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# ASSISTANCE TO BUILDING CONSTRUCTION COORDINATION – TOWARDS A MULTI-VIEW COOPERATIVE PLATFORM

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**SUMMARY:** Building construction is a complex activity, involving numerous and heterogeneous actors during relatively short periods. The methods of project management used are specific because of the complexity of the architectural “object” and the prototype character of each operation. Methods usually used in other industrial sectors (such as workflow definition or inverse engineering) are not transposable in the AEC domain. In fact, coordination modes existing in this domain are adapted to its particularities (decentralised decisions, uncertainties on the building construction methods etc.). Our analysis shows that coordination takes two major forms: on the one hand there are explicit and hierarchical methods, and on the other mutual adjustment between actors is necessary and implicit. We suggest to model this particular cooperative activity using model driven engineering based on the MOF architecture. This form of engineering allows us to define entities in relation in the cooperation at a high abstraction level. This abstraction enables us to design tools adapted to the cooperation in the AEC sector by defining an infrastructure based on a cooperation model. We suggest a new assistance tool for coordination (building construction multi-view interface) taking into account the analysis of coordination modes and IT potentialities. The tool provides a vision of the activity from coordination point of view. It adapts information representation to the user context and uses multi-view arrangements to allow the user navigating in project context. It is integrated in a cooperation platform, managing information about the project and redirects the user to other external tools if necessary. Interface views of the tool are suggested in the paper. Its design is still in progress.

**KEYWORDS:** Building construction process, coordination, awareness, model-driven architecture, process modelling, cooperative context multi-vie.

## 1. INTRODUCTION

The AEC sector can be distinguished from other industrial sector by the nature of the product that is designed and realised. Processes set up during design and construction activities are adapted to meet particular requirements.

- The building as a product has to face many constraints such as functional, technical, economical, esthetical constraints varying from one project to another. These constraints are specific to the particular context of each project.
- Numerous actors carry out project development. Some professionals are reproducing standard methods instead of solutions adapted to singular project.

- Design and construction team is ephemeral. During a project, the composition of team is evolving. Actors play at different time, so the production periods are long and irregular.
- Professionals comprising the project team are independent. They don't have strong hierarchical relations. These relations are often contractual, based on negotiation between actors. Decisions are very decentralised and each actor is responsible for his tasks.
- Time development of a project is sequential. Succession of stages is characterised by the made of irreversible decisions and the preservation of uncertainties.
- Interaction rules between actors are often informal and evolve from one project to another.

In this particular context, the mastering of cooperative processes is very important for project success. Our hypothesis is that final product quality (or building quality) depends highly on the quality of cooperation between actors during the project: interactions, exchanges, and communication.

Building lifecycle is characterized by several stages. Cooperation between actors achieves different objectives and takes different forms in each stage. We are interested here in the building construction activity where many goals are achieved:

- controlling construction delays,
- controlling costs,
- 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 than during design stage. 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. A specific role consists in coordinating activities (generally assumed by the "coordinator" or "pilot"). In particular, in this paper we focus on the specifics of the French building construction context. "Loi MOP" is a law defining precisely the different stages in a public construction operation. Missions (and roles) are clearly identified for each stage. In chapter 2 we characterize this cooperative context with three types of coordination which imply different actors.

Our objective is the design of new assistance tools for assisting cooperation. Our approach is inter-disciplinary. We look at this subject from the point of view of the analyses of existent work practices in the construction area. At the same time, we are interested in research domains such as social sciences, human-machine interface, mobile and ubiquitous computing, model driven engineering etc. These fields of research develop interesting methods that we could transpose to our needs in the AEC domain.

We will describe in chapter 3 the model approach on which we base our developments, and especially the meta-model of cooperation developed in the CRAI laboratory through different research works.

In chapter 4, we will present an experiment in assistance to the production and diffusion of the meeting-report. We will demonstrate how the model approach allows us to develop a specification for the information structure of a new coordination tool. Then, we will present the developed prototype, and its experiment on a real building construction site. The assessment on this experiment broadens our approach to coordination, beyond the meeting report document.

In chapter 5 we will come back on this question, in order to show that several tools and documents comprise information necessary to each actor for coordinating. Our proposition consists of allowing each one to have adapted information, corresponding to his needs at a precise time. We then suggest a *building construction multi-view interface*, adapted to the user-context. We will present a first hypothesis for the interface, coordination scenarios describing its role in coordination, and the global infrastructure in which it will be inserted.

## **2. COORDINATION OF THE BUILDING CONSTRUCTION ACTIVITY**

An AEC operation is characterised on the one hand by the particularities of the architectural object (situated object, prototype object) and on the other the specificities of the cooperative practices (variable teams, decentralisation of decision). The building construction stage contrasts the necessary cooperation for progress and success of a project with the internal strategies of numerous actors involved in the operation, and particularly the contractors. In these analyses we focus mainly on the French building construction context.

## 2.1 Cooperative activity vs. internal strategies

We can identify some characteristics of the building construction activity (Kubicki et al. 2005b) which distinguishes it in comparison with design stage:

- New actors are integrated into the project team: security surveyor, pilot, environmental officer, contractors. The relation between actors becomes more hierarchical (i.e. contractors follow the architect's demands). However there is a great place for informal relations between actors. Mutual adjustment is necessary to adapt the activities to the changes in the plans.
- New objects appear resulting from the design stage studies: materials, equipments, tools,
- New documents are produced such as execution plans and building or construction site plans. Architectural and technical design evolves integrating new information relative to the execution tasks. New documents are produced as execution plans, building or construction site plans. The architect has to survey the changes in the project, in relation with these new constraints linked to the building conditions: available materials, contractors' skills and competence...

Coordination activities have to determine elementary construction tasks and their time sequence. Planning has to take into account resources (human and material) and technical constraints. But the distribution of responsibilities between the actors (Brousseau and Rallet 1995), and the uncertainties of the project at the beginning of the construction stage favour informal coordination also called mutual adjustment (Mintzberg 1979). In the AEC sector this type of coordination is necessary to adjust activities to the plans and major phases of the project.

## 2.2 Coordination methods in the AEC sector

We will now try to identify the characteristics of coordination in AEC and especially during construction stage. Certain theoretical works on coordination can help us:

In its study on "dimensions of coordination", (Andersen et al. 2000) highlight two coordination modes: oral coordination and artifacts-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, where actors have a partial or complete knowledge of work of other actors, and where coordination tasks are repetitive and clearly identified (e.g. boat control). Artifact-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 (vocabulary, shared document types). This coordination is also based on the automation of some coordination tasks (those which are explicit) and the proposition of a "fine work division" reducing coordination needs.

This analyses is closer to the one proposed by (Godart 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).

Other research works focus more on cooperative processes existing in coordination activities. (Schmidt and Simone 1996) suggest the notion of coordination mechanism based on protocols and artifacts. The "coordination protocol is a resource for situated action in that it reduces the complexity of articulating cooperative work by providing a precomputation of task interdependencies which actors [...] can rely on to reduce the space of possibilities [...]". In other words, it consists of identifying options for a particular situation. 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 artifact is to transfer information about these protocols. It has to dynamically represent the execution state and the changes in these protocols.

These theoretical analyses enable us to define two hypotheses:

- Artifact-based coordination is used to define major progress lines in complex projects and possible solutions for coordination problem solving. However, anticipation and clarification of all the coordination problems is not possible.
- Oral coordination is an essential form of interaction especially for activity adjustment to the changes in the project. It's characterised by much implicit information, called background (Andersen et al. 2000).

In the AEC domain, which particularly interests us here, we can say that the architectural project, in the early construction stage, is precise concerning the objectives to be met with. Objects to be built are described in artifacts (plans, technical documents etc.). But it's less precise concerning the methods and procedures to be used (i.e. time control or task organisation). Planning activity has to give a temporal space and a logical sequence to "building task" execution. However, this artifact is under-defined. Moreover it hardly takes into account changes happening during the project. Informal relations between actors are the unique solution to adjusting tasks to the major stages planned. In this paper we suggest defining three main coordination modes in the building construction activities: "multi-actor", "inter-actor" and "extra-actor" coordination.

### 2.3 Multi-actor coordination

Multi-actor coordination aims to organise activity and to inform the entire group of what is happening in the project. It is carried out in a hierarchical organization form. 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. Several methods are used to achieve this form of coordination:

- Planning consists of the examination of each intervention in the elementary tasks to determine the sequence of these tasks and the critical path to follow.
- Building team meeting, generally once a week, is the favoured time for highlighting and solving the construction problems. The anticipation of tasks of each actor is an essential activity assumed by the pilot.
- "Building construction meeting report" is produced after the meeting, in order to validate the decisions taken during the meeting and the information distributed. This document comprises most of the coordination information concerning the building construction activity.

The tools to carry out these activities could be textual documents, graphical documents (such as plans or schemes) and planning diagrams.

We can identify some limits to this coordination form:

- Generally, multi-actor coordination is the source of a large quantity of information (i.e. written document, note, sketch, plan). The problem is that the methods used allow neither the creation of relations between information (i.e. points of meeting report) nor the easy tracing of events.
- The information is distributed in its totality and to each actor involved in the project (even if they are not concerned). We can note that all the information is useful to every actor.
- The data formats are a real problem in information exchange: digital document format, media used (fax, email etc.).
- The shared documents have no links between them (i.e. planning and meeting report). The result is that searching for information in the documents is difficult.
- Finally these methods are not easily adaptable to the changes in the project. Refreshing information to represent the building construction progress is difficult (i.e. planning changes). These problems penalise the representation of activity and therefore the adaptation of working teams to the development of the project (implying delays, mistakes, defective works).

### 2.4 Inter-actor coordination

Inter-actor coordination can be defined as peer-to-peer coordination. It consists generally of implicit and informal activities (Kraut 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. Mintzberg calls this coordination type as mutual adjustment often observed in adhocratic organizations (Mintzberg 1979). For example two actors coordinate together to make a decision about a construction detail or to solve a small problem efficiently.

Tools existing to support these exchanges are very well known and much used: GSM phone, meeting, fax or e-mail. This type of coordination ensures the adaptability of the system to the evolving project definition.

There are some limits to these coordination activities:

- Informal exchanges (such as orality), at the basis of these interactions, don't allow the actors to trace the exchanges and to keep trace of the decisions made.
- Decisions could be taken without conferring with the person responsible or the coordinator.
- Finally, we can note too that exchange formats are not really shared (sketches, language used etc.).

## 2.5 Extra-actor coordination

« Extra-actor » coordination relates to coordination activities which does not concern directly the teams of actors involved “regularly” in the activity. For example, the architect should be in relation with independent experts (e.g. to validate constructive choices). Or a contractor should choose a sub-contractor to carry out a task. This external actor (e.g. specialised firm) is not referenced in the project team: supplier, manufacturer etc.

This third coordination mode seems very close to “inter-actor” coordination but it differs in a few points:

- An “internal actor” in relation with an “external actor” has all the necessary information to do a task and he knows the project context better (deadlines, other tasks in interface etc.). So internal actors play a particular role in the coordination (that we can compare to a temporary hierarchy).
- Geographical distance is generally a critical factor in this mode of coordination.
- The action of an “external actor” could be compared to an event in the “life” of building construction. This actor doesn't have a “vision” of the context of cooperation internal to the building construction activity and he doesn't need it to act.

Adapted methods have to be designed in order to allow these distant actors, little involved in the project, to realise their tasks in better conditions, without penalising the global progress of the activity. Quality of information communication is essential to avoid risk of error: an “external” actor should have information necessary to his operation (when?, how?, with whom? etc.).

By identifying coordination methods existing at present we are able to reflect on *how to take them into account in a new tool proposition*.

## 3. TOOLS AND METHODS TO ASSIST COOPERATION

Complexity of AEC projects and associated cooperative practices lead to particular coordination modes. This production system appears today as well balanced. But we have noticed that there are some dysfunctions which reduce global quality of cooperative activities and then of the architectural object itself: information overload, unlinked information, difficulty in tracing events, risk of redundancy and contradiction between documents, lack of coherence or sometimes absence of information.

New methods and new tools have been developed for some years in order to take into account these limits of coordination. They have been developed to assist the design stage, construction stage or both.

### 3.1 Present and emerging practices

“Digital plans servers” are used for important project to facilitate document exchange. “Project management servers” allow the users to organize and manage different activities (Fassin and Pirlot 2005) such as requests between actors, tasks etc. Other collaborative tools try to associate planning and information exchange. The interoperability of tools used by different actors is at the basis of many research works. It becomes a reality in some CAD tools. This is possible by the use of exchange data formats, which are “object” oriented, such as the IFC format which is a data format for construction-oriented «objects» - see <http://www.iai-international.org>.

But these new methods remain quite unusable for everyday work. They come from other activity sectors (Industrial, manufacturing sectors) such as manufacturing industry and are not well-adapted to the AEC context and its particularities: changes in the project, uncertainties, adaptation or informal coordination.

Besides, we have seen too the development of the use of digital photography. This media appears to be interesting for its qualities of context representation and understanding (Dossier 2005).

### 3.2 Research work analyses in Information Technology

Our approach to designing new assistance tools for cooperative engineering is interdisciplinary. Research areas such as social science, artificial intelligence, software engineering (mobile computing, model driven engineering) and information systems (groupware) are sources of theoretical analyses and innovating methods that can be applied, sometimes partly, to cooperative engineering in AEC.

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. The user should be able to intervene in the software he uses, e.g. in bringing his personal expertise to adapt the tool to his application domain – cf. works on application malleability (Koch and Teege 1999, Bourguin and Derycke 2005).

Human-machine interface is a primordial factor for the use and the impact of a new tool. Ecological interfaces described by (Vicente and Rasmussen 1992) give a conceptual framework for interface design. Definition of an abstraction hierarchy allows system designer to describe the domain, and the SRK taxonomy (Skill, Rules and Knowledge) allows us to identify what type of indicator is adapted to the interaction situations.

Our approach to the AEC domain and to cooperation assistance is based on works from model-driven software engineering (Frankel 2003). Firstly the MOF structure (OMG 2000) gives us a conceptual framework to represent collective activity and relations between collaborative entities (cf. chapter 3). Beyond knowledge representation, research in model-driven visualisation (Ian Bull and Favre 2005, Kruchten 1999) allows us to imagine how to link cooperation information on a project with its visualisation in tools (cf. chapter 5).

Thus the context modelling that we will present in the next part should be associated with representation models and visualisation models (OMG 2005).

## 4. MODELING COOPERATIVE ACTIVITIES IN AEC PROJECTS

Representing the complexity and the particularities of the domain is the first step towards propositions for new assistance tools for cooperation. A cooperative project context comprises different elements in relationships. We will now describe an “abstraction” method to model this context.

### 4.1 Meta-model approach and objectives

The definition of a meta-model allows 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, project management model or in other domains such as software engineering.

The meta-modelling approach described by (Sprinkle et al. 1999) is used in the standard MOF (Meta Object Facility, FIG. 1) 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 visualisation modes included in a cooperation platform (Halin et al. 2003).

This approach is largely inspired by latest developments in Model-Driven Engineering (MDE). Especially a new field appears in Human-Computer Interface (HCI) design guided by models which interests us particularly (see chapter 7).

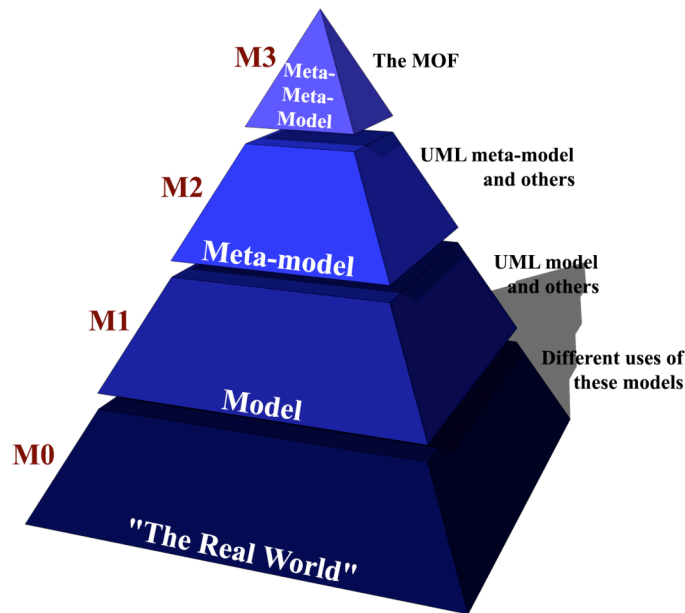


FIG. 1: The MOF architecture

## 4.2 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 (i.e. exchanges or dependencies). Modelling these concepts of cooperation will allow us to develop domain-specific applications (Hanser et al. 2002) structured on the base of the *cooperation meta-model for design and realisation* (FIG. 2). The context of cooperative design and construction activities has to represent relations and interactions between the actors, their activities, the documents they produce and the object of the cooperation:

*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. An actor often works in a group.

*Document (M2)*: a document represents a professional « deliverable » part of a contract. A document is an aggregation of files manipulated through an operating system. A document can group several other documents. Finally, actors generate documents during activities.

*Object (M2)*: The realisation of the object is the goal of the cooperation project. An object could comprise other objects (group of objects).

*Relationship (M2)*: a relationship identifies a type of link existing between two elements:

- The relationship between actors depends on the social organisation of the group (hierarchical or cooperative relationships).
- The relationships between actors and activities define the role of an actor in an activity (operational role, organisational role).
- The relationships between actors and documents are close to those used in the edition: Supervise, Produce, Comment, Consult, Revise, Diffuse.
- The relations between activities and documents are relative to the production of information: Generate, Use (technical requirements, rules, contracts).
- The relationships between actors and objects depend both on the role and the activity: drawing, calculating, building.



- The relations between documents are those used in the configuration management: new version of, refers to, is the synthesis of.
- The relations between documents (graphical, textual or table) and objects are essentially: describes, references, explains.
- The relationships between activities are relative to planning: following, preceding, being included in, and so on.
- The relationships between activities and objects are relative to production and management of object under design or realisation: designing, modifying, building etc.
- And so on...

Information regarding the context of the collaborative project can be represented and described by this meta-model. In the framework of the development of a new tool, the meta-model will allow us to structure the information exchanged in the cooperative project and to control the management of this information (visualization, exchange etc.).

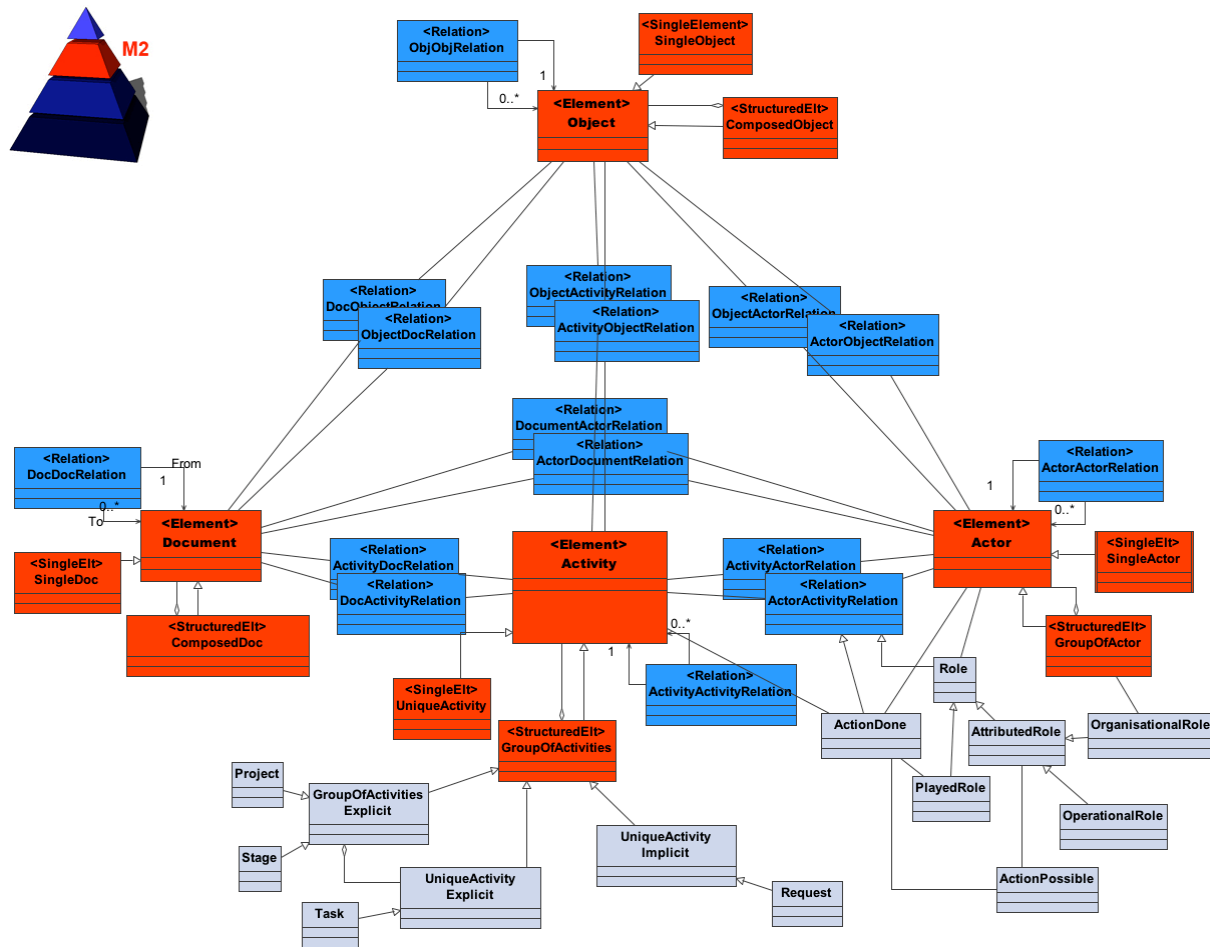


FIG. 2: Cooperation meta-model

### 4.3 Cooperative activity model (M1) in the AEC domain

Our interest focuses on the use of this meta-model in the AEC domain. Entities described at level M2 should be instantiated in domain-specific models, and particularly in construction activity.

For example, in FIG. 3 the class “actor” of our meta-model should be instantiated at the model level as “architect” or “pilot” which are types of actors in the AEC domain. The “object” of the meta-model should be instantiated in our domain in “works” and “spaces”. A “document” should be a “planning”.



## 5. ASSISTING THE MEETING REPORT DIFFUSION: “IMAGE.CHANTIER”

The quality of cooperation between actors is fundamental for the quality of the building construction processes. The latest development in Information Technology Science should allow us to increase the quality of cooperative activities in AEC.

We carried out experiment on these IT potentialities through the development of a prototype tool. The results we obtained enable us define specifications for a *digital assistant tool for cooperation during building construction* (chapter 6).

In the framework of this development we have focussed on the meeting report document. This document is produced after each meeting. It contains a large amount of “multi-actor” coordination information exchanged. We have developed the tool *Image.Chantier* to manage the diffusion of this information to each actor.

### 5.1 Meta-model instantiation

To begin with, we suggest a model of cooperation (M1) centred on the meeting report (FIG. 5). It describes the structure of the document (Grezes et al. 1994) and its links with other activities such as meeting and planning.

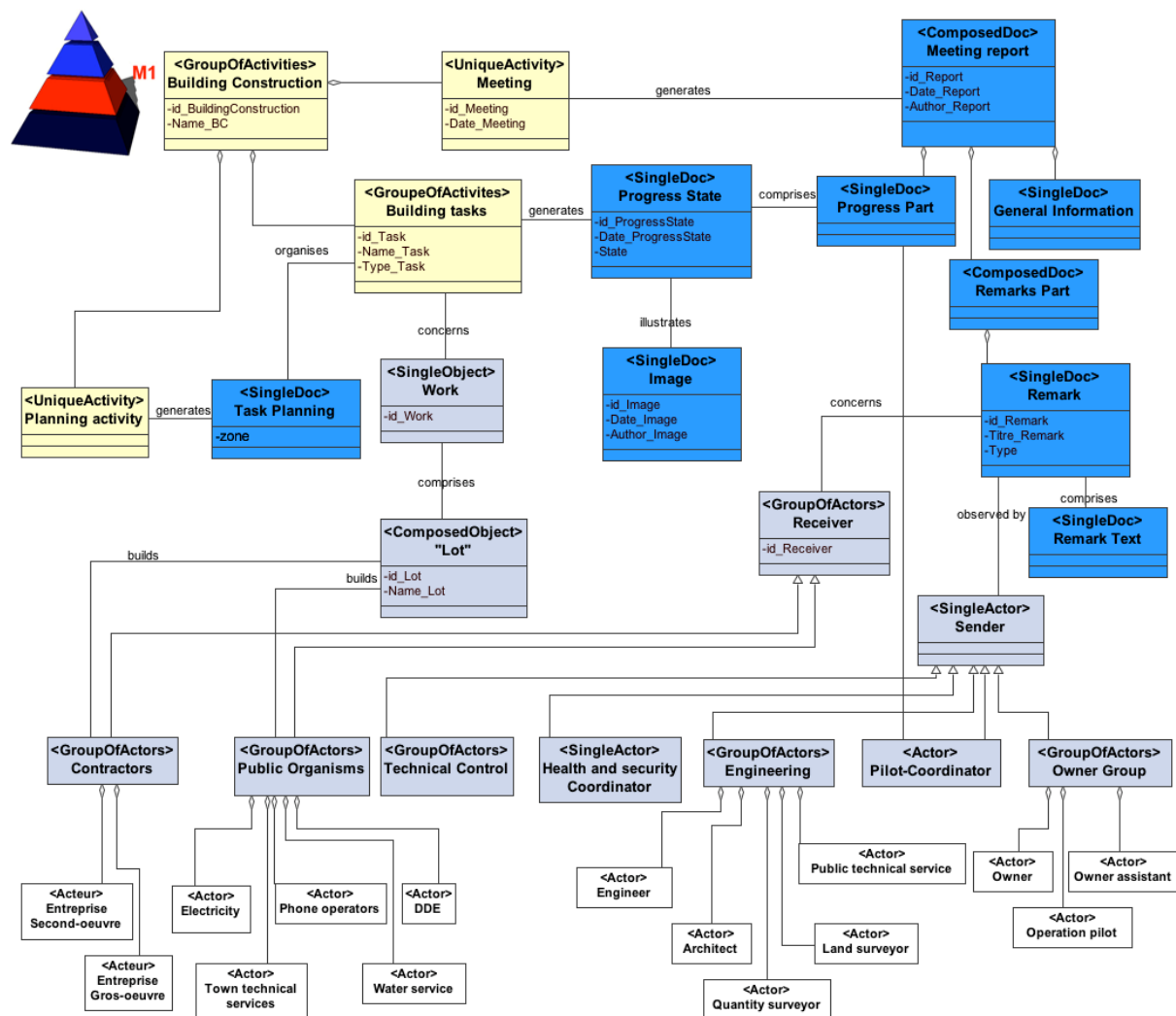


FIG. 5: A model (M1) of building construction activity focused on the meeting report

This model (M1) is the instantiation of the cooperation meta-model (M2) described in chapter 3. It demonstrates the central role played by the meeting report in cooperation during building construction.

We identify three main parts comprising the document:

- General information on the building construction activity, such as numbers of company workers, bad weather days or other meetings planned etc. We will not detail this part here.
- Information relative to construction progress (detail of real progress compared to planned progress).
- Observations that describe solved or to-be-solved problems. They are emitted by an actor and can concern one or more actors.

Entities of the model (M1) are instantiated from entities of the meta-model (M2).

The “*building task*” (M1) concept is an “activity” particular to the building construction activity. It describes particular characteristics of building construction tasks (cf. model): it concerns one or more built works situated in a zone, it’s carried out by one actor and is defined in terms of time (planning). It could be a “real task” (i.e. constructing a work) or a “wait task”, before another task (i.e. preparation).

The “*zone*” (M1) concept is an instance of the “object” entity (M2). “Zone” refers to “space” (M1). It allows us to situate the built work. It represents both a group of built works (i.e. bone structure comprising many pieces) or a topological delineation of the building site (i.e. ground floor walls). The definition of the zones varies from one site to another depending on the nature of the project (size, complexity, professionals and tasks groups).

## 5.2 Image.Chantier contribution

We have also defined and used “*points of view*” on the project context. It will give the users personalised access to information concerning them.

“Points of view” should be identified as particular views on the meta-model (M2) (i.e. representing every objects concerning one actor in an activity). In a tool, the point of view is a particular view on the model (i.e. the mason will see the built works that he is working on at the meeting date).

We distinguish between two types of points of view, “a priori” and “on demand”:

- “A priori” point of view can be defined on the base of analyses. For example, we know that in usual cases of use, a contractor needs to restrict information to his activities (i.e. built works in progress). To the contrary, architect needs to have a global view on the activity,
- “On demand” point of view should be build by the user of a tool, dynamically and relative to his needs. The structure of the point of view is the ideal structural view to help understand the system (Rousseau 2003).

Finally we have experiment with the benefits of digital image use in information transfer for coordination (Kubicki et al. 2005a). The role of the image is to be a trace of the activity in progress. It also has a heuristic function, e.g. finding new problems not detected by other methods.

## 5.3 Prototype development

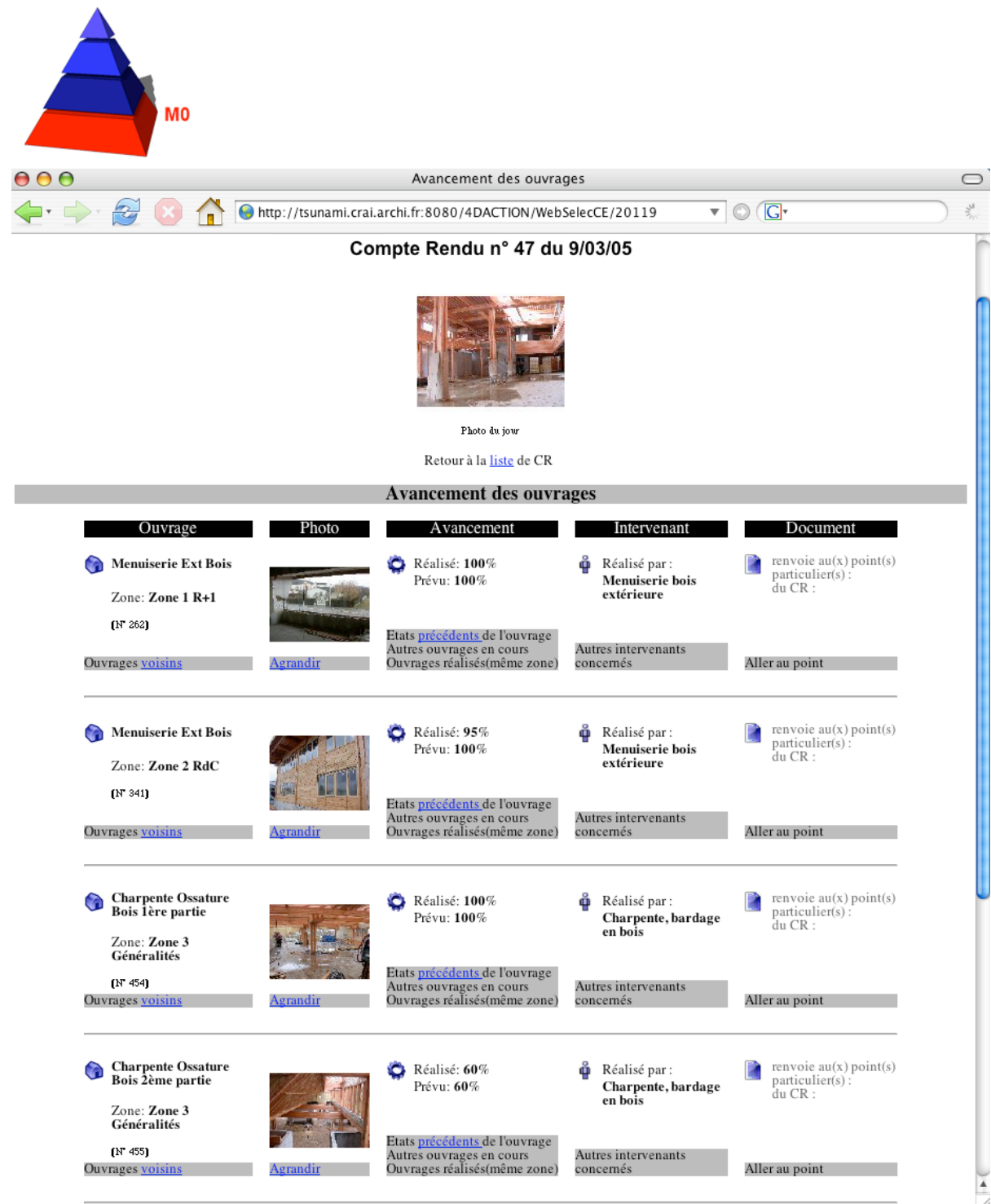
The objective of our prototype is to demonstrate the capacities of a new distribution of coordination information. The demo is available at <http://tsunami.crai.archi.fr:9292/> (login: *demo* and password: *demo*).

In this framework, we have restricted our development in order to isolate some concepts:

- The progress points: information relative to the progress of a building element.
- The particular points: information and description of a singular problem. They are characterised by a sender (author) and one or many receivers.
- The integration into an Information System allows us to manage some points of view: the prototype, in its present state, offers the user filters of the information.
- The model demonstrates that links can exist between different types of information: i.e. a particular point should concern one or many progress points. The tool suggests a chronological link (pictures of many state of progress) and a topological link (surrounding building elements).

The user just needs a web-browser to visualise information. Access to the tool is personalised by the actor role (identification by login and password).

FIG. 6 shows a screenshot of the interface of Image.Chantier prototype: the progress state of tasks. We can notice that we use the same icons for actors, documents, activities and objects in every M0 level applications. In this way, the model approach facilitates the comprehension of context by the user.



The screenshot shows a browser window titled "Avancement des ouvrages" with the URL <http://tsunami.crai.archi.fr:8080/4DACTION/WebSelecCE/20119>. The main content is a report titled "Compte Rendu n° 47 du 9/03/05". It features a central photo of a building's wooden frame, labeled "Photo du jour" and "Retour à la liste de CR". Below this is a table with the following columns: "Ouvrage", "Photo", "Avancement", "Intervenant", and "Document".





Ouvrage	Photo	Avancement	Intervenant	Document
<p><b>Menuiserie Ext Bois</b> Zone: <b>Zone 1 R+1</b> (N° 262)</p> <p>Ouvrages <a href="#">voisins</a></p>		<p>Réalisé: <b>100%</b> Prévu: <b>100%</b></p> <p>Etats <a href="#">précédents</a> de l'ouvrage Autres ouvrages en cours Ouvrages réalisés(même zone)</p>	<p>Réalisé par : <b>Menuiserie bois extérieure</b></p> <p>Autres intervenants concernés</p>	<p>renvoie au(x) point(s) particulier(s) du CR :</p> <p><a href="#">Aller au point</a></p>
<p><b>Menuiserie Ext Bois</b> Zone: <b>Zone 2 RdC</b> (N° 341)</p> <p>Ouvrages <a href="#">voisins</a></p>		<p>Réalisé: <b>95%</b> Prévu: <b>100%</b></p> <p>Etats <a href="#">précédents</a> de l'ouvrage Autres ouvrages en cours Ouvrages réalisés(même zone)</p>	<p>Réalisé par : <b>Menuiserie bois extérieure</b></p> <p>Autres intervenants concernés</p>	<p>renvoie au(x) point(s) particulier(s) du CR :</p> <p><a href="#">Aller au point</a></p>
<p><b>Charpente Ossature Bois 1ère partie</b> Zone: <b>Zone 3 Généralités</b> (N° 454)</p> <p>Ouvrages <a href="#">voisins</a></p>		<p>Réalisé: <b>100%</b> Prévu: <b>100%</b></p> <p>Etats <a href="#">précédents</a> de l'ouvrage Autres ouvrages en cours Ouvrages réalisés(même zone)</p>	<p>Réalisé par : <b>Charpente, bardage en bois</b></p> <p>Autres intervenants concernés</p>	<p>renvoie au(x) point(s) particulier(s) du CR :</p> <p><a href="#">Aller au point</a></p>
<p><b>Charpente Ossature Bois 2ème partie</b> Zone: <b>Zone 3 Généralités</b> (N° 455)</p> <p>Ouvrages <a href="#">voisins</a></p>		<p>Réalisé: <b>60%</b> Prévu: <b>60%</b></p> <p>Etats <a href="#">précédents</a> de l'ouvrage Autres ouvrages en cours Ouvrages réalisés(même zone)</p>	<p>Réalisé par : <b>Charpente, bardage en bois</b></p> <p>Autres intervenants concernés</p>	<p>renvoie au(x) point(s) particulier(s) du CR :</p> <p><a href="#">Aller au point</a></p>

FIG. 6: Screenshot of "Image.Chantier" interface (task progress part)

## 5.4 Experiment

In order to validate these propositions, we have experimented with the tool in a real building construction site: the reconstruction of the “Vincent Van Gogh” middle school in Blénod-lès-Pont-À-Mousson (France). A coordinator manages the building team and building tasks are realized by independent contractors (different than a “general contractor” case).

We distinguish between three main objectives:

- Defining what information is exchanged for coordination.
- Validating functionalities of the provided tool: structure and visualisation of information. Especially we wanted to try to verify the benefits of digital image use for assisting communication between actors.
- Beyond the meeting report usage, we were interest by analyzing the tools that actors use for accomplishing coordination tasks: specific coordination tools, communication tools and project description tools.

Different stages have been planned in this work:

- Analysis of user needs and development of the tool prototype.
- Use of the tool in the building construction framework as a visualisation tool of coordination information by the different actors.
- Validation stage by oral interviews. The goal is to determine the interest of a new assistance tool in general and more particularly to assess our propositions.

## 5.5 Comments on experiment results

The prototype tool has been shown to professionals and we can underline some interesting results:

- First, the tendency to use new tools based on ICT seems to be largely accepted by actors. Nevertheless they are not ready to use such tools in their companies. (Peansupap and Walker 2005) have identified some reasons explaining why there are difficulties in introducing Information technology in construction organisations. These reasons are linked to problematic such as innovation diffusion, change management and knowledge management.
- Meanwhile we have noticed a regular use of our tool by some actors i.e. the owner and some members of the engineering team. They were interested in the possibility of having a look at the building construction process without regular visits to the site,
- We can say too that the “proof effect” of the building construction image is globally acknowledged (verifying of the observed result compared to the expected result),
- Finally, it seems to be confirmed that the image carries out a function of anticipation and identification of new problems, particularly for distant users.

Beyond these comments focused on the prototype tool tested, this experiment on a real building construction site and the analysis of existing exchange methods have shown the central role played by the meeting report in coordination.

This is essentially due to two factors. Firstly, the pilot is the essential coordinator. He is generally the producer of this document. It centralises the major amount of coordination information exchanged and is the more up-to-date source of information. Then, at least in the French context, the meeting report has a judicial and contractual value that gives it this central role from a legal point of view.

Although meeting report is a major coordination tool it is meanwhile not the exclusive one. Actors need other tools and documents to better understand problems evoked in the report. These tools display very often the same information type (concepts) but in a different way (i.e. visualisation mode).

## 6. A COOPERATION PLATFORM FOR BUILDING CONSTRUCTION

This experiment in assisting the production and diffusion of the meeting report highlights the question as to what should an assistance tool dedicated to construction activity be?

Coordination information covers a wide domain. It comprises information on interactions, regulation and information on the designed project itself. Numerous tools and documents are therefore necessary for coordination.

Concerning the different forms of coordination identified in chapter 2, our position is this:

- “Multi-actor” coordination should be improved by tools clarifying information and making it more understandable for the actors. These tools have to personalize information for users and assist navigation through information (cf. *Image.Chantier* tool).
- On the contrary, “inter-actor” coordination has to remain essentially implicit activity in order to be efficient and to allow actors to adjust their work to the changes in the project. However it seems necessary to suggest to the actors new tools favouring their comprehension of the cooperative context.
- “Extra-actor” coordination is strongly linked to context knowledge that the internal actor has. Tools adapting information to the user should improve this knowledge.

## 6.1 Towards a multi-view interface for building construction coordination

Our proposition consists of a context multi-view representation tool. Based on “dashboard tool concepts” the role of such a tool is to allow one or many actor(s) involved in an activity to follow and monitor the progress of this activity and to measure its performance (Fernandez 2005). But this proposition goes beyond the traditional design of dashboards.

In fact we think that every actor in the building construction operation should be involved in their task coordination. For example in an inter-actor coordination case, each actor should find relevant indicators related to the activity and should be able to navigate through the project context to better understand the situation. This is a kind of democratic vision of coordination in building construction operations.

To develop this project we have looked into awareness theories (Endsley 1995, Greenberg and Gutwin 1996, Gutwin 1997). M. R. Endsley’s work underlines the different resources of awareness used by actors implied in a collective activity: perception of the relevant elements of the environment, understanding of these elements, and prediction of their state in a “near future”. Based on awareness theories we suggest defining functions for the building construction multi-view interface (FIG. 7):

- *Context perception:*  
The multi-view interface presents information in a way adapted to the user (his role, his needs etc.). Numerous visualisation modes allow the actor to be aware of their environment and to perceive the progress in the activity. Linking these views gives a highest level of perception of the context to the user. Indicators should highlight essential points (i.e. risks) in a synthetic way. We distinguish between two types of indicators: *relationship* indicators and *synthesis* indicators.  
*Relationship* indicators are the result of a specific treatment determining which concepts in a view are linked to another view. In fact “near concepts” of the project context should have different names in each model view. Our global cooperation meta-model (M2) is the key to linking these concepts. *Relationship* indicators allow us to highlight concepts in the multi-view panel and to select information during navigation.  
*Synthesis* indicators are closer to classical dashboard indicators. Analysis of process dynamics compared to its previsual progress (planning) lets us determine critical points in the activity. A specific “dashboard view” will be developed comprising indicators adapted to this type of information (green-orange-red lights, speedometer-like views etc.).
- *Comprehension:*  
In a multi-view interface, information visualisation has to be synthetic (i.e. filtered, adapted). The user should navigate in the project context in order to better understand information provided by *relationship* and *synthesis* indicators. Relationships between concepts and views are a way to explore different aspects of the context. For example, selecting an element in a view enables the user to interact with related views by transparent requests in a database. This allows the system to display a new multi-view arrangement and information content adapted to the user selection.

Moreover to explore precisely a problem, the user should have to use a specific, adapted software tool. That's why we suggest links towards usual tools in the interface. These links open destination tools and pass on navigation-context to them (e.g. an element selected in views). Available tools should also allow the sending of a contextual request to an actor (e.g. sending a mail).

- *Anticipation:*

The user should anticipate himself the future state of the process, based on indicators of the dashboard and understanding through multi-view. But if the process is modelled the dashboard should also monitor its progress and warn the actors of risks.

Figs. 7 and 8 show hypotheses of interface design for the multi-view tool. At present, we suggest four different "type of visualisation modes" (used in other tools) for the multi-view window: (1) Gantt planning view, (2) 3D mock-up, (3) text and (4) graph. A "dashboard view" comprising specific indicators is under development.

These visualisation modes are arranged specifically to the user context. During navigation user should change of view manually. Arrangements are also pre-determined for specific coordination tasks.

In FIG. 7 the multi-view is dedicated to the architect of the project. The representation focuses on 3D visualisation, which is relatively common and comprehensible for an architect. When the user selects an object in the mock-up the two other windows update to adapt their content (i.e. planning task is highlighted and remarks on meeting report are filtered concerning this object).

In FIG. 8, the multi-view is dedicated to the coordinator. This actor is more interested by schedule information, and organisation information. That's why we suggest a graph view at the centre of the window. BatMap hypergraph (Halin et al. 2003) is a project carried out in the CRAI laboratory. It displays project information in a graphical way, focusing on links between actors, documents, activities and objects.

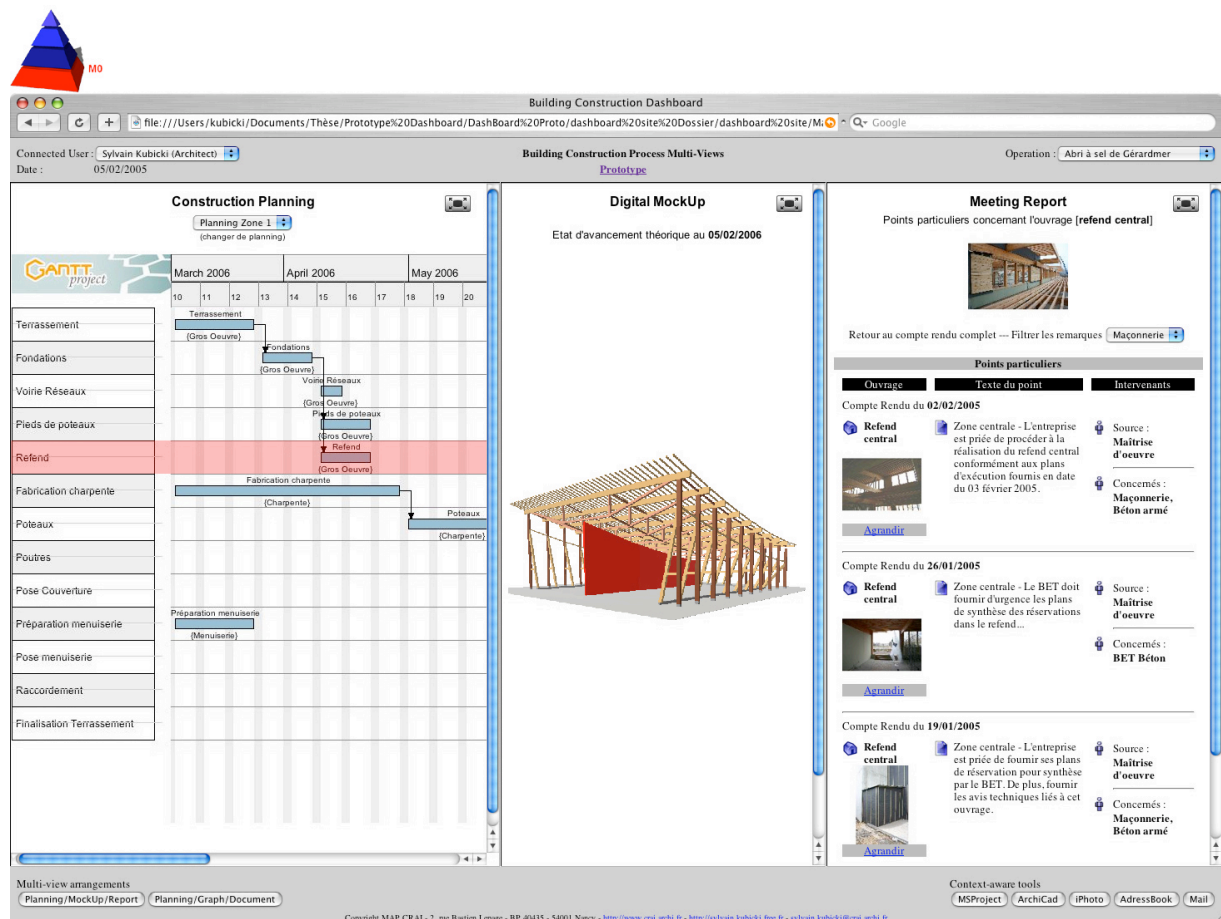


FIG. 7: A hypothesis of the multi-view interface – Architect view



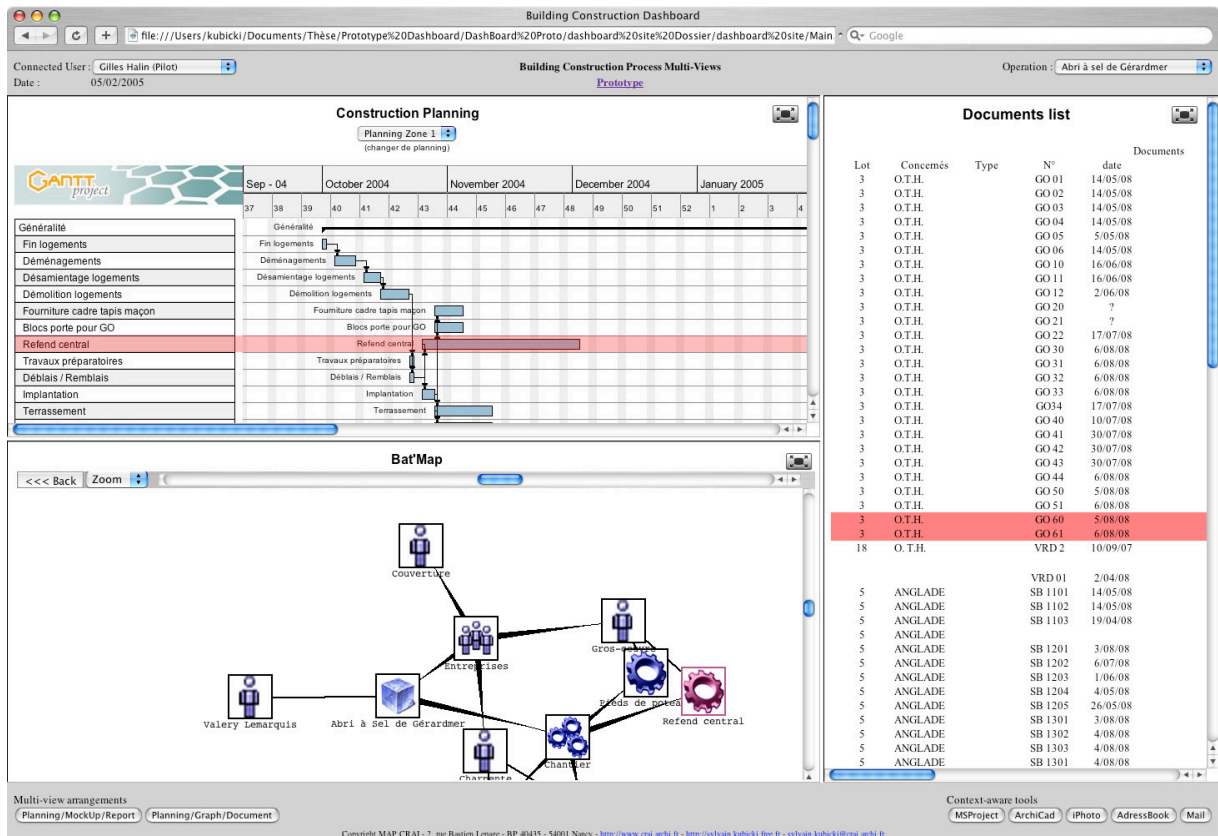


FIG. 8: A hypothesis of the multi-view interface – Coordinator view

In these figs a red colour highlights important points of the activity in order to link information concerning a specific coordination point in the different views (i.e. task delay in the planning, its explanation in the meeting report, and its 3D representation in red in the mock-up).

A toolbar is placed at the bottom of the window. This toolbar will allow the user to switch to a specific tool, i.e. to start a planning tool to have a complete visualisation of the planning.

## 6.2 Coordination scenario

The research work on this project is still in progress. For the moment we have chosen an approach with scenarios in order to evaluate the relevance of this proposition. Two scenarios are described here, one without multi-view tool and with. We were inspired by a real and relatively simple situation observed in an individual housing operation in Nancy (France). This scenario is only a basis for reasoning. It does not cover every coordination modes identified in chapter 2. It describes a case of inter-actor coordination in which awareness of group activities and project documents is fundamental.

In this building construction activity (FIG. 9) 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 final wall aspect (after being trimmed) does not correspond exactly to the architect's expectation.

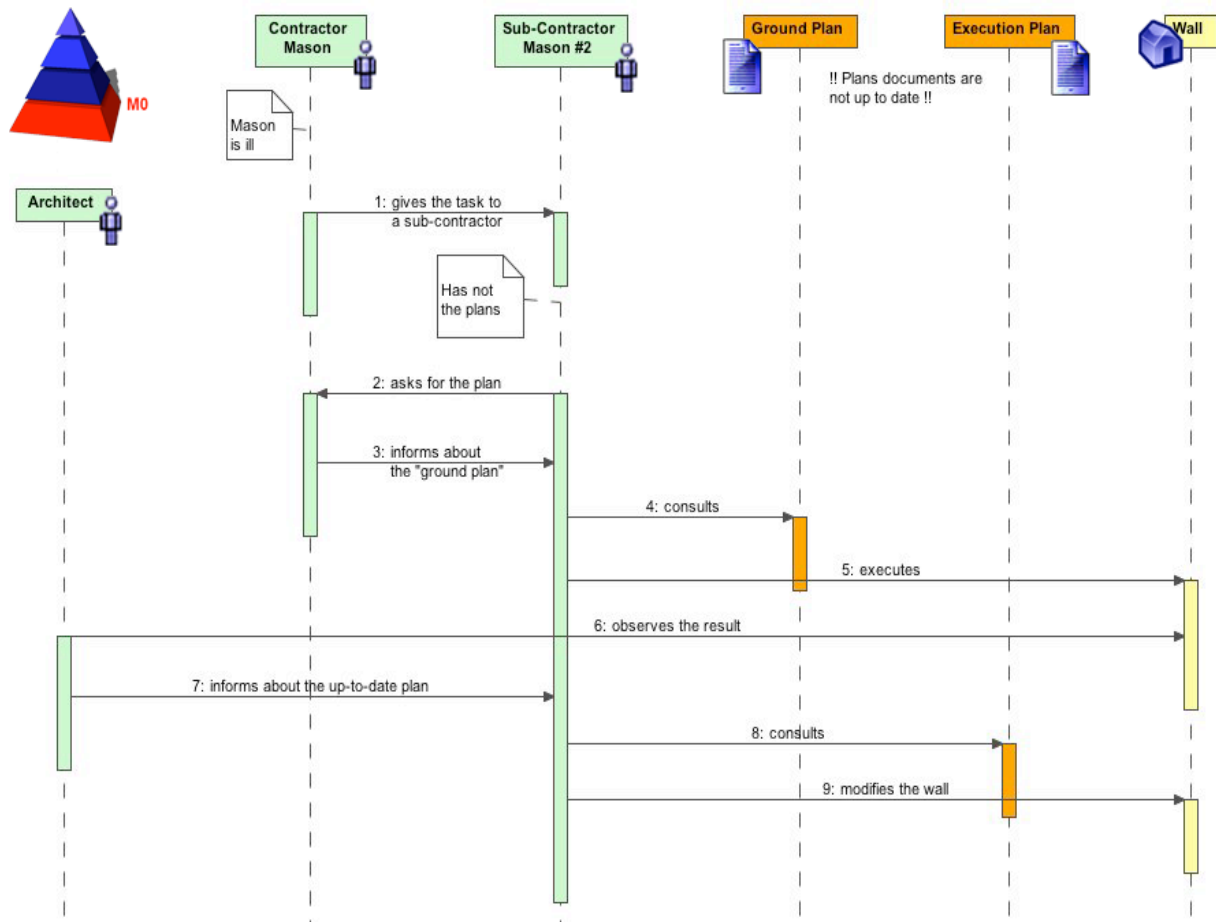


FIG. 9: Observed coordination scenario

The next scenario (FIG. 10) treats the same situation and integrates the use of the multi-view interface whose functionalities are described above.

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 multi-view interface use should be:

- to gain time in coordination information transfers,
- to allow the actors better knowing their cooperative environment (documents, activities) and to act in consequence,
- to reduce risks of errors.

This scenario demonstrates the advantages of using a coordination tool favoring awareness. For the moment it does not really allow us to validate interest of a multi-view interface based tool. The development of a prototype is in progress in order to demonstrate the interest of project multi-visualization in an awareness tool.

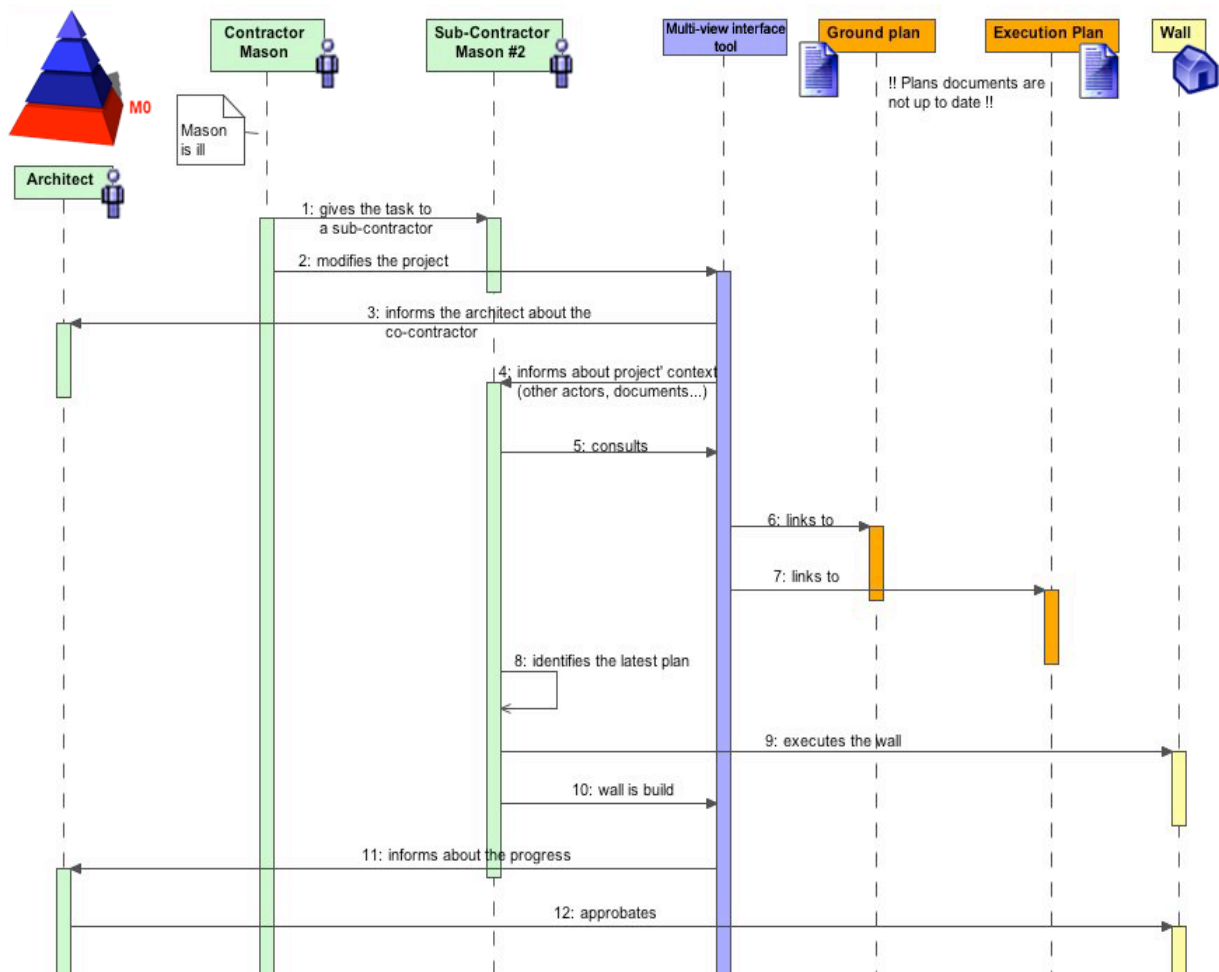


FIG. 10: Multi-view interface hypothesis in the coordination scenario

## 7. PERSPECTIVES

To develop a working prototype we are working at present on the definition of the infrastructure into which the multi-view interface will be inserted. Its vocation is to centralise information. This tool is therefore placed at the intersection of the usual tools of each actor. It should be added to a project management tool comprising all information about the cooperative project. Its structure should be an instantiation of the cooperation meta-model. Bat'Group platform developed in the CRAI laboratory for some years comprises a traditional view of the project (php-based classical interface) and a graph-based view called Bat'Map. It should be the basis for the development of the multi-view interface.

The use of multiple views requires modelling visualization modes which exist and are used in other tools: text, table, 3D mock-up, graph, Gantt diagram, 4D visualization (Chau et al. 2005) etc. The choice of a visualization mode to represent information is made through certain criteria: information type to be visualized, usual practice of a tool, skills of the user etc.

We envisage defining transformations between the cooperative context model and visualization mode models in order to manage these correspondences.

FIG. 11 shows these transformations between models at level M1 and their instances: information selections generated at level M0. Context-aware Visualisation Modes (at the bottom of the pyramid) will be placed in the windows of the multi-view interface. This infrastructure allows relevance and coherence of information displayed. It also ensures its adaptation to the user by defining his profile in the cooperation context.

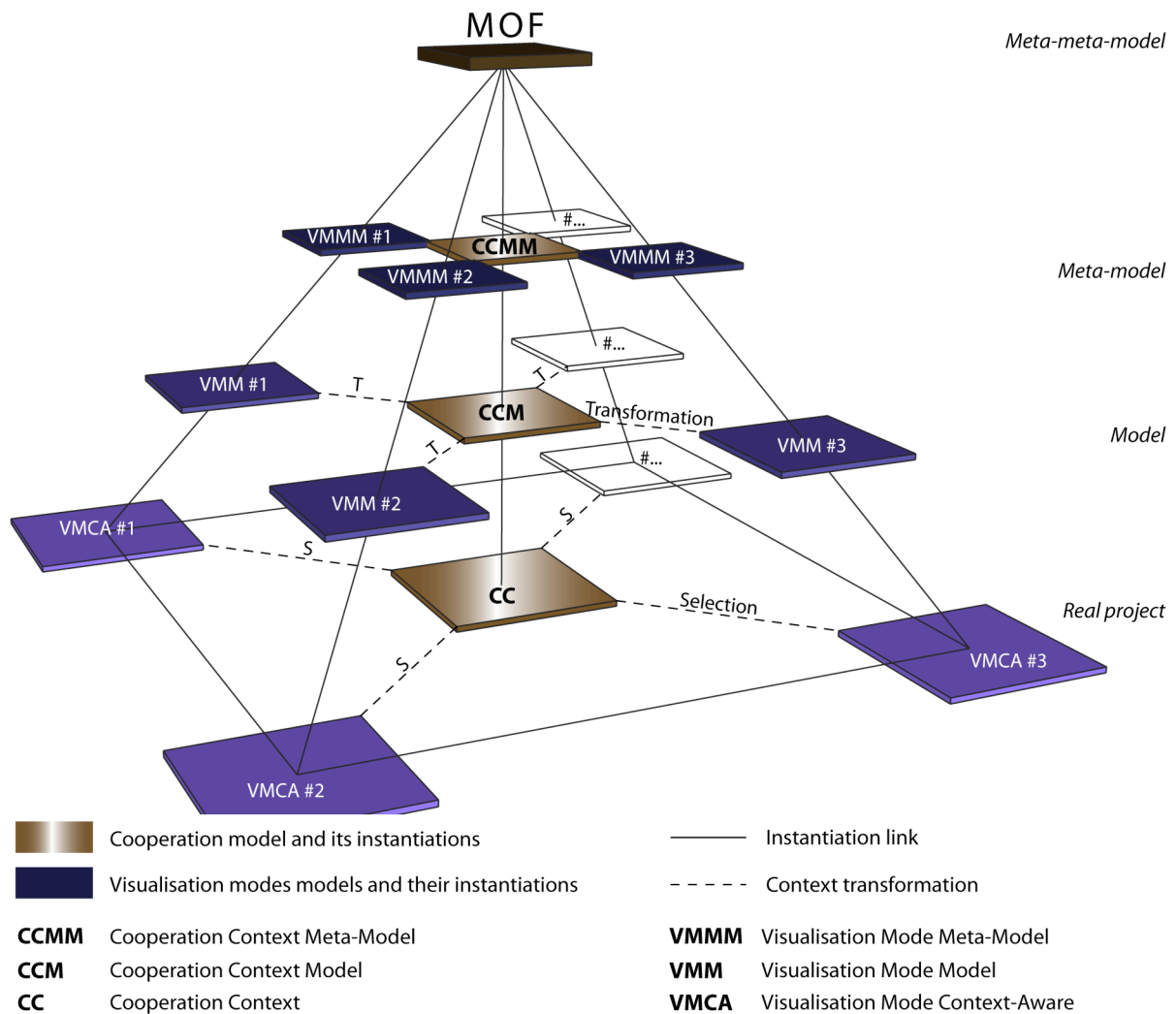


FIG. 11: Infrastructure driven by models

Information representation will use the architecture described above. It allows us to select information to be represented in a database of the project and to display it for the user in the interface. We now have to develop a context adaptation “module” managing user information: his role (and his rights to information), his preceding actions and possibly his potential needs. This module should be inserted in our Bat’Group cooperative platform.

In a Model-Driven Engineering (MDE) (Sottet et al. 2005) perspective it now appears necessary to develop other models which will help us to build this multi-view interface and to select appropriate information to be displayed.

- *A workspace model.* It defines the workspace interface (see mock-ups above in FIG. 7). It consists essentially of modelling the coherent view arrangements.
- *A conceptual model of each view.* It consists of isolating each view of the arrangement by describing their content in specific models. In fact each view has its own conceptual model because they do not share the same context. The concepts of these models are then different.
- *A user model* is necessary to adapt information content and view arrangements in the user’s context (his role in the project, tools used, tasks to be achieved etc.).
- *A task model* will allow us to describe coordination tasks usually performed during building construction (preparing a meeting, doing a plan synthesis, managing a problem of interface between actors etc.). For each task we should associate users able to perform it, adapted visualisation modes and necessary tools. We then have to link workspace, user and task models.

- *A transformation model.* This is the most important model in MDE approach. Updating views of our interface will be based on model transformations. It will let us display information content provided by a shared context (our cooperative context model) in several visualisation modes (view and workspace models). These transformations are also necessary to create relationships in each view model although their concepts are different. For example we can define a transformation to make a correspondence between a task in the planning view and an object in the 3D-mockup view. This work is still in progress. We are searching for adapted transformation languages such as ATL or XSLT (see <http://www.sciences.univ-nantes.fr/lina/atl/atlProject/languageDefinition/> for more information on ATL).

## 8. CONCLUSION

The activity of coordination of a construction operation is complex and uses both explicit and implicit tasks and information. “Multi-actor”, “inter-actor” and “extra-actor” coordination forms are necessary for project progress and adjustment of activities of each actor. The building production system seems to be well balanced between these modes of coordination but we think that each one could be improved. Enabling relationships between tools (e.g. by the way of a common model of concepts) is one of the keys to improve coordination. Tools used at present show some limits (information incoherence, lack of information etc.). During building construction these limits penalise cooperation and generate conflict situations between actors, delays on tasks or lack of quality of the built works.

The proposition of a *model-based infrastructure* and a *cooperative platform* comprising usual and new *tools* tries to solve these problems related to cooperation. This model-based platform allows us to share information and to verify its integrity in a way relevant to the meta-model of cooperation.

The *model infrastructure* that we develop will allow us to establish relations between cooperative context information and its representation in adapted visualisation modes. This work is currently in progress. We have to define the exact nature of transformations between models and the techniques to use to realise it.

The *cooperative platform* consists in a project management tool developed at the CRAI laboratory for a few years (called “Bat’Group”) and is dedicated to AEC project context. Its database enables to manage project context information (actors, documents, activities and objects of the project). We are now developing a context adaptation module to identify and manage information about users.

The *multi-view interface* is a new tool, suggesting an innovative view of information for coordination. The objective we want to reach is to give the user an adapted representation of information. It should allow him to better understand the cooperative context of the project he is working on.

We have now to define what visualisation modes are well adapted for which user, relatively to his role, his skill etc. We analyse also the possibility of interface adaptation by the user (malleability). Finally, tool ergonomics is also in question especially concerning the choice of dashboard indicators.

Finally, a major stage of this work consists in validating this proposition with professionals of the AEC domain. We envisage an experiment with architects and pilots, in order to validate coordination scenarios with and without dashboard.

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