BUILDING CONSTRUCTION COORDINATION BY AN ADAPTIVE REPRESENTATION OF THE COOPERATION CONTEXT

Sylvain Kubicki[1], Jean-Claude Bignon[2], and Gilles Halin[3]

ABSTRACT

In the AEC field, building construction is a complex activity, involving numerous and heterogeneous actors during relatively short periods. The methods of project management used have to adapted to this particularities of the domain.
Cooperation between actors is an essential factor for project success. More particularly coordination is a key activity. There are different modes of coordination existing and adapted to the characteristics of decentralised decisions, uncertainties of the planning etc.
This work suggests to assist informal and implicit coordination by the design of a dashboard tool. This tool provides the actors with indicators of the activity statement and allows them to navigate through the contextual information about the project. It enables multi-view of the cooperative context.
The development is based on a model of this context focusing on cooperative processes. We describe briefly the model architecture developed. Then we details use scenarios, first step of validation of the proposition.

KEY WORDS

Building Construction, Coordination, Computer-Aided Construction, Process Modelling.

INTRODUCTION

The AEC sector is an industrial field which is distinguished from others by some particularities. Teams' composition is ephemeral and heterogeneous. The building as a product has to face many constraints such as functional, technical, economical, esthetical constraints varying from one project to another. Time development of a project is sequential…

During building construction stage, many goals are achieved, such as controlling delays, controlling costs and ensuring the final quality of built works (e.g. conformity to plans).

This stage of building construction is characterised by relations between actors, and especially between architect, engineer, owner and contractors which become more hierarchical and contract-based.

[1] Architect, PhD Applicant, MAP CRAI Laboratory, Architecture School of Nancy, 2 rue Bastien Lepage, BP 40435, 54001 Nancy Cedex, Phone +33 383308146, FAX +33 383308127, kubicki@crai.archi.fr
[2] Professor, MAP CRAI Laboratory, Architecture School of Nancy, 2 rue Bastien Lepage, BP 40435, 54001 Nancy Cedex, Phone +33 383308134, FAX +33 383308127, bignon@crai.archi.fr
[3] Researcher-teacher, MAP CRAI Laboratory, Architecture School of Nancy, 2 rue Bastien Lepage, BP 40435, 54001 Nancy Cedex, Phone +33 383308133, FAX +33 383308127, halin@crai.archi.fr

Cooperation during this stage consists essentially of the coordination of the independent actors' teams, which don't have a global "vision" of the project context. Their "vision" is very often limited to their contract: tasks and works to build.

Coordination is a major activity during the building construction process. It should take different forms related to the types of actor's organizations. In the first part of this article we will analyse the identified organization forms and coordination mechanisms associated. Then we will describe organizations and coordination in the AEC field and especially during building construction.

Assistance tool design for coordination has to take into account these organizational particularities. Our proposition consists of a building construction dashboard to assist decision-making. It allows each actor to obtain a synthetic and adapted vision of the collective process. This proposition bases in a way of thinking where we consider that decision-making is distributed between actors, related to their responsibilities. We will describe this tool in detail in part 2.

The development of this tool is based on a description of the domain by the way of modelling. We suggest a meta-model describing the cooperative activity. This meta-model is instantiated in AEC-specific models. It allows information sharing and context visualization.

Finally we will present use scenarios of this dashboard tool. These scenarios are the first step of a validation stage of this proposition. It will help us to define precise specifications for the development of a prototype tool which is needed for the relevance enquiry.

CHARACTERISING COORDINATION IN BUILDING CONSTRUCTION

COORDINATION THEORIES

Organization forms

Studies by Henry Mintzberg appear especially interesting when it comes to distinguishing between organization forms (Mintzberg 1979). For him the main characteristics for differentiating these "environmental varieties" are the organization complexity and the change capacity. He identifies four main types of organizations: machine bureaucracy, professional organization, entrepreneurial startup and adhocracy.

We suggest contrasting "traditional" organization (bureaucratic) with new forms of organizations called "adhocratic". *Traditional organization* is based on methods and process standardization. However this model shows its limits when organization becomes more complex and dynamic. The *"adhocracy" concept* introduced by Toffler (Toffler 1970) describes perfectly the contemporary context of change management... This concept also covers a more "democratic" vision of collective work. Thus decisions should be distributed between actors and personal strategies should be preserved.

Coordination modes

The characteristics of coordination are related to these two main forms of organizations. Some theoretical works on coordination can help us:

In its study on "dimensions of coordination", (Andersen, Cartensen et al. 2000) highlight two coordination modes: oral coordination and artefacts-based coordination. *Oral* coordination is based on a knowledge background shared by the actors involved in coordination activity. Then, interaction is based on the "focus" or "object of coordination". This type of coordination is found in relatively "simple" domains… *Artefact-based* coordination appears in more complex cases (numerous actors involved, large dimension of the project, high variability). Its advantage is that it is more simple and comprehensive for the actors through the use of representation specific to their domain of expertise.

This analyses is closer to the one proposed by (Godart, Halin et al. 2001), which distinguishes between two types of coordination: *implicit* (e.g. mutual adjustment) and *explicit* (e.g. application of procedures described in rules and contracts)…

(Schmidt and Simone 1996) suggest the notion of coordination mechanism based on *protocols* and artefacts. In other words, it consists of identifying options for a particular situation and explaining it by artefacts… However, Schmidt specifies that protocols are often "under-defined" and cannot take into account all the circumstances of a coordinative situation. The role of the artefact is to transfer information about these protocols. It has to dynamically represent the execution state and the changes in these protocols.

Hypotheses

Moreover we can make a link between these coordination modes and specific organizations.

In "hierarchical" organizations protocols and artefacts are the main methods and tools used to coordinate the teams of actors. This is due to the finely definition of tasks and process.

In "adhocratic" organizations oral communication is very often used. Heterogeneous actors grouped for the realization of a task or activity use "mutual adjustment" to coordinate. They adapt the process planned to changes happening in the project...

ACTOR COORDINATION DURING BUILDING CONSTRUCTION

The organization in construction projects takes different forms. The "bureaucratic" and hierarchical model is identified in a general way. However in design and construction stages "adhocracy" appears perfectly adapted to the reality of the relationships between actors. In fact implicit grouping of actors for realizing a task or activity is current in this domain.

Coordination modes related to this context

These different organizations identified in the AEC sector engender particular coordinative practices. We distinguish between "multi-actor" and "inter-actor" coordination.

"Multi-actor" coordination aims to organise activity and to inform the entire group of what is happening in the project. It describes the explicit activities. Its objectives are to define the conditions of building construction activities and to allow a "strict" and realistic survey of progress. The tools to carry out these activities are textual documents or planning diagrams.

"Inter-actor" coordination can be defined as peer-to-peer coordination. It consists generally of implicit and informal activities (Kraut, Fish et al. 1990) from an actor to another

one. It allows the actors to work together, adapting their actions to the action of other actors and to the project development. This type of coordination, at the "actor level", can get around problems generated by the complexity and slowness of "multi-actor" coordination.

Our study focuses on the building construction activity. At this stage "multi-actor" coordination is essentially based on artefacts (Schmidt and Simone 1996) i.e. meeting reports, and on planning activities (Bardram 1997). "Inter-actor" coordination consists of informal meetings or discussions between two actors in a situation of "auto-coordination", i.e. mutual adjustment (Mintzberg 1979).

Cooperative context and actor context

In order to coordinate actors have to refer to the context of project development. They are working cooperatively in this context: participating to activities, producing documents, using tools etc. We called this space: "*cooperative context*".

Each actor has his own point of view on the cooperative activity (Hanrot 2003). This "*actor context*" influences their behaviour. The knowledge of this context is acquired through awareness processes. "Awareness is an understanding of the activities of others, which provides a context for your own activity" (Dourish and Bellotti 1992).

INTERESTING RESEARCH FIELDS FOR NEW TOOLS DESIGN

In order to suggest new tools to assist these coordination modes, we have studied areas of interest in other research fields. The relationship between the user of a system and the machine is a key-concept for tool design.

Works on context-aware applications in mobile computing or in artificial intelligence (Brézillon 2002; Dockhorn Costa 2003) show that the user and his context have to be placed at the centre of tool design in order to better answer his needs. For (Dey and Abowd 1999) a context-aware system "uses context to transmit adapted and relevant information to the user". Research in mobile computing in AEC (Löfgren 2005) shows the importance of adapting information representation to the hardware tools used: their capacities and to the situations of usage.

Interface design adapted to the user's needs at a precise time is the second research field that interests us. Works on ecological interface design (Vicente and Rasmussen 1992) suggest guidelines for HCI design related to the type of events the user has to manage. Ecological interfaces are based on SRK taxonomy (Skill, Rules and Knowledge) by J. Rasmussen which models information treatment carried out by humans (Rasmussen 1986). This taxonomy is a guide for displaying information in a way adapted to the cognitive and perceptive faculties of humans.

PROPOSITION OF A MODEL OF THE COOPERATIVE CONTEXT

META MODEL APPROACH AND OBJECTIVES

The definition of a meta-model allows us to highlight essential abstract concepts to describe context of cooperation in different domains. These "meta-concepts" of the meta-model (*M2 level*) will be instantiated in specific cooperation models (*M1 level*): building construction

activity context model, meeting-report model or in other domains as software engineering… The meta-modelling approach (Sprinkle, Ledeczi et al. 1999) is used in the standard MOF (Meta Object Facility) and is proposed by the OMG (Object Management Group).

Our proposition consists of defining a relational cooperation meta-model that takes into account the *existing relations between the elements of a project*. The objective we want to reach with this type of modelling is the description of the meaning of a project and then the proposition of adapted tools and visualization modes included in a cooperation platform: the *Bat'Group* project (Halin, Hanser et al. 2003).

RELATIONAL META-MODEL OF COOPERATION FOR DESIGN AND CONSTRUCTION

To model the activity in a building construction project we suggest an approach from the point of view of cooperative activities between actors. Modelling these concepts of cooperation will allow us to develop domain-specific applications (Kubicki, Bignon et al. 2006) structured on the base of the *cooperation meta-model for design and realisation*. The context of cooperative design and construction activities has to represent relations and interactions between the actors, their activities, the artefacts they produce and the tools they use:

Activity (M2): the activities inside a project have several "scale" levels: project, phase, and task. They should be explicit (building task) or implicit (request between 2 actors).

Actor (M2): in a project, each actor has a limited capacity of action and restricted decision-making autonomy. The actor acts inside the activities that constitute the project, gives an opinion, and keeps up a relationship with the environment while collaborating with other actors and producing documents.

Artefact (M2): The generic concept of artefact describes any piece of information or other "thing" manipulated, used or produced by actors in an activity (Kruchten 1999). It could be a document. A document is an aggregation of files manipulated through an operating system. It could be also a "model" of the object to design.

Tool (M2): Tools are a kind of resource needed to run a process. Their availability for a user could be defined in his operational role in an activity. Tools use one or several visualization modes.

Relationship (M2): a relationship identifies a type of link existing between two elements (or concepts described above):

The relationships between actors depends on the social organization of the group (hierarchical or adhocratic relationships),

The relationships between actors and artifacts are close to those used in the edition of documents: Supervise, Produce, Comment…

The relationships between artefacts (documents or models) are those used in the configuration management: new version of, refers to, is the synthesis of,

In a general way the relationships between tools and other entities of the model describe what information they should visualize and manage… The relationships between tools and actors allow defining which tool should be use by an actor (related to his role, his skill…). The relationships between tools and activities describe how tools should be associated to specific activities, which they may completely or partly automate, and so on…

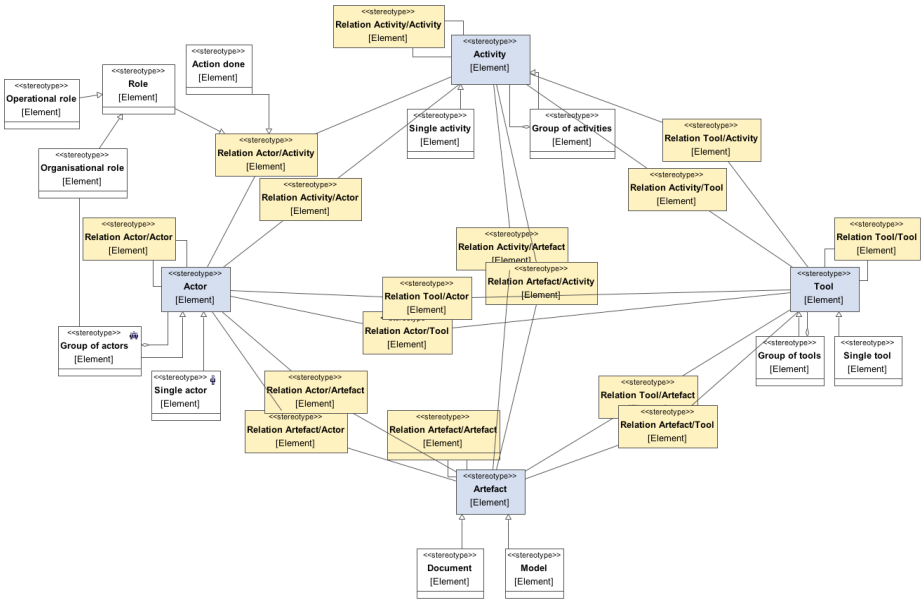

Figure 1: Meta model of the cooperative context

This meta-model describing cooperative context is generic. We will use it to instantiate a specific model dedicated to the AEC domain and especially to the building construction activity. Such a model should structure and define the classes of a database… Moreover we use these key-concepts of cooperation to design domain-adapted interfaces of the tools. The prototype tool "Image.Chantier" (Kubicki, Bignon et al. 2005) has been designed and realized in such a way of thinking.

BUILDING CONSTRUCTION DASHBOARD

WHAT TYPE OF ASSISTANCE TO COORDINATION?

Coordination mechanisms used in multi-actor and inter-actor situations are very different. Methods and tools used by the actors are obviously adapted to these situations.

We have already made a proposition for increasing multi-actor coordination quality: "Image.Chantier" (Kubicki et al. 2005). This tool aims to clarify and better diffuse information by way of new IT tools. It is based on the meeting report document and suggests an adapted diffusion of coordination information to the actors.

Collective activity during the building construction stage is a finely defined process (planning and task progress control). But despite this, there remain a lot of room for adjustment in situation… This is due to the dynamic aspect of architectural specifications and also to the technical, organizational or supplier constraints which are anticipated with difficulty. However we think that a large amount of coordination information is not explicit… So it is not often situated in meeting reports. Moreover inter-actor coordination situations are numerous. Actors involved in such situations need a good knowledge of the project context in which they intervene and have to take decisions…

PROPOSITION OF A BUILDING CONSTRUCTION DASHBOARD

Our proposition consists of providing the actors with indicators of the project statement, and a navigation and comprehension tool to better understand the project context. The "building construction dashboard" is both a dashboard of cooperative process and an awareness tool.

We suggest defining functions for the building construction dashboard based on the 3 levels of awareness identified by Mica Endsley (Endsley 2000):

Context perception: It consists in allowing the user to visualize coordination information using content-adapted visualization windows called *BoardGets*. Information it-self has to be adapted to the user (his role, his needs…). With this focus indicators have to be chosen in order to alert the user of problems happening during process progress,

Situation comprehension: Information it-self is not enough. The user should be able to access to a level of comprehension of information, in order to understand the project's state. Multi-visualization (3 windows) of the context is a way to provide user with different forms of context understanding. Moreover the dashboard should be connected to other tools adapted to the comprehension of problems,

Anticipation: Since the process is finely modeled the dashboard should also monitor its progress and warn semi-automatically the actors of risks.

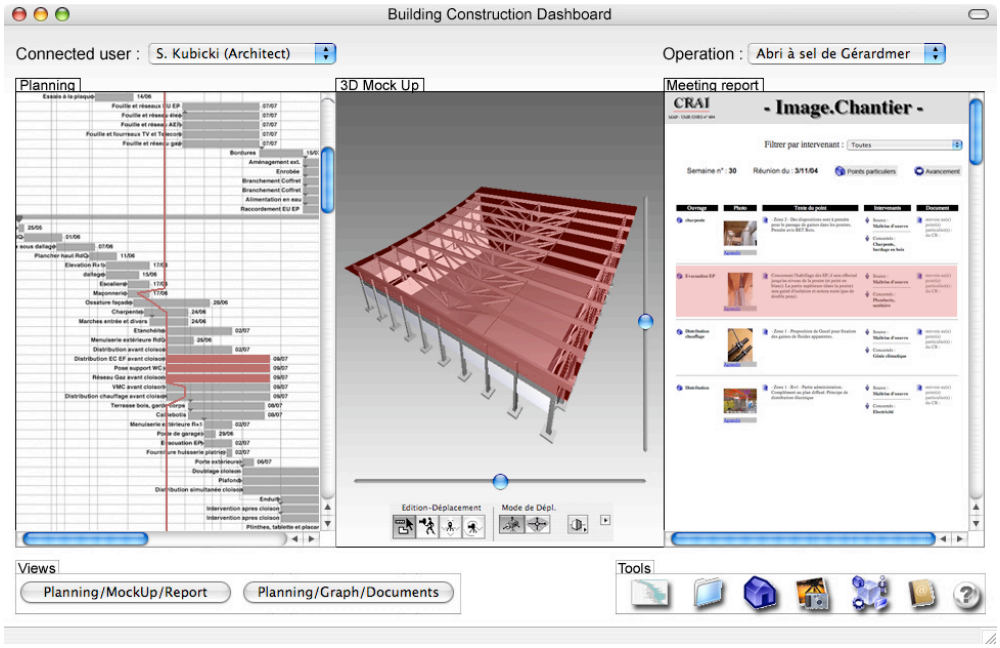

Figure 2: Dashboard interface

Figure 2 shows hypothesis of interface design for the dashboard. At present, we suggest three different visualization modes (*BoardGets*) in the window, used in other tools. These *BoardGets* are arranged on the dashboard specifically to the user context.

The dashboard presented here is dedicated to the architect of the project. The representation focuses on 3D visualization, which is relatively common and comprehensible

for an architect. We can imagine a dashboard view dedicated to the pilot. This actor is more interested by schedule information, and organization information. The multi-view arrangement should take into account information about this user-context and provide a specific arrangement, e.g. planning + activity graph + list of documents available…

A red colour highlights important points of the activity in order to link information concerning a specific coordination point in the different views. Buttons on the bottom allows the user to change *BoardGets*' arrangement: they can switch from an arrangement to another. A toolbar is placed at the bottom of dashboard window. This toolbar will allow the user to switch of tool, i.e. to start a planning tool to have a complete visualization of the planning.

THE PLACE OF SUCH A TOOL: USE SCENARIOS

The research work on this dashboard project is still in progress. We have chosen an approach with scenarios in order to evaluate the relevance of this proposition. Two scenarios are described here, with and without dashboard. We were inspired by a real and relatively simple situation observed in an individual housing operation.

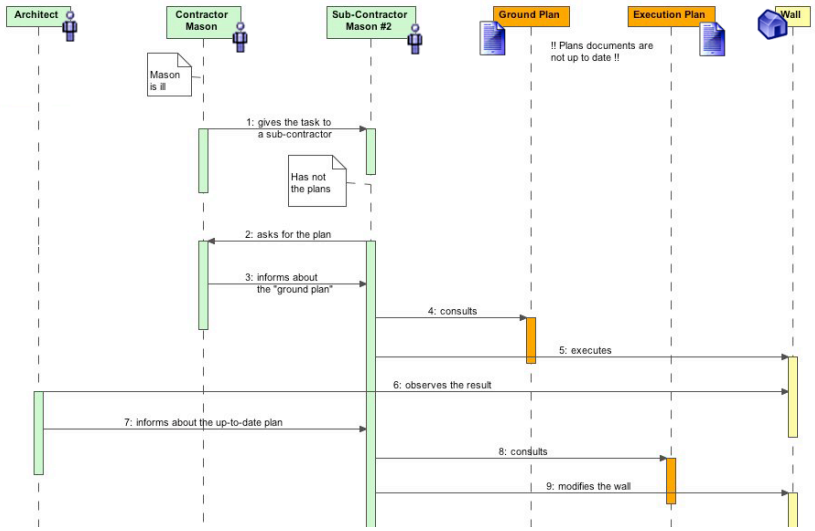

Figure 3: Observed coordination scenario

In this building construction activity (Figure 3) the mason has been ill. To ensure the progress of task realisation, he has taken a sub-contractor in order to build a wall. This other contractor was not in the original project team. He uses an old plan (ground plan) that was erroneous to build the wall. The architect has then asked this contractor to reduce the wall length that did not correspond to the new project.

Consequences of this coordination problem are:

Financial consequence: over budget because of reworking on the wall,

Quality consequence: the wall aspect does not correspond to the architect's expectation.

The next scenario (Figure 4) treats the same situation and integrates the use of a dashboard whose functionalities are described above.

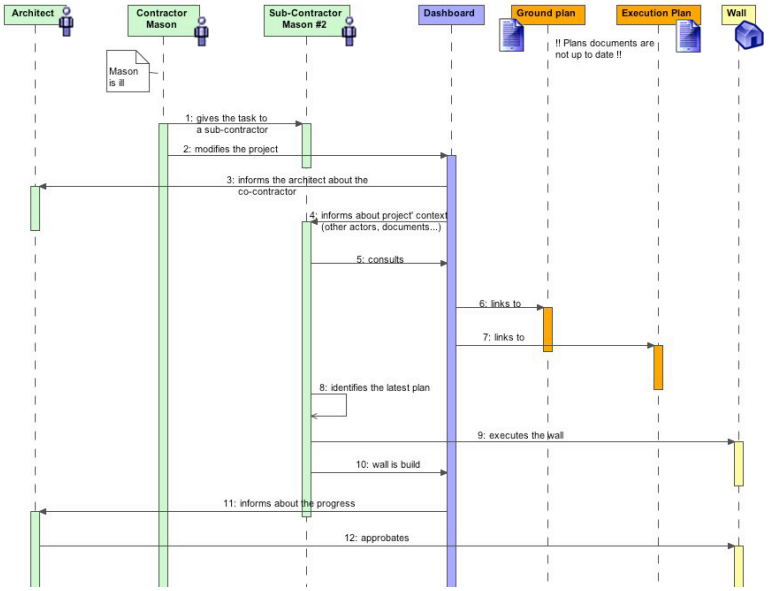

Figure 4: Dashboard hypothesis in the coordination scenario

We underline the advantage of an awareness tool informing the project's actors of changes. The architect is warned about new actor apparition (the sub-contractor). He should verify that he has the latest documents to work on. The new actor is also informed about existing documents necessary for his action and about the tools for using them...

The advantages of the dashboard use should be a gain of time in coordination information transfers, to allow the actors better knowing their cooperative environment and acting in consequence, to reduce risks of errors…

PERSPECTIVES AND CONCLUSION

We are working at present on the modelling of the visualization modes (*BoardGets*) used in the Dashboard. Multi-visualization of the cooperative context will be possible by the correspondence between cooperative context models and *BoardGets* models. To enable this correspondence it is necessary to define models transformations allowing to select context information and to display it in *BoardGets*.

In order to conclude we have presented a study about coordination of actors during the building construction activities. Organization types and coordination modes identified lead us to the original proposition of a dashboard for decision assistance. We focus in this proposition on the importance of inter-actor coordination in the cooperative process. Indeed this form of coordination is essential for process adaptation to the changes and uncertainties of construction projects. Moreover we think that providing the actors with contextual information should allow them to better auto-coordinate by increasing their awareness of the project context.

The development of the software infrastructure (models and transformations) is in progress. In parallel we are developing final specifications for the dashboard prototype. Scenarios and dashboard screenshots will allow us to interview professionals to have a first feedback on the relevance of the proposition and to adapt the final specifications.

REFERENCES

Andersen, P. B., Cartensen, P. H., and Nielsen, M., 2000, "Dimensions of coordination." *LAP 2000. The fifth international workshop on the language-action perspective on communication modelling*, Aachen, Germany.

Bardram, J. E., 1997, "Plans as situated action: An activity theory approach to workflow systems." *ECSCW 97 Conference*, Lancaster, UK.

Brézillon, P., 2002, "Modeling and using context: Past, present and future." *LIP6 2002/010*, LIP 6 Laboratory, Paris.

Dey, A. K., and Abowd, G. D., 1999, "Towards a Better Understanding of Context and Context-Awareness." *1st international symposium on Handheld and Ubiquitous Computing*, Karlsruhe, Germany.

Dockhorn Costa, P., 2003, "*Towards a services platform for context-aware applications*," PhD Thesis, University of Twente, Enschede, The Netherlands.

Dourish, P., and Bellotti, V., 1992, "Awareness and Coordination in Shared Workspaces." *CSCW 92 Conference on Computer Supported Cooperative Work*, Toronto, Canada.

Endsley, M. R., 2000, *Situation Assessment Analysis and Measurement*, Lawrence Erlbaum Associates, Mahwah, NJ.

Godart, C., Halin, G., Bignon, J. C., Bouthier, C., Malcurat, O., and Molli, P., Year, "Implicit or explicit coordination of virtual teams in building design." *CAADRIA 2001*, University of Sydney, Key Centre of Design Computing and Cognition.

Halin, G., Hanser, D., and Bignon, J. C., (2003). "User Adaptative Visualization of Cooperative Architectural Design." *International Journal of Architectural Computing*, 01(02), p. 89-107.

Hanrot, S., 2003, *Enjeux pour l'ingénierie de maîtrise d'oeuvre*, Plan Urbanisme Construction Architecture, Pratiques de projet et ingénieries, Paris.

Kraut, R., Fish, R., Root, R., and Chalfonte, B., 1990, "Informal communication in organizations: Form, function, and technology." *Human Reaction to technology: Claremont symposium on applied social psychology.*, Beverly Hills, CA.

Kruchten, P., 1999, "Unified Process Model (UPM) - A model of the Rational Unified Process." *IPTW'99*, Villard-de-Lans, France.

Kubicki, S., Bignon, J. C., and Halin, G., 2005, "Digital assistant for the cooperative construction process in AEC." *CIB W78 Conference*, Dresden, Germany.

Kubicki, S., Bignon, J. C., and Halin, G., (2006). "Assistance to building construction coordination. Towards a context-aware dashboard view." *ITcon Electronic Journal of Information Technology in Construction*, Special Issue on Process Management. (To appear in April 2006).

Löfgren, A., 2005, "Socio-technical management of collaborative mobile computing in construction." *CIB W78 Conference*, Dresden, Germany.

Mintzberg, H., 1979, *The structuring of organizations: A synthesis of the research*, Prentice-Hall, Englewood Cliffs, NJ.

Rasmussen, J., 1986, *Information processing and Human-machine Interaction: An Approach to Cognitive Engineering*, North Holland, New York.

Schmidt, K., and Simone, C., (1996). "Coordination mechanisms: Towards a conceptual foundation of CSCW systems design." *Computer Supported Cooperative Work: The journal of collaborative computing. Kluwer Academic Publishers.*, 5, p. 155.200.

Sprinkle, J. M., Ledeczi, A., Karsai, G., and Nordstrom, G., Year, "The new metamodeling generation." *IEEE Conference and Workshop on Engineering of Computer-Based Systems*, Nashville, Tennessee.

Toffler, A., 1970, *Future Shock*, Random House, New York.

Vicente, K. J., and Rasmussen, J., 1992, "Ecological interface design : Theoretical foundations." IEEE Transactions on Systems, Man, and Cybernetics.