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Proceedings of the International Conference on
Computing in Civil and Building Engineering
W Tizani (Editor)

A 3-D learning environment for teaching the collaboration to civil engineers

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Abstract

This article concerns an investigation into a new methodology and computational tools facilitating a collaborative learning environment in the field of civil engineering. Desk research by way of literature search has been applied on projects in four countries. The results of the empirical studies have shown three problems in the collaborative environment: semantics, synchronisation and communication.

Besides these handicaps, there are professional handicaps. The article sketches a scenario for a virtual environment for collaborative learning with network technology and simulation games. This will lead to a filter mediated interaction model. The scenario is illustrated with three screenshots of the interface.

Practical, professional tools, based on the methodology and the mock-up, will be developed in an international effort.

Keywords: education, collaboration methodology, virtual environment, sustainable development

1 Objective of the investigation

Collaboration is an important aspect of modern engineering and business activities, arising from the growing complexity of artifacts as well as the organizations who design, build, and operate them. Collaboration increases the pool of knowledge and skills available to undertake large-scale activities (which often exceed the capacities of any individual), allows for division of labor, and helps the participants arrive at solutions they could not have conceived on their own. On the other hand, failure to collaborate often results in cost overruns, missed schedules, and diminished satisfaction of all parties involved.

Fostering positive collaboration in engineering- and business-related fields is difficult, due to the different disciplinary backgrounds of the participants. Collaboration across cultural and gender boundaries is even more difficult. Yet, the globalization of many engineering and business enterprises fosters, even demands, exactly this kind of collaboration. In the construction industry, for example, it is now common to engage the service of architectural firms in the United States, engineering firms in Europe, and construction firms in Asia, for projects that are commissioned and built in every part of the world. We investigate a new methodology and computational tools for understanding multi-disciplinarity, cross-cultural collaboration in collaborative eco-conception and eco-construction, which lead to the definition of the 3D learning environment for the education of civil engineers.

After several years of teaching courses on collaborative design, collaborative technical writing, and collaborative design in virtual world, we develop and implement the methodology and the content.

The objectives of the courses are to provide students with hands-on experience in creating and building, collaboratively, a virtual passive house or a virtual ecological city, and a social place in Cyberspace.

In the physical world, students in civil engineering met face-to-face twice-a-week in class, for lectures and discussions that dealt with theoretical issues, placeness and virtuality, calculation, materials, foundations, etc., as well as conceptual, functional challenges of constructing a passive housing or ecological city. During these meetings, students used a variety of tools and media: CAD-tools, sketches, calculation tools, norms, etc.

They work together (team of civil engineer students) online with students in architecture and in urban studies from other universities in France or from foreign countries. They acknowledge that there are others working on the same geographical location albeit they have been assigned different individual plot. We do not explicitly let the student make groups of two or more, we regard this exercise as teamwork among civil engineers and other individual or team from one or multiple domains.

On-line students met on *GoogleEarth* where they put they projects. They can consider their neighbor's design while they are designing on their private workplace and on the public workspace (*GoogleEarth*). They are creative together when two or more students decide to share their resources, their competencies, and combine them to design and construct a more elaborate passive house or ecological city in favour of their neighbours.

They share their ideas and discuss on the hypothetical scenarios during the evolution of the design process with the help of chat, forum, whiteboard or even through *Moodle*. Teachers often logged on too, and observe more than to participate in the enfolding process.

2 Research methodology

We perform a literature study into territorial projects financed by the local authorities or by a project developer in four countries. We took a constructivist approach (Avison, Myers, Le Moigne 1995, Baumart 1997). The model for the empirical studies is based on four central aspects of the eco-conception and eco-construction process: the generation of design solutions, the communication, the evaluation of design solutions and decision-making. This model emphasises that a good decision-making is important on several levels in the architectural design process (Morin1990, Callon1996, Emmitt and Gorse, 2003, Kalay, 2004, Lundequist, 1992c, Schön, 1991). These give a certain dynamic to the process to avoid the sequential understanding of the process from the 1960s (Lundequist, 1992b). The generation of design solutions is the most important criteria for the decision-making in the eco-conception and eco-construction process. A decision can directly impact on both the architectural design process and the product, in the form of a new requirement.

The model is also based on three levels. We distinguish the individual solving a process, for example the civil engineer finding a solution regarding a foundation or the roof. Another level deals i.e. with the interaction between the architect and the civil engineers. The last level comprises the whole processes. The use of levels allow us to structure and organize the different approach by taking into account the different research fields like, individual theories, group theories, organisational theories and societal theories. The methodology and a mock-up have been tested by students in four countries, working together on a hypothetical design project.

3 Results of the empirical studies

The client organisation and the building authorities are defining the overall constraints, requirements and aims. It impact on both the design process and the design product. The computergenerated drawings made by the architect are used as the basis for communication, evaluation and decision-making. There are three main problems:

- *Semantics*: information developed by one professional may not be comprehensible to others, due to the particular language and conventions each profession uses to code and represent its work.
- *Synchronization*: information is developed incrementally and a-synchronously: the information one professional needs to get from another professional may not yet be available. To avoid delays, the first professional may have to make decisions on the basis of assumptions, which may or may not be true. Moreover, there is not a clear sequence of decision-making: the work of each professional may constrain the work of others.
- *Communication*: there needs to be a way to share information in a timely and accessible manner. The World-Wide-Web may be the solution to this problem.

The interoperability is not the main problem anymore since the IFC and BIM are a standard. Besides technical problems, social and professional impediments were signalled. Architects, engineers, construction managers, facilities managers, building owners, and end-users all have different world views. In general, the project developer and local authorities have a budget for the construction of the building. The do *not* want to *increase the building costs*. They are taking care about the design solutions and check if these could *satisfy the future users*.

The building authorities' architects often emphasize the *quality* of artefacts over their function, purpose, and the processes of making them. Engineers tend to emphasize the *function* or *purpose* of the artefact, placing less emphasis on the process of making, and still less on its formal qualities. Construction managers are interested mostly in the process of *making*, whereas facilities managers are interested in the process of *maintaining*.

Hence, to collaborate we need to develop a shared understanding of the qualities of the product and the goals it strives to achieve. The professional impediment depends on the further education and standards used.

4 Virtual environment for collaborative learning for civil engineers

The CAD systems used within the design process, support drafting and modelling rather than special design attributes and analytical capabilities. CAD systems allow architects and designers to produce a huge amount of drawings and realistic representations of design solution. Other computer programmes offer better support, like *SketchUp*. The virtual reality offers way to innovate form generation. Other IT systems propose a design agent, an intelligent agent. The network technology allows easy and fast access to information. It contributes more to accelerate the design process than the CAD tools. The problem remains still the effect of information overload (Davenport & Beck2002).

Traditional models of the conception and construction use a single knowledge base or data base. It is precisely the uniqueness, the pre-established cataloguing of the building organism, its components and the process that reveals that these models are visibly unsuitable for urban, architectural and building design. It is actually characterized by a localized multidisciplinary process. The gaps in the software system supporting building design reside in the rigidity of the data bases, which do not allow inconsistency, in the difficult of having incoherent knowledge bases of the various operators, in the incongruity of multi-semantic objects, in the synchronicity of the process itself in which the IT objects referring to a process of urban, architectural and building design are simultaneously modified by several operators. We define the workplace as follow. The workplace means the place in which actors work in their conventional design process.

The distribution and centralisation of knowledge is similar to the design workspace in which they are called upon to work. Each team has its private workplace with its specific information (e.g. architectural team, economical and financial, electrical engineering, etc.). The work space is divided into a number of private design workspace. The design workspace represents a distributed structure of private design workspaces. Each one referring to one of the numerous participants involved in the design process for the implementation of expert solutions.

This structure is linked to an overall design workplace, shared by all the participants. They can visualize the merging of all the partial solutions. Then they are able to see which one should be verify. During the process each participant can create or modify his own personal design instance and his own personal workplace with the help of his expert knowledge and his own personal tools.

This is part of the overall design instance constituted by the merging of all the partial expert instances in the overall workspace. To merge them is still an open issue, unless we maintain multiple versions, each labelled with the author's name. Then someone has to merge the individual contributions into one composite.

Another relevant factor within ICT is interoperability, like the standard "Industry Foundation Classes' (IFC) (Ekholm, 2003, Kiviniemi, 2004, Tarandi, 2003). It allows the development of the 3D product model or building information modelling (BIM). Such models are based on the definition of objects (products) containing so-called intelligent information (Ekholm, 2003, Tarandi, 2003).

This approach is inadequate in the fields of urban, architecture and construction, because the same data can be interpreted differently by the participants, based on their own roles, knowledge, and cultural understandings. As a matter of fact current interoperability design problems related to commercial application programs are solved within the domain they have been built for as they all have very often a similar, but specific, point of view.

In conclusion, the model wills underly the application programs themselves, as these concepts are implicit and tacit between the actors of that domain.

Such a problem is not a big deal between actors of the same discipline-specific domain, but it is crucial to be solved in cross-disciplinary design in order to allow and improve collaboration. Its solution is not concerned with mere interoperability formats. The question remains: How can we make concepts related to products explicit and understood by all actors? How can we overcome the symmetry of ignorance?

Currently, an export of application programs to/from low ontology level (IFC) for machine interoperability purposes is available - to the condition that software companies support new IFC specifications.

The dominant way of using IFC specification (low-ontology) today is still a one-direction batch translation of large data sets from an application into the common language and vice –versa. Collaboration using IFC specification exists in the industrial practice, but is based on « ad-hoc » agreed procedures between single specialisation for a single project.

Each entity can have a set of properties (geometric, physical, values) and attributes (function, methods or computing programs), a set of belonging relationships with other entities (part-of / whole-of), a set of inheritance relationships (class-of / is-a), a context (the condition) dependent set of rules of compatibility with other entities (check-list, adjacency-list, etc.), inference engines to activate and manage constraints. The whole is formalized into a syntactically coherent IT structure.

Ontology provides a valuable support for representing and sharing terminology, concepts and relationships within a given domain. A large number of expert's community can develop ontologies as an underlying base for their work, including collaboration in design.

Our approach will focus on sharing meaning, not only data. It is based on the hypothesis that meaning is produced by placing the data within the appropriate cultural and professional frame of reference. Since the professionals who participate in the design of a building do not share the same educational, professional and cultural backgrounds, the frames of reference they use to construct meaning are different, resulting in different outcomes, which often lead to misunderstandings, conflicts, and ultimately construction delays and cost over runs.

Our approach overcomes this problem by introducing the notion of discipline- and culture-specific “filters,” which will help the actors re-construct the original meaning of the other participants in the collaborative effort, thereby fostering a closer alignment of intents and results. There are 2 filters. The first one interfaces common knowledge with the expert knowledge. The filter mechanism is the interface between the shared information and the private information. There is some project-dependent and some project-independent information in each part. The knowledge filter works at the level of concepts (ontologies, properties, relations, values). The second filter (instance data filter) works at the level of the individual data. It connects each individual data structure representing a personal instance to the data structure representing the overall instance. It is triggered by the first filter.

The role of the filters is to connect the shared data with the actor’s own disciplinary- and culturally-specific frame of reference, thereby helping the actors construct disciplinary- and culturally appropriate meaning from the shared data.

The filters are envisioned as customizable computational tools that ‘expand’ the shared data by adding to it discipline- and culture-specific information, derived from specific knowledge bases. They work bi-directionally : extracting specific meaning from the shared data, and re-formulating disciplinary- and culturally specific information into shareable information which other filters can interpret according to their own disciplinary and cultural knowledge bases.
This will likely involve dictionaries of meaning—translators of common concepts between different frames of reference. The common data will use XML tags, so the filters can identify and connect the appropriate objects to the disciplinary-specific knowledge bases. We explore the feasibility of the hypothesis.

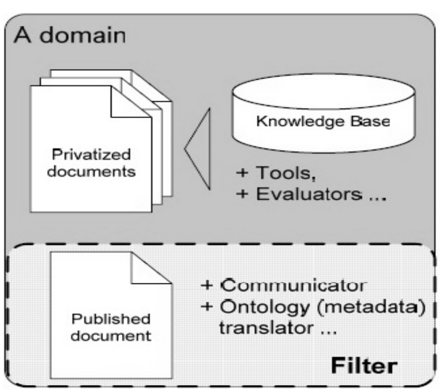

Figure 1: Overview of the filter

We employed case studies drawn from architectural and urban design and from the construction field, which will elucidate both the process of collaboration and the disciplinary frames of reference used by the participants. We will then construct a mock-up, in the form of a game, a simplified, role-playing collaboration simulation ‘game,’ which will emulate the typical interactions between the different participants in the building industry. It will use agent-based computational tools to simulate some of the key principles derived from the case studies and the proposed methodology.

The use of game-like simulations to understand complex phenomena is a well-known strategy in fields where knowledge is acquired through experimentation, and strategy is developed through experience. In addition to simplifying complex phenomena and putting the players in an un-encumbered learning mood, games also provide a universal means of communication, transcending cultural, social, and gender difference. By using abstractions and well-defined rules, the game will focus on the core issues of the simulated phenomena of design collaboration. To test the simulation game, and by extension the methodology, it has been 'played' by architecture and engineering students in the U.S.A., Italy, Algeria and France.

The student in civil engineering make decisions and negotiate with each other, they use their own representations and knowledge. Based on their methods and resources, they must satisfy two sets of goals: shared (or common) project goals, and the experts' individual goals, which derive from their role, personality, culture, education, interests, etc. One participant's primary source of contemplation should be others' most recent works. In this vein, we assume that there are two conceptual workspaces, public and private.

The shared representation is not a pile of data but a set of metadata to define domain vocabularies. Each domain has its own encoding/decoding way following the rule of vocabularies. In the public space, only the latest version of the participants' works should be placed while they can make as many revisions as possible in their own private space. An explicit way to make their works is "publish."

5 Scenario

The goal is to build an ecological building. Each actor has his own knowledge and point of view on the project. Each filters the information of the other, interprets it and proposes it in the form conformed to the point of view of the actor. The filtering allows representing one object by combining the domains of each actor.

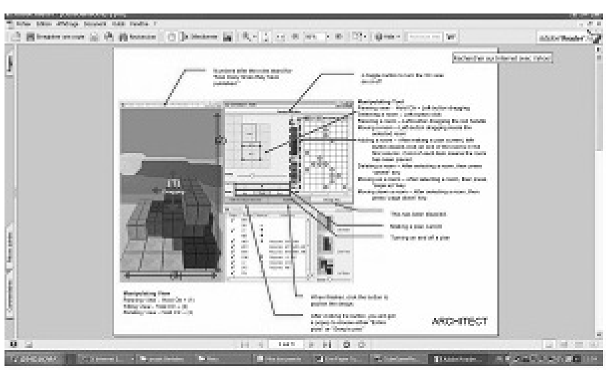

Figure 2: Interface as seen by the architect

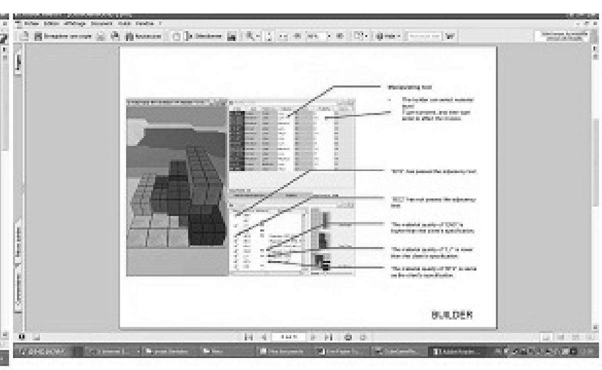

Figure 3: Figure as seen by the civil engineer

The client (local authorities, project builder) asks to build an ecological building with a certain budget and a number of floors, flats, and rooms per flat, conform to the environmental laws, and the request from the future users. The architect plans the house with the application "App-Arch" (e.g. AutoCAD). He designs the building with geometrical data. During the design process, he uses his ontology like ("wall", "windows", "roof", 'floor", etc.) and assigns them to its conception. The filter of the architect sends the first version of the conception. The published data contain geometrical aspects and XML tags bound to these data.

After a couple of tries with "App_STR" in his workspace, he decides to put two steel pillars and call them "steelcol". The construction engineer controls the feasibility from his point of view. First, the filter of the engineer takes the last version of the document written by the architect.

It put a link between the representations of the wall represented by the architect with its properties that it possesses about the load bearing. These properties are given to the wall of the architect. Then the filter put the drawing of the (plafond) in its representation. The roof can be modelisemodelled as a structure composed by girders and pillars made of steel.

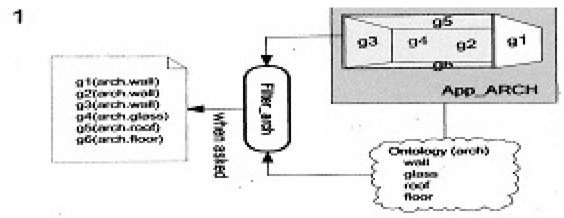

Figure 4: Filter of the architect

The civil engineer attributes the property of load-bearing to the wall « gl » and « g3 », in order that the wall can carry the roof (g5). The filter of the engineer edits the geometrical data and stores the semantic information that the civil engineer has added (see fig. 5 below).

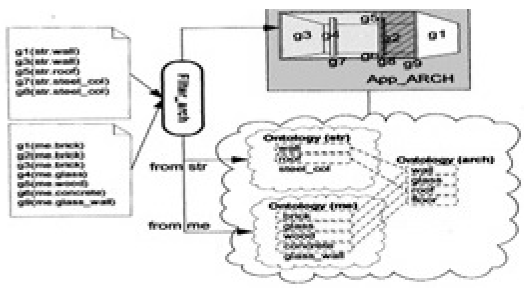

Figure 5: Architect looks for changes made by the engineers

The mechanical engineer analyses the design with the help of "App_ME". He sees that the energy level is too low for the big glass façade. He thinks that it is better t have only 1/3 of the façade made of glass and should be "wall of glass", object (g9). This object has its own ontology. He writes a text concerning the changes that should be made. Then the filter of the architect looks for the data that have been published by the civil engineer and the mechanical engineer.

The architect is able to see the changes and also to read interpret them. He knows how asked for a change and sees the point of view of both engineers. He accepts the two steel pillars, but he does not want to renounce to his glass window. He puts 3 small walls between the glass window 'g9, g10,g 11). Since the architect knows about the ontologies of the both engineers, he can communicate with them by using their terminology.

Every time the project can be visualised in its globality (see fig. 6 below) :

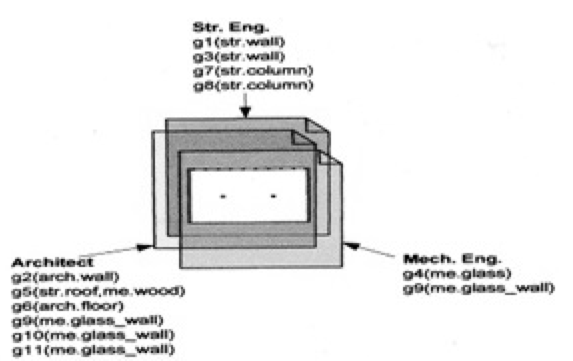

Figure 6: Global view of the project with filters

The virtual picture allows representing the imaginary. It is easy to update and it reduces the distance between the actors. We are also working on the ambiance: How to represent the imaginary? How to represent the unknown? How to qualify the imprecision of a design picture in order the project elaboration become a debate, a seduction, a negotiation, before being a description of the product to be realized.

5 Lessons learned

One of the major finding was the importance of building trust within the creative team, among the students themselves, and between the students and the teachers. It is a gradual process. Students have to recognize the strengths and shortcoming as individuals first, and then to accept it.

Some students in civil engineering were better at the conception and construction, other have better skills in mastering the technology. The role of teacher was to help the students to realize that one opinion is not better than another one, and that a multiple points of view co-exist. It allows them to accept each other's ideas, take the better idea to get a better result. We notice that the quality of the result corresponds to the average quality of the group.

The course was evaluated. The students wrote that they learned much more than in "classical courses", how to be critical, how to negotiate a solution with a team, to work with other people, to understand better the point of view of the other actors. Borrowing ideas from others is allowed. They also claimed to learn about intercultural communication principles, to recognize the importance of the terminology for the project management process and for the writing of their documents.

6 Further research and conclusion

Implementation of the methodology in the form of a serious game in the form of an educational simulation game will help to communicate the principles of collaboration to civil engineer students, who will become knowledgeable about the issues, rewards, and difficulties involved.

We will investigate the use of Multitouch Technology for the collaborative learning and immersive environments.

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