information between the agents participating in the project. There is an agreement between Portuguese-speaking countries that there is a pressing need for standardization of

terms, which occurs in isolated and non-institutionalized forms (Jacoski, 2004). The current scenario in the building industry in Brazil is represented by three types of companies: those which have incorporated innovations and IT tools into processes, average-sized companies which are seeking innovations and IT uses, and small business companies (which constitute the majority) restricted in terms of the use of computational tools. Practically all of these companies use digital designs, especially 2D.

2. NEW TECHNOLOGIES - OLD PROBLEMS IN THE BUILDING INDUSTRY

Several studies conducted in the building industry around the world show the fragmentation of the production chain as one of the main causes of performance problems.

The building industry is fragmented because it does not have companies that can influence the market significantly, and it also presents serious difficulties in relation to information aggregation over the entire sector, due to dispersion of the data and the heterogeneity of participating agents.

This problem has not only been detected in the production chain, but it is also present in the process management within companies. The flow of information between departments, designers and sectors, in general, occurs in a dispersed way and often with no control of the data flow.

Some recent studies such as: Construction Task Force/UK (Aouad and Sun, 1998); or studies not as recent (Banwell 1964, Higgin and Jessop 1964); also found a great number of communication problems caused by a lack of coordination, low efficiency, low quality and the existence of isolated solutions. Latham presented a Review of Construction Procurement in Brazil, in which the same situation occurs. Work practices influence the relationships between the agents, with negative effects on costs and quality of the construction products (Latham, 1994).

The information above gives an idea of the difficulties associated with solving these problems, which have been present for many years and persist in several countries, each with its own specificities. Solid solutions that should be considered in the resolution of problems relating to various aspects are: communication, administration of processes and relationships between the agents. Currently, there is an emerging consent, not only regarding diagnosis, but also in relation to finding an effective solution to the relationships between the agents of the design process; a more relational and consistent way that could allow collaboration in activities to be introduced, so as to decrease interruptions in the process due to communication problems, industry fragmentation and a disintegration culture (the agents acting as opponents) (Nicolini *et al*., 2001).

The factors against technological integration of information in the construction industry are (Cintra, 2000):

- Fragmentation of the production chain;
- Lack of standardization for information exchange between systems;
- Lack of transparency in the processes;
- Low management quality in the industries and companies, and in the design.

Although there are associations among the factors mentioned above, there is no doubt that technological progress acts as a generator of improved conditions for all the agents in the process and it also promotes integration between the design agents, extending this relationship to other members involved in the process of executing the project. When there is previous involvement of the contractor in the process of design elaboration, there is also improvement in the process for two reasons. The first is that the contractor's contribution provides information on decreasing future unnecessary costs. The second is that usually the designs do not show enough detail. So, there is a lack of the more significant information needed to carry out the work. Thus, it is not possible to enhance the buildability, contributing to a poor quality of the design (Murray, Lai and Nkado, 2001).

A productivity increase can be obtained via a rigorous analysis of the requirements, incorporating the difficulties of the subsequent phases and maintaining a rigid control over the modifications until the end of the constructive process; in this way it is possible to reduce the time spent on the design process and the requirements for modifications (common today).

In this sense, with the use of IT as integration tools, possibilities have been generated in the flow of data between the participants of the design process, with reduction in the number of mistakes and improvements in the coordination, data integrity, and design quality (Faniran *et al*., 2001). One of the most important benefits that IT offers to the building industry is the automation of the processes (Love and Gunasekaran, 1997).

3. THE LACK OF INTEROPERABILITY AND THE TECHNICAL INTEGRATION OF DESIGNS

With the diffusion of Information Technologies and Communication, and the increase in computational tools for Architecture, Engineering and Construction (AEC), which has occurred in recent years, a great quantity of digital information has been generated. Thus, it has become necessary for the sector to promote data standardization so that data can be shared among the participants and partners in the design business.

With the focus the design process, it is possible to see that the lack of interoperability among systems, data, software, and information is a problem that precedes the effective implantation of technical integration (Jacoski, 2003). Interoperability has been the center of attention for research in the sector that uses data transfer, representing a concern for the companies that seek to achieve interoperability between software applications executing different functions but that could share similar data (Jacoski and Lamberts, 2003).

Many of the difficulties take place in the transfer of files from CAD software (and are already known), and also the use of CAD files combined with other tools used by the sector, such as software for structural analysis, cost estimations, building simulation software and others; all of these present problems originating from a lack of interoperability.

In order to achieve a wider interoperability, it is necessary not only to have a syntactic equivalence among the entities represented by the systems, but also the equivalence of concepts and meanings of those entities. Thus, efforts need to be made toward contemplating ”Schemas” that can facilitate data sharing, in relation to new conceptions and the use of the same schema for the community that uses the same data parameters.

Some researchers have proposed systems-based data interoperability, whose conception is based on ontology (Aouad and Sun 1998, Murray, Lai and Nkado 2001, Jacoski and Lamberts 2003).

For the organization of the ontology, fundamental characteristics should be taken into consideration; some of these are described as follows:

- Open and dynamic: To adapt to the changes of the associated domain, it should be as automated as possible;
- Interoperable: It should be easily interoperable over a wide domain and adaptable to new requirements, but also be very simple;
- Easy maintenance: It should be at the same time dynamic and easily maintained by specialists;
- Semantically Consistent: It should maintain the concept and logical relationships;
- Independent of context: in relation to ontology, it should not contain very specific terms in a certain context, because terms can then be widely used (on a large-scale).

The difficulties encountered by the sector in creating a syntactic interoperability are also a result of cultural and regional problems. The ambiguity also exists in some concepts already adopted by the participants, and the agents of a design usually adopt different nomenclatures for the same object.

This concern is important because a particular product needs to have the same term, as it can be used in the market for different purposes. In this sense (mainly in terms of standardization), the introduction of the IFC represents important progress in the search for interoperability among systems.

The technical integration through a distributed model of data can be based on the creation of a centralized design model using CAD 3D/4D (Caldas and Soibelman 2003, TOCEE 2000, Soibelman and Peña-Mora 2000). There are many examples of initiatives in this area, which include ISOSTEP, the IFC (Industry Foundation Classes) developed by IAI – International Alliance for Interoperability, and the specification aecXML - by the AEC Working Group (Eastman, 1999), and others – bcxml, ifcxml, etc. (Amor 1998, Anumba 1999, Anumba and Watson 1992, Brandon and Betts 1995, Cutting-Decelle et al 2001, Faraj 2000, Li, 1998).

4. LOSSES DUE TO A LACK OF INTEROPERABILITY IN 2D DESIGN

The integration in building design and the transfer of information is an indispensable theme for discussions on improvement of the current production process in the sector. It is always necessary to have resources to find solutions in this area and these should have the capacity to adapt to the relationships between the agents in the design process with more consistency.

The design offices have particular characteristics, mainly in relation to the sharing of common information. The problem of the lack of interoperability among the computational tools is of particular relevance to the interaction between the design stages. This problem is present in 2D designs, still used on a large scale in small design offices. It will not take long before the use of 3D dimension becomes consolidated, but this research was carried out to show how much wastage of time and resources there is at this moment.

An analysis of the cost of the lack of interoperability in 2D design will be presented through ”case study ” developed in design offices in the south of Brazil.

4.1 The research in the design office

The research focuses on the quantification of the time spent on design, as a way to show and to defend the need to incorporate new models for integration of the process. The following items were investigated:

- Lack of Interoperability;
- Interruption of manual details;
- Problems with data transfer;
- Requirements for the quantification of materials;
- Design revision;
- Design corrections/modifications.

Considering the difficulties generated by the characteristics of each design and of each case, the observations made and the information obtained in offices regarding the design production process and the experience accumulated by the offices were also taken into consideration.

After this investigation, it was possible to generate a synthesis of the interoperability losses in design, providing an indication of the amount of time wasted in the design phase. This part of the research looked for inspiration in research carried out by the U.S. Automobile Industry and by the National Institute of Standards and Technology - NIST, which focused on the need for a reorganization of the sector to decrease losses caused by the lack of interoperability in data sharing (Brunnermeier and Martin, 1999, Brunnermeier and Martin, 2002).

At the beginning of the design process, the specifications are the first piece of information that can offer positive relationship conditions for the vendors, manufacturers, and other agents. It is in the design phase that the interoperability problems begin to be generated.

In order to identify the ways in which the problems occur with the lack of interoperability, the research was focused in “top of line” design offices having the best practices in relation to design, and which stand out in the market due to their use of better IT technological resources. It was defined that four offices would be used (one in each modality), those that already had some advancement in the use of information technologies and communication - ITC. This choice was made in an attempt to reduce the effects of the lack of relation between the offices with ITC, obviously with the objective of not making the problem worse.
In order to understand the methodologies used in the research, the following points were considered:

- Documents and process analysis of each office;
- Characterization of the office through quantitative structured data;
- Observations of the several design stages, including cost control, time control, modifications and deficiencies of the design;
- The process flow, identifying the activities carried out and the procedures adopted.

The observation of the design process was carried out with each modality of building design being divided into stages. During two weeks all process was investigated. All the existing elements of information within the process were identified as well as the relationships they maintained with the agents of the development process of the design. To each occurrence of data transfer to other agent, or any action that modified the productivity, the updated records were registered in a database, with the annotations of the time wasted in each situation.

The experiment took place in offices with different modalities of design: architectural, structural, hydraulic, and electric, using the list of the daily procedures of the office, as well as of the documentation used for internal information control. The time in each activity and each interruption was written down in a table of control.

The structured interview with the specialists was of great use, since several common problems were found. In spite of the problems occurring frequently, they do not necessarily appear in all designs.

The result of the investigation in situations that caused productivity loss due to the interruption in design was to identify the situations of non-interoperability between the several digital designs, of information transfer and of other situations. The companies studied were in top of market in use of information technologies, because this result in all design offices can be more representative and is possible that the percentage of losses very bigger if is taken in account the set of offices.

It is possible to see that the greatest losses are in architectural design and the least in structural design. The average loss in the design modalities was found to be 22.5%.

TABLE. 1: Loss in design caused by a lack of interoperability

Modality of design	Individual loss for design in %
Architectural	31
Hydraulics	24
Electric	19
Structural	16
General	**22.5%**

The research investigated problems in the sharing of information among the design agents, suggesting solutions employing emergent technologies.

Results from this investigation led to recommendations regarding information parameters for a protocol of information distribution among the design agents.

The study seeks to identify which information is needed in order to manage the interference problems among designs, making recommendations regarding how these data can be modulated for use in computational tools of great potential and the web. Using a standard for the transfer of information, the research led to a model adapted to the existing procedure in the design process and to the increase in innovative IFC.

4.2 The construction of the prototype

The sequence of tools for implantation was defined through the observation of the possibility for virtualization and integration of the processes in the design sector, the remote use of the information (and the registration of this) in text languages, provided by the use of objects of IFC associated with XML language, to use in a web environment.

This type of research aims to offer a contribution regarding the use of computational technology resources in the building industry (Betts, 1999). The design process already uses several languages (forms) to represent aspects of the product being developed, which are:

- Semantics: Verbal or textual description of the object, can specify the material or the process that will be used in each situation;
- Graphics: Sketches, technical drawings and perspective;
- Analytic terms: Equations, rules and procedures that are used to define the product form or function.
- Physics: Models in reduced scale, prototypes, scale models.

The use of text files is particularly important due to the fact that the drawing of objects could incorporate information besides giving a graphical representation. Generating text files of a design developed with the use of IFC, would increase the possibility of achieving the syntactic and semantic exchange information with the files of drawings (bearing in mind that these have gone through standardization, created by the IAI - International Alliance for Interoperability). In Fig. 1 shows a set of processes of the design of the prototype, which are necessary in terms of functionality and operation.

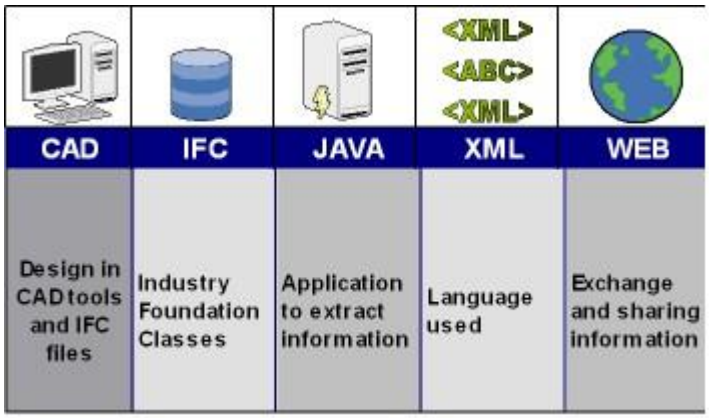

FIG. 1: Process of information management.

In Fig.2, a view of the proposal is shown. It can be seen that after the creation of the CAD design, the objects are automatically defined in IFC, being transformed into XML files through a tool called "translator", in attributes associated with terminologies used in the construction business. This markup language can be used on the web for applications such as: market research, extranet use, information sharing, automatic search, material quantification, budgets, simulations and other possibilities.

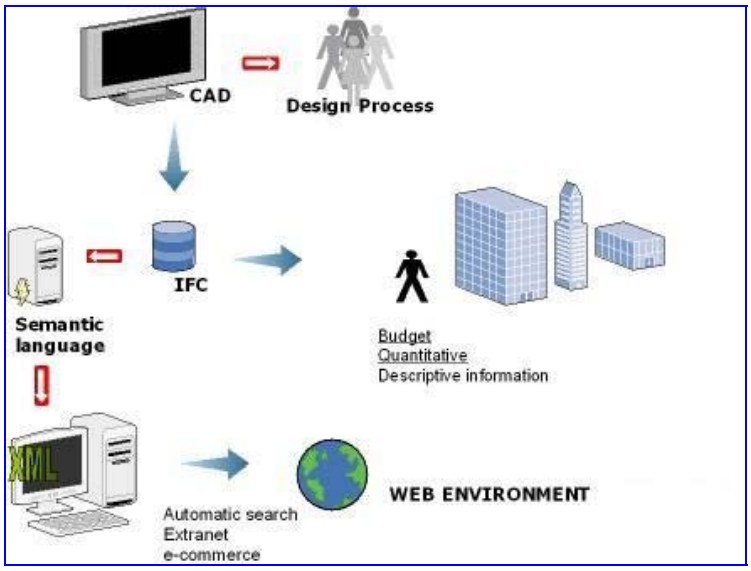

FIG. 2: Functionality of general conceptualizations.

To construct an effective example of the study, some selected objects of the design were defined to show the attributes and to define the protocols necessary for the transfer of information. The objects were: door, window, wall, structures and pipes. Each of these objects was defined through a protocol, composed of five classes of attributes (structured from interviews with specialists). These classes could contain the values of attributes necessary for the transfer of information.

Five types of classes were defined: Drawing elements, physical material properties, specification of the constructive system, information of interferences in design, and the administration of interferences. In the case of this study, five attributes were also defined in order to facilitate communication regarding "design alterations": observations, author, interferences, localization, and resolution period.

The attributes of the door can be seen in Table 2:

TABLE.2: Attributes of element door

Drawing attribute	Physical	Specification	Interference	General
Layer color	Width	Type	Observation	Design name
Layer name*	Height*	Standard	Author	Design Type
Scale line*	Thickness*	Color	Interference	
Thickness line*	Weight	Code	Drawing	
Plot pattern*	Description*	Price	Time	
Situation - x y z*			Situation	
Rotation *				
Elevation *				
Insert wall width				
Hyperlink *				

** Default CAD*

Some attributes were automatically extracted from the CAD tool (the software Architectural Desktop 2005 was used - *AutoDesk*®) in the generation of the object drawings (which are identified by an asterisk in Table 2). The ones not marked are from this study.

For establishing this protocol, the standardization of information is necessary, and this becomes indispensable to the integration of agents in the production chain.

During the design this relationship between the agents involved in the process, with the use of computational tools, can contribute to enhancing communication regarding changes in the construction project.

To accomplish this technical possibility, the research used the exchange of syntactic and semantic data generated from design, as a form of facilitating some routines, in communication, data transfer, compatibility of files, etc., changing the terms of classes to the Portuguese language.

The implementation of the prototype compatible with the IFC (Industry Foundation Classes), allows the sharing of information on objects contained in the design such as: doors, windows, walls; information on interference in modalities of design agents, etc. This attribute is in accordance with standard IFC, which have the task of standardizing the attributes of the several objects used in designs, among other modalities such as architectural, structural or any other types supported by this model.

An intermediate layer was developed (software) to manipulate the data of IFC files. The software is responsible for extracting and standardizing these data. In this way, it is possible to transform data coded in IFC language into other types of data and also to transform them into information for the users. The intermediate application was developed in JAVA language, which takes as inputs the IFC file standardizing data using XML language. The use of XML language (e*X*tended *M*arkup *L*anguage) is due to the structured data of its schemas.

After the transformation of the information extracted from IFC files and the generated of XML schema, it is possible to integrate them through the web.

In summary, the procedure was carried out in the following stages: Customization of the CAD tool, exportation of IFC files, Java Application, XML file, information sharing on the web:

Customization of the CAD tool: To input the information, the customization of the tool CAD was necessary because the data is introduced through this;

IFC file: The CAD tool through the device of exporting the IFC file, a file is generated with the standardization of the drawing elements;

Java Application: The software was implemented with a focus on the generation of information extracted from the IFC file, for the assembly of a group of elements with syntactic and semantic significance;

This software makes use of **”**defined strings**”** in order to facilitate the transforming of data to the user language. This transformation provides an understanding of information when using these strings in computational tools and in the web environment;

XML File: Through the standardization of the elements and attributes, the XML file is created automatically through Java application, it being possible to use information structured in a ”schema XML” (with the information being in the Portuguese Language);

Sharing of information: This is the phase of information use in a web environment, where searches can be carried out regarding all aspects of the design objects (door, window, etc.), and the information collected can be transferred from ASCII to other tools, providing countless opportunities of information sharing including quotes, market research, availability of materials etc.

The software was development in prototype, due to financial limitation, but even so, it should be noted that this research is the first application of IFC in Brazil, generating a national paper (Jacoski, 2003), and consequently disseminating the IFC classes (Jacoski, 2004). Recently, another doctorate thesis was defended on the subject (Ferreira, 2005).

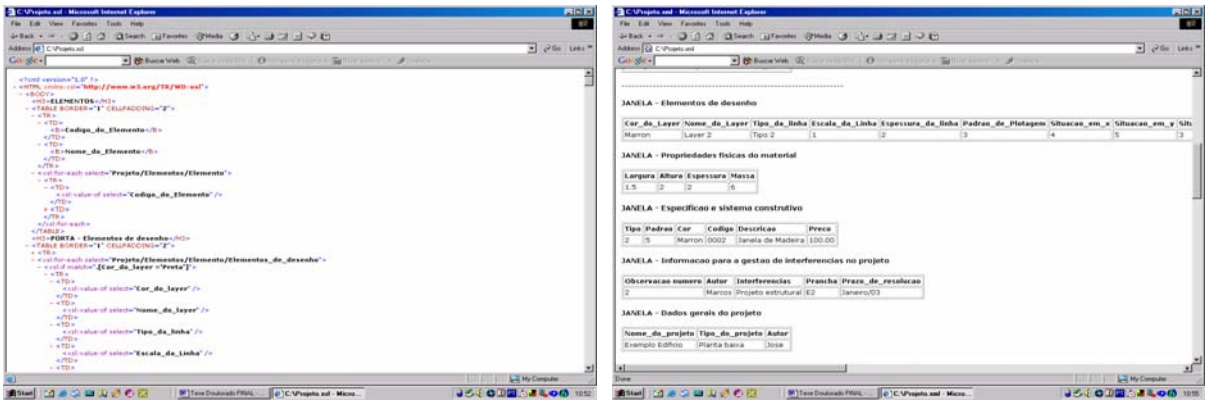

FIG. 3: XSL file and objects translate in Portuguese language in web environment

5. CONSIDERATIONS ABOUT THE INTEGRATION OF THE COMMUNICATION IN CONSTRUCTION

With the increase in the use of information technologies in the construction industry there is an increased occurrence of tools available for employment in activities in the middle of the process, contributing satisfactorily to an increase in productivity, and an improvement in the quality of the products. In this context, a high degree of interdependence between the different types of design was identified, which demonstrates the need for the circulation of up-to-date information among everybody involved, decreasing the problems in the process.

This research found a productivity loss of 22.5% in the design offices (in 2D design). In order to change this situation, the integration of information starting from the design can become a viable tool. Also, this can be considered as an essential mechanism to decrease mistakes, increase teamwork, efficiency gain and speed, with a subsequent improvement in quality and productivity.

Nowadays the transfer of information between the design participants is inconsistent; there is usually only exchange of information in part of the design team. A lot of information is lost, and in some cases it is generated in contradiction and in other situations unnecessarily duplicated. Due to these facts, the design tends to be delayed and more expensive than necessary.

This research has identified the need to prepare the existing instruments in the sector to adapt the technological resources to the design processes. An effort should be made towards the standardization of the vocabulary used in the construction business, as a form of reducing the semantic divergence in the nomenclatures used by the several participants of the sector, besides the need for equivalence with the international systems of classification. With the growing use of languages text (like XML), the vocabularies tend to acquire a significant importance.

With the participation of several agents in the process and with improved conditions for collaborative work (with

more intensive and interactive performance between the partners), it becomes necessary to organize the information so that this occurs almost simultaneously with the design process.

In this sense, the solution proposed for the use of a web environment, receiving text information directly from the design, offering this information to the partners would are able to use it in their CAD system, or other application, is a contribution to the solution of problems that still represent barriers to the evolution of the design process.

As far as the prototype is concerned, a test was conducted with the object attributes and this led to an adequate exchange between different design offices. The situations of interferences were present on the web in a common place, representing real conditions of quality improvement in the sharing of information.

The software - prototype demonstrates the practical viability of the technical integration through the web, being constituted by an experience that offers significant gain in information exchange in the design process.

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