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Philosophy and Structure of a CWE-based Model of Building Design

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Abstract: Building industry involves a far greater number of professional profiles than all other industries, and it wastes about half of world energy consumption: these two figures are already indicative of the economical importance of this sector beyond all the technical and environmental implications. Anyhow, while the complexity of the building process and of its products is ever increasing, the quality of the buildings is often inadequate, as not complying with the required performances, budget and timing. These difficulties, generally all the greater the more 'creative' the design, are often aggravated by misunderstandings, lack of data, and the different aims pursued by the various actors, owing to the close links that exist between actors, activities and resources. To overcome these difficulties we propose a CWE-based process/product model (and an underlying formalization of the information exchanged) of an ICT system through which numerous actors exchange knowledge and interact in carrying out consistent solutions of a design project.

1 The Scientific and Professional Context

In developed countries building construction and management involve a greater number of people and professional profiles than all other industries [1]. In Europe the building sector (residential + commercial + business) wastes more than half of the total energy consumption [2, 3].

These two figures are already indicative of the economic importance of this sector above and beyond all technical and environmental implications that make this field so relevant in every social context.

In any case, at least in technologically developed countries, two aspects often emerge that point to the need for thorough-going improvement in the sector: on the one hand the ever-increasing complexity of the building process and its products, which makes it ever more difficult to manage; on the other hand, the inadequate quality of buildings produced through this kind of process, which fail to comply with the required performances and exceeded budget and timing constraints [1].

Complexity in building process management has extensive repercussions in the form of large losses of economic resources and reduced building quality has a very adverse effect on energy consumption and on environmental quality.

Many of these faults are due to inadequate design quality, often the result of inconsistency among parts of the designed objects, of incoherencies among design specifications and of incongruity between standards and design solution performances [4].

Building design consists of a collective process directly made up by numerous professionals as well as, indirectly, non professionals (all called 'actors' herein [5]), which is characterized by the co-presence of numerous disciplines, specialist skills, and processes. It is part of a broader process which leads to the construction, the refurbishing and ultimately the demolition of the building as a product. The actors have to interact in order to reciprocally integrate the parts of the design solution to which they all have contributed, although the cultural backgrounds of the numerous actors and their different scientific and disciplinary training related to the entities (objects, relationships and aspects) involved in the building process implies the so-called ‘symmetry of ignorance’, an often hard to overcome barrier that makes it extremely difficult for the actors to interact with and understand each other.

Moreover, the overall process is fragmented because of the different regulatory, environmental and cultural contexts and phases.

These difficulties, generally all the greater, the more ‘creative’ the design, are often made worse by misunderstandings, lack of data, and the different aims pursued by the various actors.

One of the authors has been working for over 25 years on large building design projects as a professional involved in project top management throughout Europe. On the basis of this experience the authors are able to state that, due to building design process inadequacies, cost overshoots of up to even 100% often occur and it is not unusual, for the length of time required to complete and deliver the work, to exceed initial estimates by as much as 50%. This happens because in the current professional practice the first solution is often given priority, as soon as it can be deemed barely acceptable. Any alternative hypotheses are neglected as they would involve longer times or greater design costs and that there are not specific tools for an integrated design.

Furthermore, an impoverishment is often observed in the final project quality with respect to the initial idea as a result of simplistic solutions adopted to overcome reciprocal misunderstandings concerning technical, constructive and engineering problems and/or opportunities.

All this makes it very difficult to produce a high quality, coherent and efficiently designed synthesis in terms of architectural form, construction technology, structures, technical installations, energy management, costs, sustainable building, etc.

This problem elicits the pursuit of other forms of process and application tools which can enhance design efficiency, save time and help develop creative ideas.

As complexity is an inalienable component of the present building process and its multidisciplinary character, the quest has to be oriented towards forms of design process that can facilitate a fruitful interaction among actors, so as to overcome the previously mentioned limitations.

2 The Aims and Objectives of a New CWE-Based Model

Collaboration is the highest form of interaction in design as it implies that actors can help each other to better understand how their work is going to match that of the others and to better perform their tasks. It requires that the actors involved in any stage of the process exchange information and knowledge, thus activating mutual understanding [6, 7, 8, 9]. Collaboration enables new design solutions to be found through the contribution of any actor suggesting solutions to problems; it helps allow different actors’ solutions to converge into one overall design; it helps reciprocally modify any actor’s solutions to better fit into the overall design; it helps discover reciprocal malfunctions among actors’ solutions; it helps develop creativity through the interaction of different skills.

However collaboration is difficult to apply to complex design works and processes, and difficulties increase over time due to delocalization of actors in time and place, different human languages and, most of all, ‘symmetry of ignorance’ whenever a sufficiently broad common knowledge is lacking.

Collaboration in design has always existed, in different ways and using different methods and techniques depending on time and the cultural environment. In our culture, until a few decades ago and often even now, collaboration has relied on the physical exchange of documents and discussions based on them.

Traditional methodologies and tools, based on meetings and direct interaction among actors, have shown their inefficiency in the present design process due to the previously mentioned factors. This leads to an increase in the number of meetings with a good number of professionals, due to the number of disciplines involved and their interrelationships.

The introduction of computing in building design has modified the way to convey information: drawings and documents are now transformed into digital data structures, implying the use of new tools for producing and exchanging them.

An efficient collaboration among the actors in the course of the design process consists in the capability of any actor to propose potential solutions to other actors, to make others understand them and together to modify solutions according the suggestions received.

In order to do this, some basic features are required:

- a correct, efficient, non ambiguous and secure communication and acquisition of information;
- the presence of as many specialists' knowledge as is required by the complexity of the designed product;
- the presence of a *common knowledge*, that has to be agreed by the interacting actors, so that they can basically and correctly interpret the meaning of the communication and understand it;
- the presence of *shareable knowledge*, i.e. the part of an actor's specialist knowledge that s/he allows the other actors to know;
- a semantically and technically correct connection among the shared knowledge and the *specialist knowledge* owned by the actors.

All this shows that the *fundamental bases of collaboration rely on knowledge* and *on the way it is communicated among the actors*, independently of the means and tools adopted in the design process.

3 ICT, New Media and Current Research Project Limitations

To overcome the limitations of methods and tools traditionally used for building design, information and communication technologies and new media have been applied, transferring them from other fields where they first were developed.

At present, several software devices are available on the market, conceived in order to enhance domain-specific design capabilities and to resolve even very complex tasks within well defined disciplinary boundaries (such as in structural, energy, lighting, acoustics, HVAC design modelling and simulation etc., as well as in even highly sophisticated architectural representations). Although they can well work within the domain they have been built for, they actually do not help design to be collaborative, even make it more difficult as they increase the communication and understanding gap among the different specialist actors even when applied to the same objects the latter are working on.

The lack of mutual understanding is mainly due to the actors' use of a low level of semantics of ICT tools that forces them to use synchronous methods to exchange information at a high level.

It is thus an exclusive task of actors to 'translate' meanings, perceive differences among different versions, carry out comparisons among different solutions, and point out conflicts and contradictions. All this hinders an easy and efficient collaboration among them.

So as to manage these problems side by side with conventional commercial CAAD systems [10, 11] such as typical graphics aided ones (AutoCAD, Microstation, etc.) and integrated or parametric ones (Architectural Desktop, Revit, AllPlan, Triforma, Project Bank.), alternative Knowledge Engineering based approaches have been proposed by several researchers [12, 13, 14, 15, 16] .

A few academic studies on the subject have been carried out in recent decades to support collaboration throughout the building design process as limitations of current software and ICT tools were established. Different systems have been proposed for the representation of knowledge and the structure of the designed objects by means of Knowledge Bases, KB, [17, 18, 19, 20, 21, 22].

Although these systems refer to different models of the design process they are all similar in that they make use of a single Data Base or Knowledge Base. On account of the unique, pre-established cataloguing of the building, of its components and of the process, these models are patently unsuitable for architectural and building design, as this is actually characterized by a context-situated, multidisciplinary and not fully coherent process. These critical aspects of the design process are not accidental, sporadic or occasional but part and parcel of architectural design itself. So far, the complexity of the design project has not yet been simulated correctly as it has been reduced to a single actor or single KB (exhaustively defined in [13, 23, 24, 25]), while the aspects regarding procedures, timing, decision-making hierarchies, intellectual property, incoherence, etc. have not yet been taken into sufficient consideration.

A few research teams at the international level are attempting to bypass these limitations, albeit with different objectives and following different methods. Unlike the usual paradigm of ‘semantic impoverishment’, they rely on the paradigm of the ‘semantic richness’ of the information exchanged by all the actors. This leads to a formalization that, in order to be exhaustive, is so huge as to be practically unmanageable, and that takes into consideration the model of a unique all-comprehensive process/ product, inclusive of all the aspects, characteristics, attributes, and behaviours of all the entities (the ‘semantemes’) it is made of. The criticism made is that the corresponding logical concept is therefore plethoric and at the same time fragile for such a difficult task. However far-sighted and exhaustive one is, gaps emerge during the design work, making it necessary to redefine the initial logical concept, or to conceive logical concepts that need to be enriched with new semantemes during the design work.

4. An Environment to Support Collaboration

Collaborative building design can be defined as a process characterized by a high degree of interdisciplinary, delocalization of activities, subdivision of activities, timely use of information and correct use of advanced methods and technologies [26, 27, 28, 21, 12]**.**

To develop new tools for correctly and efficiently supporting collaboration, it is necessary to rethink what collaboration in building design requires and on how it can be activated in the whole process. This leads to the quest for a model of building design process and product that simulates how actors actually work and how they can efficiently collaborate.

In the following pages the philosophy and structure of *an overall model of building design collaborative process* will be illustrated, which has been drawn from the attentive consideration of the complex, interdisciplinary best design practice of excellent professionals, who not only exchange data and prescriptions but, above all, concepts, intentions and goals. The model considers the actual design process as a (not always) logical iterative standardized sequence in which a number of actors are present and interact on the same project.

Such a model allows a system to be defined, or rather *an environment supporting an interleaved building design,* able to solve the above mentioned problems, namely, to improve actual design in quality and timing.

Design activity can be defined as ‘the skill to choose among hypotheses’. Therefore, to improve it, we need on the one hand to have *new methods and technologies that can help the choice*, i.e. checking, verification and modelling; and on the other hand, *an easy way to share new hypotheses*. In this way, phase by phase, each actor can get to better know his own design aims and may propose new design solutions that the other actors agree with more fully [29, 28]. The actors involved can therefore better understand each other, correctly communicate and exchange information among themselves, detect contradictions in the proposed solutions and validate the result of the process. This *philosophy* helps actors to enhance their own knowledge, leads to a greater awareness of design choices, increases the exploration and control of design solutions in terms of creativity as well as of quality and quantity, improves project and product and reduces time and/or costs, as well as increasing process efficiency, thus setting up a 'virtuous circle' among the various 'actors' in the project.

Such a model:

- takes into consideration all the aspects of the *knowledge common* to the various actors involved in the collaborative design process, as well as all the features of the *specialist knowledge* of any actor;
- allows any actor to develop his *own (partial) design solution* of the design project by means of his specialist knowledge and to translate it into the common knowledge;
- allows any actor to merge his own (partial) design solution with the other actors' ones, in order to generate the *overall design solution*;
- allows any actor *to* (basically) *understand any solution proposed by other actors* as a part of the overall design solution, since it is translated into a common knowledge being, therefore, understandable by all the actors involved in the design phase;
- singles out the *contradictions inside the overall design solution* at any time along the course of its development.

In synthesis, such a model is aimed at improving collaboration among all the actors involved in a design process. It allows them to interact much more effectively than in the usual direct way that may make them not to understand each other. As a matter of fact the model allows the actors to interact through the *overall design solution,* that can be understood by everyone by means of the *common knowledge*. Any actor can be aware of side effects of his/her specialist actions by means of *other actors' considerations* on these effects, since they are translated into the common knowledge (fig. 1).

5. The Structure of the Design Process/Product Model

The basic idea of the pursued research is to combine the collaborative design paradigm with the need of several SpKBs bypassing the limitations defined earlier. So that the above-mentioned model representation is conceptually based on a *highly structured representation of the knowledge* used along the design process and the investigation of the way it is exchanged among the actors.

The building, as a final product, is made up of a set of entities linked by a complex set of relationships. Its representation in the past has been made through analogical data structures, such as drawings and documents, made intelligible to others through technical education and experience. In the present computational environment digital data structures by themselves are neither intelligible nor operable in design and construction.

To make them such (i.e. to build and modify them along the design process and to make use of them in the construction) they must be linked to the knowledge (formalized or not, human or not) used to generate them.

An attentive examination of the actual design process shows that the knowledge for developing the project is owned by the actors; moreover the latter have in common a more restricted domain of their knowledge that they have agreed upon and that allows them to interact and to understand each other.

The first feature of the model is therefore based on the *formal representation of the knowledge used along the whole design process* achieved by means of Knowledge Bases, KBs. This term is used here to indicate, on the one hand, the structure of all the features considered (meanings, geometry, attributes and relationships) and, on the other hand, all the formal (generally mathematical) models that allow their behaviour to be simulated and verified. A KB is thus considered herein in a broader sense than the one generally used in current literature and referred to previously.

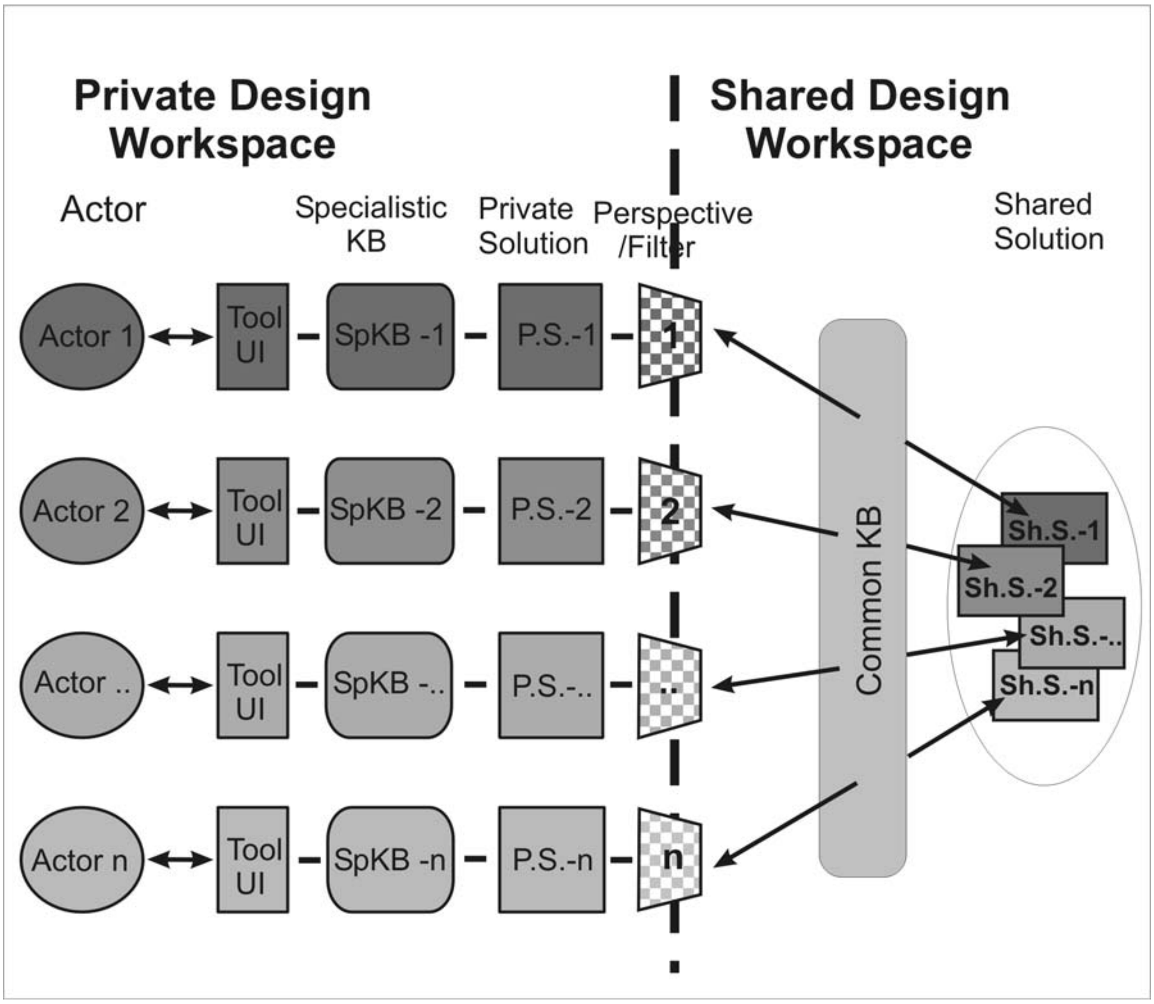

Figure 1. The actor relates his own private design solution with the other actor's ones through the Common Knowledge Base.

The knowledge necessary to carry out a full design project is made up of as many sets of Specialist Knowledge Bases, SpKBs, as there are specialist actors and one Common (and agreed) Knowledge Base, CKB, that allows all the actors to basically understand each other and communicate.

A SpKB is thus a model of the knowledge of an object (in the broad sense) in a specific disciplinary domain, including semantics, properties (attributes) and relationships, plus a specific model of behaviour.

The spread of information and knowledge among the actors by means of several shareable SpKBs allows the actors involved, as in the actual design process, to propose a collection of specific and partial design solutions. The overall solution, the result of the interleaving of the various personal solutions, is made possible by means of the CKB that the solutions have been 'translated' into through a simplification process, and made intelligible to all actors.

This means that any design solution worked out by any actor is made of building entities and relationships that are owned by the same actor who built it; whereas the design solution as a whole, at any time, is defined by the interleaving (which is however not necessarily consistent till the end of the process) of all the design solutions worked out by the different actors and translated by the CKB.

This feature of the model is crucial as far as supporting collaboration is concerned: the CKB, including all and only the knowledge agreed by all the involved actors, actually assumes the role that is generally lacking in the present complexity of the design process, allowing the actors to interact and basically understand each other, directly *on the design solution itself*, which can be viewed and managed in the same way as they customarily do in their usual representation.

To allow this kind of interaction, the model makes the dissemination and centralization of the KBs correspond to a similar articulation of the design work space the actors are accustomed to working in. Therefore *the Design Workspace the solution is developed in, may be subdivided into as many Private Design Workspaces, PDWs as there are specialist actors involved, and a Shared Design Workspace, SDW.*

Any actor can then, in the course of the process, create or modify his own design solution of the project in his own PDW, making use of his specific SpKB, his customary tools and the CKB. His design solution is just a part of the overall design solution, made up of agent instance representations and relationships among them. Along the design process he can then himself verify the internal coherence of his private solution in relation to his SpKB, and, when it is deemed to be the most satisfactory, *translate* it into the CKB. He can thus check the consistency of his own design solution against those of the other actors and, when deemed satisfactory, *publish* it in the SDW in order to make it visible to all actors.

The published design solution is simply one version of the evolving design; therefore it does not need to be totally coherent. The model thus allows a design solution to be incoherent at any stage, but at the very end of the process when the final solution is considered as accepted by all the actors. The design solutions displayed in the SDW can therefore be inconsistent both internally and among themselves.

The fundamental problems underlying the model involve:

- the *representation* of the building entities and relationships, the validity of which must be guaranteed in the SDW as well as in any actor's PDW;
- the need of simple *agents* (both logical and ICT) for easy management, but at the same time possibly enhanced with new characteristics at will, inside the SpKBs of the specialists;
- the *translatability* and *interpretability* of the agents in the actors' various semantic universes;
- the *modification* and *integration* of the agents according to the choices made by any actor for his own representation;
- the *verification* of local and overall performances;
- the *identification* of conflicts and their resolution.

In any design solution some of the objects should have the possibility of being managed by more than one actor and related to each other by different kinds of relationships owned by different actors, any of whom can hierarchically add/modify attributes, values or relationships. In this case the same agent instance should have more than one instance and any instance should be owned by one actor. The agent instance thus defined is called '*valency*'. This term is borrowed from chemistry and physics to indicate a different electromagnetic state of the same atom in a different context; in this case it is used to indicate a different 'situation' of the same agent when considered by another actor.

To avoid contradictions, in the SDW all the valencies of the same object-instance are related to each other and their inconsistencies are automatically pointed out, until the actors accept to converge on a single, more consistent design solution; a design solution thus generally includes agent instances whose valencies are included in other views. As any valency is owned by a different actor, they can modify agent prototypes by adding new ones, changing attributes or relationships to better converge.

At any time the design solution as a whole is made up of the interleaving, in the SDW of all the partial design solutions made by any actor and published in the SDW.

The relationships among the different design solutions are established by means of those among the corresponding valencies. In order to maintain the computational structure, any modifications of agent prototypes and agent instances and their relationships, according the actor's SpKB, must be done in his own PDW, in order to be 'viewed' first by himself, then, if satisfactory, the resulting view has to be shown (published) within the SDW, in order to be 'viewed' by all the other actors.

6. The Structure of the New CWE-Based – Methodology

According to the model, Collaborative Design may thus be considered as the process of modifying the design solutions and goals of any actors, pursuing their harmonization until a more satisfactory and consistent shared interleaving one has been reached.

The model allows a dual articulation of the 'views' of any object:

- a first one, within any PDW, which makes it possible for any actor to see his own design solution, conceived and represented as a specialist solution of his own SpKB;
- a second one, that allows any actor to see his own solution within the SDW of the whole design solution interleaved by means of a (syntactic & semantic) translation of CKB.

As previously shown, a crucial role is played in the model by the *Knowledge Bases*. Indeed, if there were no Knowledge Bases or other semantically significant instruments, we would have to cope with comparatively difficult exchanges of data, with problems of communications protocols, with comparatively anguished attempts at highlighting the difference among the projects carried on by the various actors. In this case little ICT assistance would be available and each actor would have to directly cope with the different design situations in order to detect any differences and/or design contradictions. In order to bring about a decisive improvement in the design process, the model must evidently have several Intelligent Assistants, IAs, (with relative Knowledge Base, Inference Engine, User Interface, etc.).

The communication among the different SpKB occurs through the central CKB by means of the 'translation' into a simplified, shared form of representation. A second crucial role is thus played by the '*filters*', through which any solution developed by any specialist actor by means of a SpKB in the corresponding PDW is 'translated' into the SDW where the CKB elaborates the shared model of the overall design solution (fig. 1).

One basic property of the model is that each actor can work with his customary methods, algorithms, programs, tools. Moreover, he has his own specific means for representing the complexity of his solution of the design problem and for resolving possible design contradictions in his own PDW, the merits of which others cannot go into.

In this way, the model makes available the strictly necessary information and knowledge among the actors, the other specialists' knowledge, which is not strictly necessary for the other actors, remaining confidential. Moreover, as well as avoiding the ineffective simulation of the centralized building model, it also makes it possible to safeguard non-secondary design aspects such as privacy, intellectual property, the history of project versions, ease of using one's own customary tools.

The model does not obstruct his way of constructing his 'private' solutions: it is intended furthermore to offer the possibility of real time verification of any contradictions to which his design solution would lead vis-à-vis the constraints/opportunities defined by the other actors.

The model develops a two-fold field: on the one hand, the integration, dissemination and coordination of the knowledge into the design process; on the other hand, the representation and subsequent formalization of the knowledge of building features and technologies.

The former can accommodate the knowledge stemming from other scientific disciplines involved; the latter is aimed at defining a software system capable of managing it in a collaborative way.

The model is structured so as to integrate the design process and high-technological industrial construction methods in an ICT-Collaborative system.

Its implementation in a software system is being developed along the following paths:

- representing the information of the *Semantic Layers* implicit in the various documents, drawings, blueprints etc. produced during the design process. The semantic layers can be defined along a three-tier schema: logical agents (concepts), ICT agents (codes) and physical agents (infrastructure);
- framing *logical objects* into: *building entities* (e.g., components, with their geometry, dimension, hierarchy, etc.) that are product-oriented ones; *actors* (e.g. subjects and the paths of their invention) that are performance-oriented ones; and the *context* (locality, culture, regulations, etc.) that is process-oriented one;
- defining an *XML-based protocol*, integrated with *ontologies and IFC*, to implement the Semantic Layers: the protocol is the communication layer of the IAs, supporting individual actors' knowledge communication, translation and sharing;
- defining a "*game*" to study in a more restricted, although meaningful, field the problems explained beforehand. A simplified system of design process in an architectural design course will be a powerful e-learning tool.

The game is conceived of as an e-learning tool that can assist university students; it will act as an assistant in order to explore design solutions, acquire knowledge and become aware of design constraints.

7. Some Implementing Aspects

CollKAAD (Collaborative Knowledge-base Assistant for Architectural Design) is a prototypical implementation of a CWE for architectural engineering.

CollKAAD has been conceived with the following basic features:

- support of the online and the offline collaboration among various actors, each using an installation of CollKAAD working jointly with software tools s/he is familiar with;
- symmetrical (P2P) structure with logical client-server configuration (possibly negotiated at the beginning of each online working session, or statically defined);
- service oriented design, based on local services (replicated on any participating installation) and global services (carried out by the installation acting as a server during the session at hand).

The prototype is devised to be widely open to further expansions and interfaces: we have developed a set of basic services, together with a set of drivers with the aim of current software to be used.

CollKAAD supports activities located on the client and explicitly invoked by each user during design session. These features that run in the *foreground* by an interface, are partially implemented and include:

- management and set-up services, such as: session control, project selection, role definition and selection, definition and editing of constraints and filters, (un)mounting SpKB and CKB;
- communication among actors (voice, text, hand drawing, file exchange): these activities are made available by wrapping existing communication tools;
- shared graphical editing: the prototype currently includes a driver for Autodesk Architectural Desktop 2007, interfaced by a component which intercepts editing events

on the represented objects and provides handling for a series of services, starting from the replica to other concurrent users

Several services are run in the *background* and support collaborative work, including:

- recording: this is a base for further services, such as versioning and synchronization of offline sessions;
- filtering and transcoding: these are basis for mapping between models of different users the tentative replica of each actor's editing operation;
- managing Private Design Workspace (on each client) and Shared Design Workspace (on the current server);
- constraint checking and reaction.

The implemented CollKAAD is aimed at achieving a high degree of flexibility and control of the design process. Each registered project in CollKAAD has a defined life path based on stages: the life path is a state diagram which depicts the design process for this specific project; each stage has a set of specific roles (each assigned to some of the actors) with given rights, and a set of rules which control/determine a transition to another stage. These features provide the possibility to model, and enforce, radically different design processes and evolution rules.

8. Business Benefits an Expected Fallout

The expected fallouts of the proposed Model are of three different kinds.

First, specific to the building product/ process design, has the following outcomes:

- a more detailed investigation of the process logic, a comparison between the latter and the pathway envisaged by current legislation and regulations, an identification of critical aspects of the process in order to improve it;
- a better control and management of the design activity and the project's evolution to improve their quality/cost ratio, as far as the various phases (early conception, preliminary, detailed, constructive);
- a more competitive advantage of European construction industry improving the efficacy and efficiency of the product-chain by means of an asynchronous communication and knowledge sharing and expertise;
- a more efficacious representations (and formalizations) of all the agent-prototypes and agent-instances that can have a positive side-effect in services' providers and Telcos.

A second, general fallout could have strong long-term impact, with these outcomes:

- a design activity at a high level of abstraction of the design logic: underlying reasons, intrinsic coherence, relations with the context, iteration between actors and agent, aware criteria of choice, metarules;
- an emerging of new, more sensitive applications tools that, when envisaged and developed, would lead to a drastic reduction in project management time;
- a deeper exploration of the nature of collaborative design processes as a horizontal collaborative process, from early conception, through manufacturing, to construction and maintenance;
- a competitive advantage to the production process, as an effective CWE increases creativity, that plays a key role in market success.

The third impact will have social and educational outcomes:

- an e-learning tool, a 'game', that can assist university students; it can act as an assistant to explore design solution, acquire knowledge, be aware of design constraints in a complex field as it is architectural and building design process. The 'game' has such a characteristic: it can be easily applied to other educational field;
- a general promotion of knowledge among professionals and workers, by the spreading of e-learning tools in industry, school, services' society.

To attain these goals we need, and are looking for, a strong and ‘collaborative’ partnership with European ICT industries, software houses, design firms, engineering firms and construction industries, along with universities and professional training.

9. Conclusions

For many years the authors have studied design paradigms in the field of architecture. They are mainly interested in the early phases of the project when, within a short space of time, actors have to choose among different options that will have a very great impact on the outcome. Indeed, although the largest part of the overall building cost is situated in the construction phase, its definition is practically made in the very beginning of the process, along the with preliminary design choices.

The authors have observed that many of the faults found in building production (cost and time overshoots, performance inconsistencies and so forth) are due to design insufficiencies, often related to building process complexity and to its fragmentariness. Excessive specialization of the actors involved in the design process makes them often unable to productively interact so as to converge on a satisfactory solution.

The authors believe that continuous close collaboration among the actors throughout all the design process is a solution to this problem. In such a collaborative process actors have tasks that overlap each other (and for which they are often jointly responsible), so that they have a mutual interest in a successful outcome of their work. Collaboration is therefore an environment in which actors are aware of and share others’ problems, check if them are already present in their domain, work at their best, while being helped to avoid mistakes; it can also help spread creativity in the process and generate innovations.

The currently available ICT tools and new media do not provide adequate support for collaboration, and often just create new gaps in actors’ interaction.

To overcome technical and conceptual difficulties inherent in collaboration, the authors have set up a general building process/product model as a basis for developing an environment for supporting collaboration in architectural and building design.

The model, based on formalized knowledge, mimics what happens in the best design firms, implements IA agents, boosts the exchange of ideas, allows formal and non-formal representations, shows up conflicts, manages incoherence problems, integrates the whole process by means of ICT instruments.

It is applicable to the full design/product process for producing new ‘smart items’, from a spoon to a skyscraper. This new environment is intended to allow a ‘quality-based work world’, on the one hand, avoiding common mistakes, checking consistency, coherence and requirement fulfilling and managing the complexity of the process, and on the other hand, improving process/product quality, spreading innovations and enhancing creativity.

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References

[1] CNR (Italian National Research Council), PFEdilizia – Rapporto finale 1997 (Final Report of Building Sector Researches), Franco Angeli Ed.

[2] Behling S and Behling S: 1996, Sol Power- The Evolution of Solar Architecture, Publication of READ (Renowable Energies in Architecture and Design) Group, Prestel, Munich.

[3] ENEA, (public Italian National Body for Alternative Energy), Energia e Ambiente 2006 (Environment and Energy 2006 – annual report), ENEA, Rome.

[4] Carrara G.: 2002, Il processo edilizio e il processo di progettazione (Lecture notes on Architectural Engineering course), Dept. Architettura e Urbanistica per l'Ingegneria, Sapienza - University of Rome, Rome.
[5] Wix, J. (1997). ISO 10303 Part 106, BCCM (Building Construction Core Model) /T200 draft.
[6] Gross, M.D., Yi-Luen Do, E., McCall, R., Citrin, W.V., Hamill, P., Warmack, A., Kuczun, K.S.:1998, Collaboration and coordination in architectural design: approaches to computer mediated team work, Automation in Construction, **7**(6), 465-473.
[7] Kvan T.: 2000, Collaborative design: what is it?, Martens, B. (guest ed.), Special Issue eCAADe '97, Automation in Construction, **9**(4), 409-415.
[8] Jeng, T.-S., Eastman, C.M.: 1998, A database architecture for design collaboration, Automation in Construction, **7**(6), 475-483.
[9] Kolarevic, B., Schmitt, G., Hirschberg, U., Kurmann, D., Johnson, B.: 2000, An experiment in design collaboration, Automation in Construction, **9**(1), 73-81.
[10] Laiserin, J.: 2001, AEC Collaboration, CADence, **16**(6), 10-17.
[11] Laiserin, J.: 2000, Collaborative AEC Design, CADence, **15**(11), 10-17.
[12] Carrara, G, and Kalay, Y.E.; 1994, Past, present, future: process and Knowledge in Architectural Design, in G Carrara and YE Kalay (eds.), Knowledge-Based Computer-Aided Architectural Design, Elsevier Science Publishers B.V., Amsterdam, pp. v-vii, 147-201, and 389-396.
[13] Eastman, C.M.: 1999, BUILDING PRODUCT MODELS: Computer Environments Supporting Design and Construction, CRC Press, Boca Raton, FL.
[14] Eastman C.M., Jeng, T.S., and Chowdbury, R.: 1997, Integration of Design Application with Building Models, in R. Junge (ed.), CAAD Futures 1997, pp. 45-59.
[15] Papamichael K., La Porta, J., Chauvet, H., Collins, D., Trzcinski, T., Thorpe, J. and Selkowitz, S. (1996). The Building Design Advisor, Design Computation: Collaboration, Reasoning, Pedagogy, Proceedings of ACADIA '96 Conference, Tucson, Arizona, pp. 85-97.
[16] Kalay, Y.E.: 2001, Enhancing multi-disciplinary collaboration through semantically rich representation, Porter, W.L. and Goldschmidt, G. (guest eds.), Special Issue: Design Representation, Automation in Construction, **10**(6), 741-755.
[17] Reffat, R. M. and Gero, J. S.: 2000, Computational situated learning in design, in J. S. Gero (ed.), Artificial Intelligence in Design '00, Proceedings of AID'00 Conference, Kluver Academic Publishers, pp. 589-610.
[18] Kavakli, M. 2001, NoDes: kNOwledge-based modeling for detailed DESign process - from analysis to implementation, Automation in Construction, **10**(4), 399-416.
[19] Eastman, C.M., guest editor: 1998, SPECIAL ISSUE: TEAMCAD Workshop, Automation in Construction, **7**(6).
[20] Turner, J.A.: 1997, Some Thoughts on the Existence of a Generic Building Object, in R. Junge (ed.), CAAD Futures 1997, pp. 533-552.
[21] Carrara G. and Fioravanti A.: 2002, 'Private Space' and .Shared Space' Dialectics in Collaborative Architectural Design, Collaborative Decision-Support Systems, Focus Symposium and InterSymp-2002 Conference Proceedings, Baden-Baden, pp. 27-44.
[22] Ren, Z. and Anumba, C.J.: 2004, Multi-agent systems in construction - state of the art and prospects, Automation in Construction, **13**(3), 421-434.
[23] Maher, M.L., Balachandran, B. M., and Zhang Dong, M.: 1995, Case-Based Reasoning in Design, Lawrence Erlbaum Associates Inc., NJ, USA.
[24] Schmidt R.F and M. Schmidt (eds.): (1996, Computer Aided Concurrent Integral Design, Springer-Verlag, Berlin-Heidelberg.
[25] Kim, I., Liebich, T. and Maver, T.: 1997, Managing design data in an integrated CAAD environment: a product model approach, Automation in Construction, **7**(1), 35-53.
[26] Björk, B.C.: 1999, Information Technology in construction: domain definition and research issues, *Computer Integrated Design and Construction*, **1**(1), pp 3-16.
[27] Björk, B.C.: 1992, A unified approach for modelling construction information, Building and Environments, **27**( ), 173-194.
[28] Carrara G., Fioravanti A., Nanni U.: 2004, Knowledge Sharing, not MetaKnowledge. How to join a collaborative design Process and safely share one's knowledge, Intelligent Software System for the New Infostructure, Focus Symposium and InterSymp-2004 Conference Proceedings, Baden-Baden, pp. 105-118.
[29] Rosenman, M A., and Gero, J S.: 1996, Modelling multiple views of design objects in a collaborative CAD environment, Gero, J.S., (guest ed.), Special Issue: Artificial Intelligence in Computer-Aided Design, Computer Aided Design, **28**(3), 193-205.