Digital assistant for the cooperative construction process in AEC

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ABSTRACT: The article focuses on specificities of the building construction stage as cooperative activity. We identify methods and tools of coordination at present used and detail their limits. Modelling the concepts of cooperation in design / construction and the relations between these concepts allows us to describe the domain and suggest new tools. We present an experiment in progress with the prototype *Image.Chantier*. This tool provides a new form of distribution of coordination information, based on the meeting report document structure. The assessment of this experiment has led us to suggest new specifications for a building construction management system: *a digital assistant for cooperation during building construction stage*.

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.
- Time development of a project is sequential. Succession of stages is characterised by the made of irreversible decisions and the preservation of uncertainties.

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…

We are interested in the building construction stage. During this stage, many goals are achieved:

- Controlling construction delays,
- Controlling costs,
- Ensuring the final quality of built works (i.e. conformity to plans).

Cooperation during the building construction stage focuses on coordination of the different actors of the construction process.

We present the cooperative particularities of the building construction activity and the associated methods and tools.

We describe the conceptual model we have developed to represent the concepts of cooperation in AEC. This model is the base of our propositions for cooperation assistance tools using potentialities of digital technologies.

We have implemented this model in a prototype tool and we are experimenting with it on a real building construction site.

This experiment and its results allow us to formulate new specifications for a *digital assistant to cooperation in building construction stage*.

2 THE BUILDING CONSTRUCTION ACTIVITY

The building construction stage is the project stage where the object (the building) moves progressively from a virtual state to a realised state.

2.1 *Cooperative activity vs. internal strategies*

We can identify some characteristics of the building construction activity (Kubicki et al. 2005):

- New actors are integrated into the project team[1]: security surveyor, pilot, environmental officer, contractors… The relation between actors becomes more hierarchical (i.e. contractors follow the architect's demands),
- New objects appear resulting from the design stage studies: materials, equipments, tools,
- 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,
- 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.

2.2 *Coordination methods used at present*

The survey of building construction consists of ensuring the coordination of teams' actions. We can distinguish between "multi-actor" coordination and "inter-actor" coordination.

2.2.1 *Multi-actor coordination*

Multi-actor coordination aims to inform the entire group of what is happening in the project. It's an explicit activity. Its objectives are to define the conditions of building construction activities and to allow a strict surveillance of progress. There are two major activities in this coordination type:

- 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 construction meeting report", generally once a week, allows the coordinator to verify the progress statement with all the actors involved in the project, and particularly to identify and solve the existing and anticipated problems. A meeting report is produced, validating the decisions taken during the meeting and the information distributed.

The tools to carry out these activities are textual documents or 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 don't allow the creation of links between information (i.e. points of meeting report) or 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 not 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…),
- 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).

2.2.2 *Inter-actor coordination*

Inter-actor coordination can be defined as peer-to-peer coordination. It consists generally of implicit activities 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.

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.).

By identifying coordination methods existing at present we are able to reflect on *how to take them into account in a new tool proposition.* We think that inter-actor coordination needs its highly implicit form to function. Further propositions don't suggest the need to replace it…

[1] In this article, we focus on the specificities of the French building construction context.

2.3 *New methods and tools*

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

"Digital plans servers" are used for important project to facilitate document exchange. "Project management servers" allow the users to organize and manage different activities (Le Begge et al. 2004) 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[2].

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

But these new methods remain quite unusable for every-day work. They come from other activity sectors such as manufacturing industry and are not well-adapted to the AEC context and its particularities (cf. part 1).

3 MODELING COOPERATIVE ACTIVITIES IN AEC PROJECTS

Representing the particularities of the domain is the first step towards propositions of new assistance tools for cooperation.

3.1 *Meta-model approach and objectives*

The definition of a meta-model allows us to highlight essential concepts to describe context of cooperation in design and construction. These "meta-concepts" of the meta-model (*M2 level*) will be instantiated in specific cooperation models (*M1 level*) (meeting-report model, project management model etc.).

For example, the class "object" of our meta-model should be instantiated at the model level as "space" or "built work".

The meta-modelling approach (Frankel 2003) used in the standard MOF (Meta Object Facility) is proposed by the OMG[3] (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 graphical representations (Halin et al. 2003).

3.2 *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 cooperation between actors (i.e. exchanges or dependencies). Modelling these concepts of cooperation in the AEC sector will allow us to develop specific applications structured on the base of the *cooperation meta-model for design and construction* (Fig. 1).

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 (building elements or spaces) (see figure 1):

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.

Document (M2): a document represents a professional « deliverable » part of a contract.

Activity (M2): the activities inside a project have several "scale" levels: project, phase, stage, and task. The activity can also be characterised by its nature: design, execution, planning, coordination, or prevention activities.

Object (M2): The object is the goal of the cooperation project. We distinguish two types of objects: building elements and spaces. Its definition evolves from design to construction stage: from virtual to real building.

Relationship: 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 objects depend both on the role and the activity: drawing, calculating, building,
- The documents describe the object (graphical, textual or table information). They are generated by actors during activities,
- The relationships between activities are relative to planning: following, preceding, being included in, and so on.

[2] IFC format is a data format for construction oriented « object ». http://www.iai-international.org

[3] http://www.omg.org

Information regarding the context of the collaborative project can be represented and described by our meta-model.

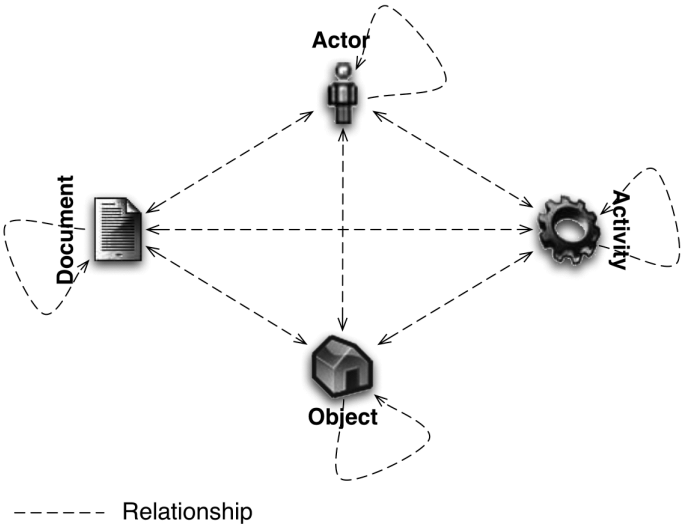

Figure 1. Concepts of the meta-model (M2) of cooperation in design and construction.

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 (visualisation, exchange…).

4 A DIGITAL ASSISTANT FOR COOPERATION DURING BUILDING CONSTRUCTION

4.1 *Experimenting some potentialities of digital technologies*

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*.

4.1.1 *A prototype tool to diffuse coordination information: "Image.Chantier"*

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.

To begin with, we suggest a model (M1) of cooperation centered on the meeting report (Fig. 2). It describes the structure of the document (Grezes et al. 1994) and its links with other activities such as meeting and planning.

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

We identify 3 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… 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 "*construction 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).

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).

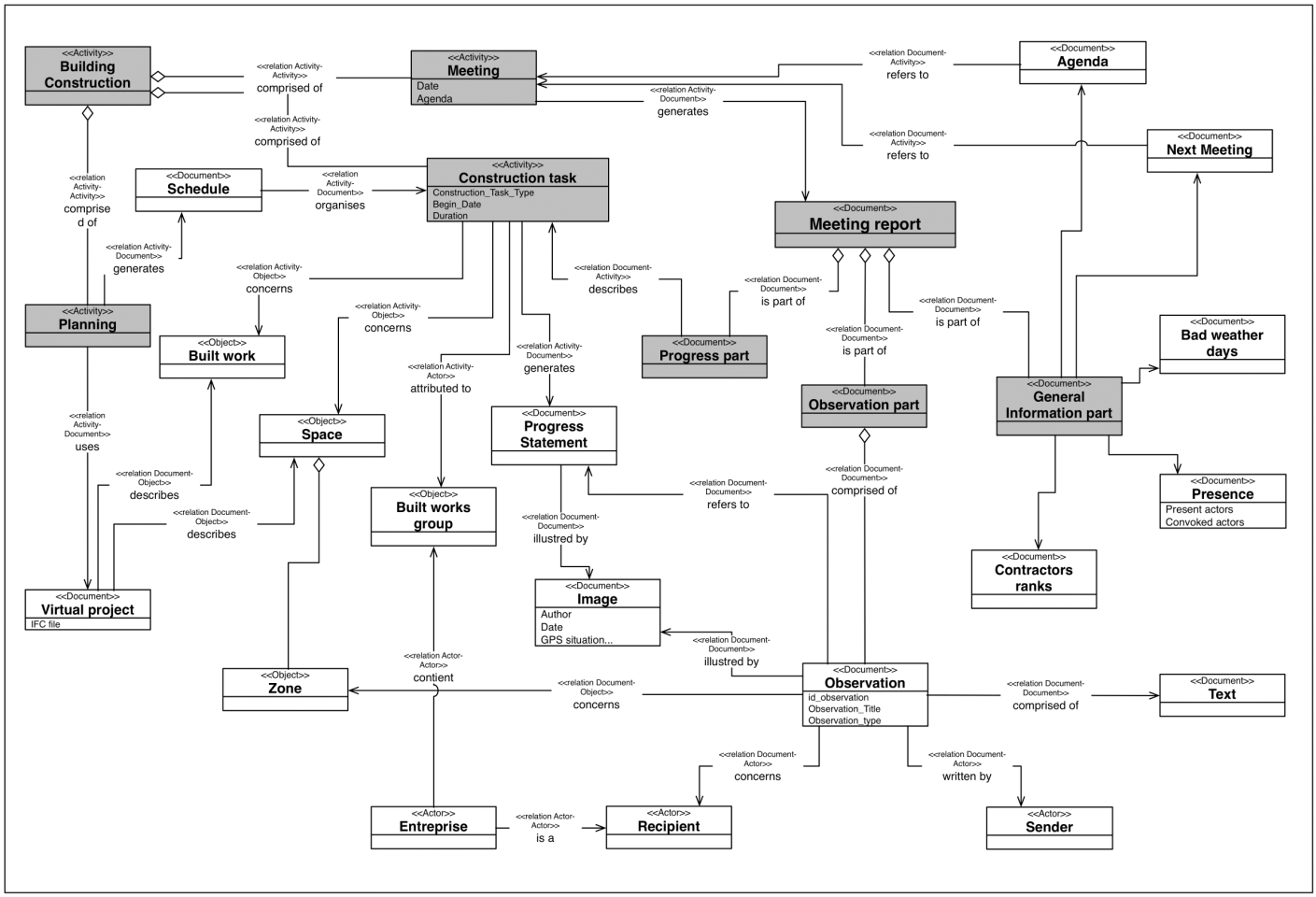

Figure 2. Cooperation model centered on the meeting report.

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. The role of the image is to be a trace of the activity in progress.

Modelling these concepts linked to the meeting report allows us to build the database structure implemented in our prototype tool.

The objective of our prototype[4] is to demonstrate the capacities of a new distribution of coordination information.

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).

4.1.2 *Experiment*

In order to validate these first propositions, we are now experimenting with the tool in a real building construction site[5].

We distinguish between three main objectives:

[4] Demo available at http://tsunami.crai.archi.fr:9292/ (login: *demo* and password: *demo*)

[5] Reconstruction of the "Vincent Van Gogh" middle school in Blénod-lès-Pont-À-Mousson (France). Cartignies & Canonica Architects.

– Defining what information is exchanged for coordination,
– Validating functionalities of the provided tool: structure and visualisation of information,
– Verifying the benefits of digital image use for assisting communication between actors.

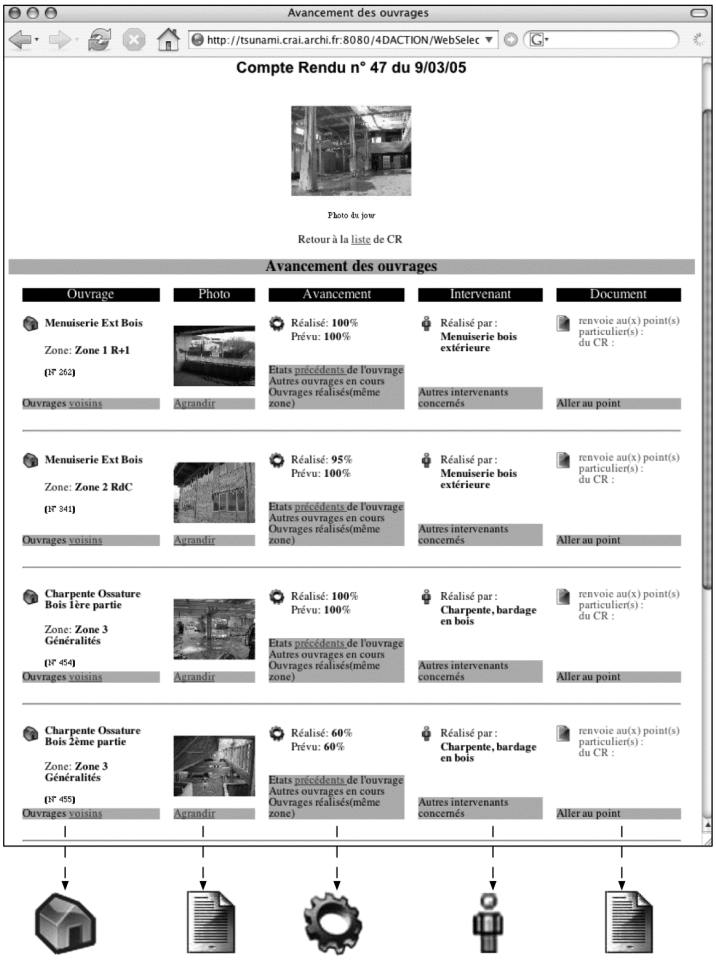

Figure 3. Screenshot of the interface (progress information)

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.

4.1.3 *Comments on experiment results*

Despite the fact that the validation stage is still in progress we can underline some interesting results rising from interviews of actors:
– First, the tendency to use new tools based on IS seems to be largely admitted by actors. Nevertheless they are not ready to use such tools in their companies,
– Then, we have noticed a regular use of our tool by some actors: 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.

4.2 *Specifications for a digital assistant for cooperation during building construction stage*

The theoretical analysis and experiment described above allow us to suggest some hypotheses on the utilities and benefits of an assistance tool for cooperation during building construction.

Beyond the propositions of instrumentation of the meeting report explored in the prototype called *Image.Chantier*, it appears that a larger tool should assist building construction management.

We have identified the visualisation and representation of the project context as fundamental for actors.

The model of cooperation centered on the meeting-report, used in our prototype tool allowed a logical representation of context elements in the interface (*activity*, *actor*, *object* and *document*).

The meeting report is a limited document. Latest developments of our cooperation meta-model and work on the meeting report model let us imagine new specifications for a *digital assistant for cooperation during building construction*. Such a tool has to:
– Integrate *time* management (*activity* M2) through a link between coordination information (meeting report) and task planning (e.g. situating the problem in time),
– Favour *spatial* (*object* M2) comprehension of the built works related in the documents. Built works properties come from the design stage and can inform construction activities (i.e. situating the problem spatially). Different representation modes are available to provide such information: digital mock-up for 3D representation or digital image taken on the site,
– Display *actor* (M2) organisation and structure, i.e. hierarchy? ,
– Inform about links between activities or actors and *documents* (M2), i.e. what are the documents referring to this built work?

4.2.1 *Linking coordination information and planning information*

Numerous research works focus on the integration of the time dimension in the designed object. 4D consists of integrating 3D mock-up and execution planning. These works try to anticipate the building con-

struction activity by providing a link with design activities…
Building construction management is composed of two major activities of coordination:
– Building construction "setup" consists of planning the execution of the different building construction tasks within the time scale,
– Building construction surveillance allows the coordinator to control progress and schedule.

At present we observe that the link between coordination documents (e.g. meeting report) and planning does not exist. However this link is essential, i.e. for analysing the effects of a coordination problem on the work schedule or a new task combination etc.

The different sources of "multi-actor" coordination information have to interoperate in order to ensure the surveillance of construction progress (increasing quality of information).

The comprehension of coordination information *related to time* is part of *project context* comprehension. It favours quality of individual actions and "inter-actor" coordination.

4.2.2 *Using digital medias to situate the objects*

Different medias should be used to situate the objects spatially. Their properties allow us to imagine specific use cases:
– 3D representation allows us to represent "designed built works" (i.e. digital mock-up),
– Construction site image represents built works under construction or already built.

The 3D digital mock-up and image let us display information relative to the point of view of the user on the project context.

For example the visualisation of interfaces should be the point of view of the pilot. In the model, an interface is represented by the link between tasks (e.g. follows). A digital mock up can isolate the built works in question and display it.

4.2.3 *Visualisation*

The 4D methods that we analysed suggest that we complete information coming from the design stage with building construction planning information.
Tanyer and Aouad (Tanyer et al. 2005) describe the limits of these propositions especially concerning visualisation that "*should include more than just the graphic representation of the building*". Planning activity is another subject of research. In 4D research works, planning information completes the 3D model of the project (Chau et al. 2005).

Visualisation of information is a problem because of the complexity of the 3D model and the size of the planning document.
The combined use of different visualisation methods should allow us to facilitate the comprehension of the organisational context by the user. The choice of a visualisation method depends very much on the entity (M2) to be represented:
– Objects (M2) are described by the image or the digital mock-up,
– Activities (M2) and links between them are represented by graphs (as Gantt or Pert graphs),
– Documents (M2) and actors (M2) are described in lists of text or tables,
– The relations (M2) between entities (the context in general) should be visualised by a hypergraph.

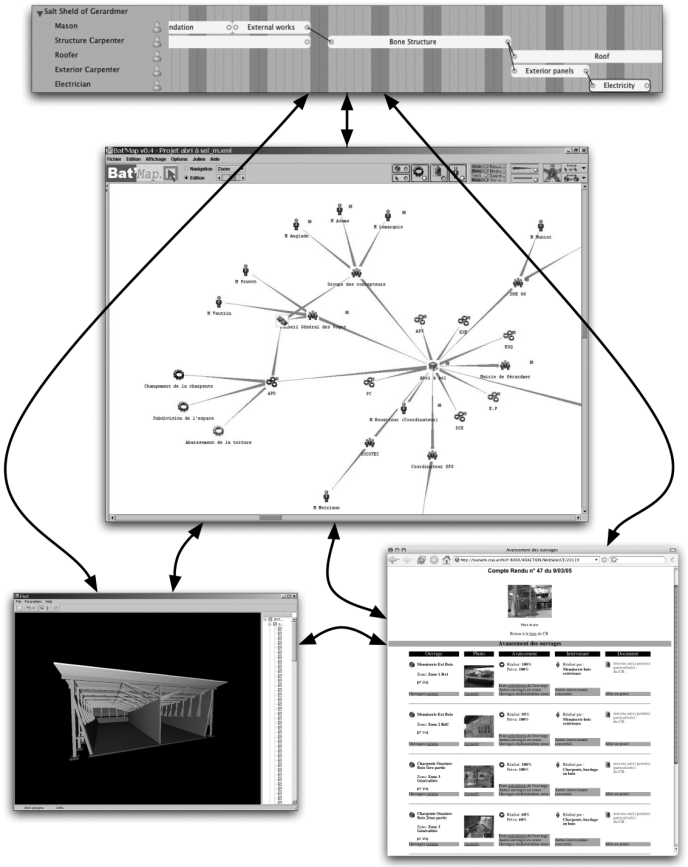

Figure 4. Representation modes, links and transitions between information.

Technologies of hypergraphs have been experimented with in recent works, allowing the user to have a graphical visualisation of the organizational context. Bat'Map prototype tool, developed by the CRAI (Halin et al. 2003), focuses on the design stage. In Bat'Map, the hypergraph is used to represent the organisation in design activity.

We suggest using such a representation method in a tool for the building construction stage. The point of view should be centered on the *building construction task.*
These different modes of visualisation should become *visualisation modules* of a *digital assistant for cooperation in building construction stage.*
In order to optimise the interface of the tool, it will be necessary to think about the needs of the different types of users.

The system should suggest a group of predetermined modules, relative to the identified needs or actions of a user.

For example, planning and text allow the user to visualise the consequences of a coordination problem for the activity (i.e. delays). Planning and digital 3D mock-up allow him to locate spatially the built work(s) in question…

5 CONCLUSION

The AEC production sector is at present undergoing significant changes. Particularities of the building, resulting from design and realisation activities, require the adaptation of the work methods of the different actors involved in a project.

New tools have been appearing for some years capable of assisting the different professionals in their activities. But we observe that these tools are designed to serve the strategies of independent actors, in their own companies. They do not favour or facilitate dialog and cooperation between the different actors.

The cooperation meta-model (M2) described in part 3 of this paper focuses precisely on the relations existing between the different entities comprising the project context. These relations are the basis of cooperation.

In the building construction stage, cooperation between actors is essentially a coordination activity, especially the coordination of tasks carried out by the contractors. The model centered on the meeting report (M1) is an instantiation of the meta-model (M1). It shows the central role of this document in construction activity coordination.

We have experimented with a prototype tool to establish the potential benefits of Information and Communication Science on the diffusion of coordination information:

- Managing points of view of the information,
- Creating and using links between diverse information sources,
- Adapting visualisation of information, based on the meta-model concepts.

The experiment shows that such new tools interest the professionals and they are conscious of the potentialities of these tools in their everyday work.
Our study is now being directed towards building construction management and cooperative activities, beyond the meeting report document.

Time management begins with the building construction setup when execution planning is drawn up. The digital mock-up, coming from the design stage, is enhanced with schedule information (4D).
During the construction activity, coordination information is produced and exchanged (meeting-report). Capitalising this information is essential to manage building construction knowledge (technical, organisational etc.) and to re-use it during design stages.

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