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# **Understanding pre-construction simulation activities to adapt visualization in 4D CAD collaborative tools**

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## **Abstract**

Pre-construction phase is very important in construction project life cycle. It enables minimizing risks, waste and overheads, maximizing productivity and reliability during construction phase, and to design more accurate and feasible schedules. The collaborative use of 4D CAD models and simulations appears to be an innovative solution to support many of simulation activities during this phase. But the visualization adaptation to business requirements of actors remains a challenging issue. This paper presents the pre-construction collaborative simulation activities and describes a method aiming at adapting visualization in 4D collaborative tools. A formula for ranking visualization modes and related metamodels are also proposed.

## **1. Introduction: importance of visualization in pre-construction collaborative practices**

Increasing productivity and efficiency is an important issue in the Architecture, Engineering and Construction (AEC) sector. This sector is mainly characterized by fragmentation, heterogeneous teams with low lifetimes and many uncertainties. 4D CAD modeling and simulation is one of the greatest innovations in recent years. It consists in linking a 3D model of the building with the works planning in order to simulate the construction development over time. 4D CAD techniques can fill several needs from design to project management through constructability analysis and tasks planning [1]. Literature shows that several applications have

been proposed to improve the 4D CAD use ([2]; [3]; [4]). In addition, studies have shown the real impact of the use of 4D CAD in construction projects ([5]; [6]).

More recently, [7] showed that the collaborative use of 4D CAD is particularly useful during the pre-construction phase for comparing the constructability of working methods, for visually identifying conflicts and clashes (overlaps), and as visual tool for contractors, subcontractors and suppliers to discuss and to plan project progress. So the advantage of the 4D collaborative use has been largely addressed. Moreover, some studies have been conducted both in the scientific world as well as in the industrial world to improve it ([8]; [9]).

But an important issue that remains in today's collaborative use of 4D CAD in construction projects is related to the adaptation of visualization to the actors' business needs. As collaboration is particular from one project to another, the business requirements regarding visualization also evolves. Collaborative practices [10] can help to describe them and to understand most common pre-construction activities. Moreover, in the AEC field several visualization modes can represent the same concept and actors choose one or the other of these modes according to their specific needs related to the task they have to perform. For example, tasks planning may be represented by a Gantt chart or by a PERT network and building elements can be depicted with a 3D model or a 2D plan. The classical view (3D + Gantt) usually proposed to all practitioners in most of the current 4D tools seems therefore not suiting the needs of every actors and situations of use. So, adapting the visualization to individual business needs could significantly improve the collaboration.

We rely on Model-Driven Engineering (MDE) to propose a method aiming at designing business views. The aim is not to automatically generate user views but to guide the groupware designers in selecting the appropriate visualization modes and in composing them. To support the method, we propose a business view metamodel to firstly describe and then compare view models. A metamodel to describe the user's visualization tasks is also defined. The goal is to design adapted views according to actor's business practices in collaborative 4D simulation, so it is important to understand the simulation activities related to pre-construction phase. Relying both on literature review and on a preliminary survey with AEC professionals, we propose in this paper to understand these simulation activities, to find how they can be described and how this description can be used in our view adaptation method.

## **2. Understanding site preparation collaborative simulation activities**

### **2.1 Pre-construction phase and site preparation activities**

A facility development life cycle process involves a number of phases and activities that complement each other. According to [11], these phases include “pre-construction, construction, operation and maintenance, and commissioning.” More recently, [12] divided this process into five main phases: feasibility, entitlements, building permit, construction, and property management phases. We consider that pre-construction includes feasibility, entitlements and building permit and starts “when a parcel of land becomes available for consideration” [12]. It “encompasses a broad set of characteristics of a facility, including client requirements, specifications of functional systems, dimensions, given and calculated loads, computed stresses, bill of materials, construction plans, schedules, and cost estimates” [11].

So, one important goal in the pre-construction phase is the site preparation. This involves taking steps to ensure that the construction phase takes place under the best conditions. According to [13], site preparation is based on studies and specific plans (drawings, installation plans, etc.), administrative preparation (site opening notice, demolition permit, registries opening, etc.), material preparation (temporary roads, site board, etc.) and organizational management setup (contractors’ mailing list, site rules, meetings and activities planning, etc.). During this phase it is necessary to anticipate problems, clashes and other defects both linked to the construction process as well as the designed building itself. Then, construction processes simulation is necessary. With the evolution of technology, more and more aspects can be simulated in order to make a reliable construction planning.

[14] identifies 3 groups of planning processes: core processes, facilitating processes and controlling processing. Core processes, that have clear dependencies, concern scope planning and definition, activity definition and sequencing, activity duration estimating, schedule development, resource planning, cost estimating and budgeting, and project plan development. Facilitating processes are quality planning, organizational planning, staff acquisition, communication planning, risk identification and quantification, risk response development, procurement planning and solicitation planning. Controlling processes enable to measure the performance of the executing process and to send feedback to the planning process. They are overall change control, scope change

control, schedule control, cost control, quality control and performance reporting.

## **2.2 Collaborative simulation activities**

AEC projects teams are comprised of a network of interdisciplinary players, with varied roles, responsibilities, goals, and objectives. “They are created to produce complicated project solutions through the sharing of highly specialized knowledge” [15]. “Most actors only take part for a limited time. Therefore, the organization is continuously changing during the process” [16]. During the site preparation, it is essential to early involve these stakeholders in order to take into account their viewpoints, to make relevant the simulation and to design a planning that takes into account the needs of all. This is especially true because “effective collaboration in simulation modeling is possibly one of the key factors in the success of simulation project” [17].

Collaborative simulations during site preparation concern activities sequencing, estimating activities duration, scheduling resources and costs, identifying conflicts and clashes (overlaps), managing reservations and comparing the constructability of construction methods. It also serves as a monitoring tool during the construction phase.

These collaborative activities in a project can mostly be described as processes that show the actors’ activities. An example of process that show collaboration among actor’s in order to build the site planning and to manage reservations is presented in [18]. But if “some of the most important roles in a building project organization are played by the client, designer, contractor, sub-contractor, material supplier, machine supplier, and the user” [19], as said, each construction project sets up a specific collaborative context in which the different roles of actors are not always the same. Then processes are not repeatable and are often specific to the particular situations of each construction project [20]. It could be therefore appropriate to describe them as more common and widespread collaborative practices [10].

Based on literature review and a preliminary survey with some industry professionals, a certain number of pre-construction collaborative practices can be identified, including site scheduling, cost budgeting, clashes and conflict management, safety and risk management, reservation management, procurements planning, communication planning. Moreover quality aspects are also simulated and different kinds of defects are anticipated.

### 2.3 Describing pre-construction collaborative practices

Relying on the literature review and according to our specific needs regarding collaboration situations description, collaborative practices can be described as sets of *sub-practices* (collaborative or individual) with a group of *involved actors*. Sub-practices are characterized by an *information need* and *outputs*. The actors have a business profile (architect, engineer, etc.) and play a *role* in the collaborative context. If the business profile of an actor is fixed as it is linked to his every day's occupation, the role concerns the practices assigned to him in the project's collaborative context and can be different from a project to another.

For instance, "collaborative site scheduling" can be considered as a collaborative practice. So, in a given collaborative context, one can see in table 1 the sub-practices, the responsible actors, their information needs and related outputs. We note that the outputs of a given sub-practice is often the information needed by another sub-practice.

Collaborative practice	Sub-practices	Responsible actors	Information need
Collaborative site scheduling	Building elements listing	Architect	Pre-list of building elements, building representation
	Activities definition	Supervisor	WBS, pre-list of construction activities
	Activities duration estimation	Sub-contractors	Activities description
	Activities sequencing	Contractor	Dates, activities durations, building representation
	Schedule development	Supervisor	Activities planning

**Table 1:** An example of description of collaborative site scheduling practice

### 2.4 Collaborative use of 4D CAD and limits

Collaborative construction simulations are important in pre-construction phase, including for site preparation. Recent advances in the Computer-Support Collaborative Work (CSCW) technologies make it possible to develop a shared virtual workspace to support close teamwork and project integration between construction organizations and professionals physically located at dispersed places [21]. But some specific construction simulation practices require some special tools. 4D CAD appears to be an innovative simulation solution. Many research efforts have been made to advance the 4D CAD technology from simple 4D animation of construction progression to interactive 4D simulation of alternative construction processes ([22]; [23]). Moreover, research works showed that

the collaborative use of 4D CAD is particularly useful during the pre-construction phase ([7]) and efforts have been made to improve the collaborative 4D planning ([24]; [8]; [9]).

An important aspect of the construction industry is the flexibility that characterizes the management of projects [20]. Indeed, each stakeholder of a cooperative project's context has his own interests, his methods and specific practices. In this context generic solutions are difficult to adopt successfully. It is then important to adapt solutions to the needs of actors. One of the key points in adapting CSCW tools is to design visualizations matching the business requirements of actors. Considering previous 4D developments, the usual standard view (i.e. Gantt planning associated with 3D model) currently proposed to different actors in most of 4D CAD tools does not take into account this adaptation. Specific requirements related to practices performed by particular roles (planning of interventions and reservations request for a contractor; simulation and integration of works' interfaces for an engineer, etc...) are not considered.

In the next section, we propose a method for designing user views in 4D collaborative tools. This method takes into account the actors' business needs and enables to compare visualization modes, in order to choose the most appropriate ones and to compose multiple views adapted to the business needs. These views are called "business views".

### **3. Towards a method to design business views**

#### **3.1 The method**

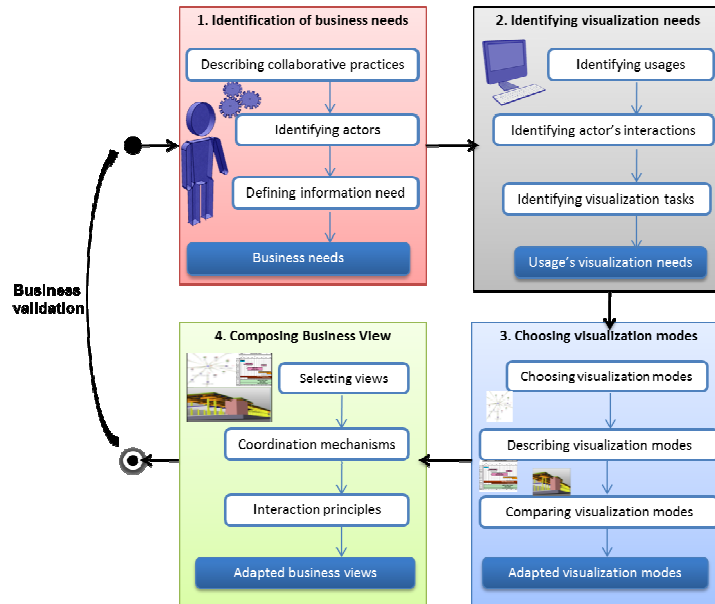
To adapt the visualization to actor's business needs in 4D collaborative tools, we propose a 4-steps method (Fig. 1).

- The first step identifies the business needs of actors. This consists in formalizing the collaborative practices in order to identify the sub-practices performed by the different involved actors. Knowing these sub-practices helps to better define the business needs. Business needs can be described as the set of information and operations that actors will need in order to perform their business activities related to a collaborative practice.
- In the framework of the collaborative practices, actors use groupware to perform their business activities. During these activities, we can identify specific usages that we have to understand and describe. The purpose of the second step is to determine the visualization needs for each actor. Visualization needs are interactions and visualization tasks that a user will need to perform in front of a computer-supported tool. Visualization tasks are "the analytic and exploratory tasks that a user

might need or want to perform on the data” [25]. At this stage we use the taxonomy proposed by [25] to describe such visualization tasks with a single and accurate formalism.

- Once visualization needs are known, it is then possible to compare the possible visualization modes in order to choose the most appropriate ones in relation to the expressed needs. In the third step the visualization modes are described and compared. Visualization modes are the techniques used to represent information. According to [26] they can be described through the structure of the technique, the graphical attributes and the supported interaction principles. The most appropriate visualization mode is the one that matches better to the user’s visualization needs. To this end, we can use the formula presented below to rank visualization modes for a given business need.
- When appropriate modes are selected for each actor, it is possible to select those that may be composed together to form multiple coordinated views. To this end, it is important to study the coordination mechanisms and the interaction principles associated with the visualization modes (fourth step). Note that this step is not well defined for now and will be an important issue in our future works.

At the end, adapted business views composed for each actor, will be validated to ensure that the propositions respond effectively to the expressed business needs.



**Fig. 1:** Method to compose business view



### 3.2 Comparing adapted views (step 3): business views metamodel

Model Driven Engineering (MDE) approach recommends the use of metamodels to define domain languages, so each model has to conform to its metamodel. In order to model visualization modes and to choose the most adapted ones, we propose to adapt and use the business view metamodel described in [26]. This metamodel, based on a literature review in the fields of Human-Computer Interaction and Information Visualization, shows that a model of business view has to describe content, using a technique with some interaction principles (Fig. 2).

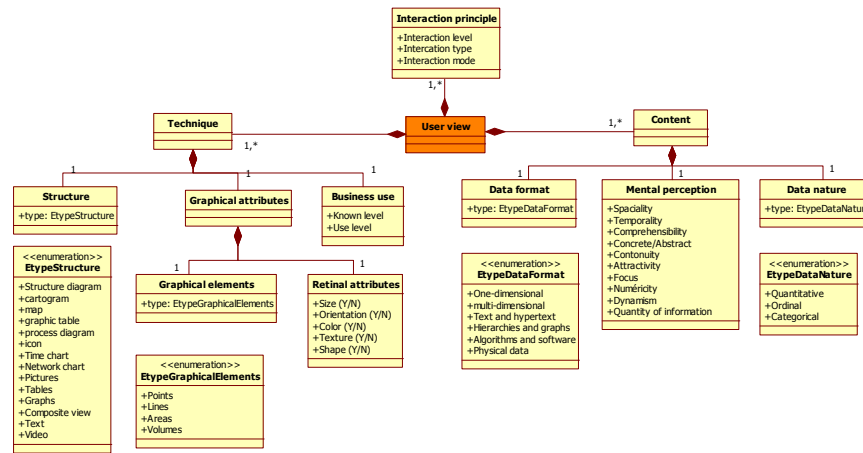


Fig. 2: Business view metamodel

### 3.3 Describing visualization tasks (step 2): visualization tasks metamodel

The taxonomy proposed by [25] leads us to define a user visualization tasks metamodel as shown on Fig. 3. Such a metamodel allows describing abstracted form of user's visualization tasks according to a same formalism. A visualization task could be a simple visualization task or group of visualization tasks. Simple visualization tasks are *Compare* (e.g. dimensions, items, data, values, etc), *Identify* (e.g. clusters, correlations, categories, properties, etc), *Visualize* (e.g. data, domain attributes, n dimensions, etc.), *Determine* (e.g. mean, median, variance, amplitude, differences, statistics, etc.), *Locate* (e.g. items, clusters, distances, graphical primitives, etc.), *Configure* (e.g. normalizations, classifications, zoom, dimensions orders, etc) and *Infer* (e.g. hypothesis, rules, trends, probabilities, cause/effect, etc.).

As an example we describe the business task of an engineer having to verify validity of contractors' reservations with a 4D tool. In terms of visualization, he has to:

- *visualize data* (i.e. visualize the elements of the building representation);
- *locate position* (i.e. locate the positions of the reservations);
- *identify dependencies* (i.e. identify the dependencies among tasks and reservations);
- *compare values* (i.e. compare the values of simulation sequences with the dates list);
- *determine any variance* (i.e. Determine if there is any variance between simulation sequences and dates list);
- *infer trends* (i.e. infer if reservations are valid or no).

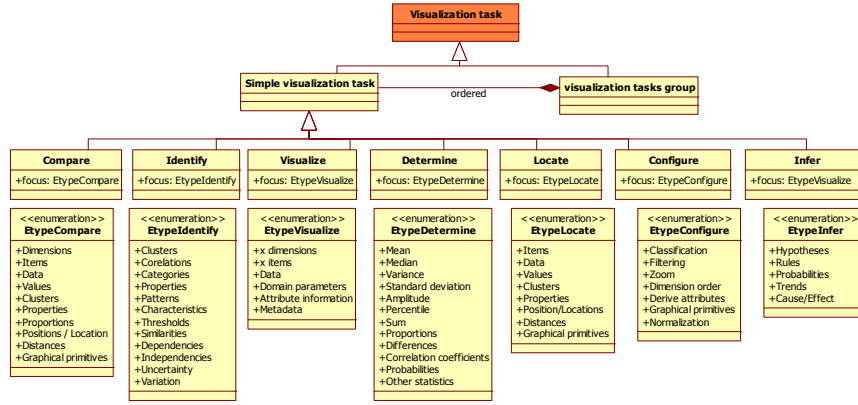


Fig. 3: User's visualization tasks metamodel

### 3.3 Formula for visualization modes ranking

We are working on a scoring system that would rank visualization modes according to usage needs. By assessing the criteria (technique, content, interaction principle, visualization tasks, etc.) an *adaptation score* ( $As$ ) should be assigned to each visualization mode. This score is calculated for each actor and each sub-practice with the formula below. So, the relevance of a criterion is related to the information needs and to the visualization tasks.

$$As = \frac{\sum_{i=1}^n Nc_i}{n} \quad \text{with} \quad Nc_i = \frac{\sum_{j=1}^m P_j}{m}$$

Note that  $A_s$  is the average of the  $Nc_i$  and  $n$  is the number of criteria while  $m$  is the number of proprieties for a criterion  $i$ . The score ( $Nc_i$ ) of a criterion  $i$  is then the average of its properties relevance ( $P_j$ ) scores according to a visualization requirement. The visualization requirement is both an information need and a need for visualization tasks. The properties relevance scores ( $P_j$ ) are -1, 0 or 1 depending on whether the property  $j$  is clearly unsuited, poorly adapted or well suited to the sub-practice. Each  $Nc_i$  may vary between -1 and 1.

#### **4. Case study**

We consider a case study related to site preparation collaborative context and apply our method to a specific collaborative practice: "Collaborative site scheduling". We assume that in specific situation some given actors are responsible for each sub-practice shown on table 2.

##### **4.1 Step 1: Identifying business needs**

The first stage is to describe the specific collaborative practice, identifying sub-practices, responsible actors and information needs. For the example of collaborative site scheduling practice, Table 1 could be the result of this step. So, we know which sub-practices will be performed and the responsible actors. The information needs are also identified. But this is not sufficient enough to choose appropriate visualization modes. We need to add the visualization tasks to be sure to take into account the actor's visualization needs.

##### **4.2 Step 2: Identifying visualization tasks**

After understanding business practice context, we will identify in this section the visualization tasks the actor will have to perform. For this, we will divide the sub-practices into elementary usages that will call for specific visualization tasks. The visualization tasks model will help us in this description (table 2).

After this step, we know exactly which kind of information actors need to visualize and their visualization tasks. For each information need, many visualization modes may be possible. We need to compare them in order to choose the best adapted ones according to actor's visualization tasks.

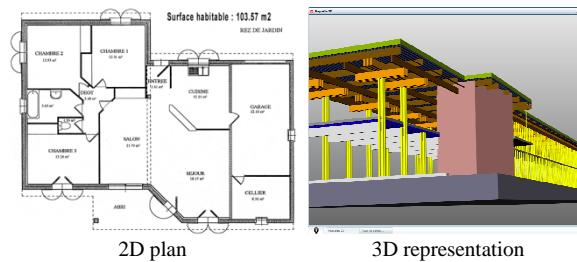
##### **4.3 Step 3: Choosing adapted visualization modes**

In this step, we will use the business view metamodel to describe the possible visualization modes for every expressed visualization need. In instance, for the sub-practice "Activities sequencing", actor need to

visualize the dates, the activities durations and a building representation. The building representation could be a 2D plan or a 3D representation (Fig. 4). In this case, we need to describe these two visualization modes in order to compare them. According to the metamodel, we can have the description of views shown in table 3.

Collaborative practice	Sub-practices	Elementary usages	Visualization tasks
Collaborative site scheduling	Building elements listing	Consult elements pre-list	<i>Visualize (focus: data)</i>
		Find appropriate elements	<i>Locate (focus: items)</i>
		Create elements listing	<i>Configure (focus: classification)</i>
	Activities definition	Consult activities pre-list	<i>Visualize (focus: data)</i>
		Consult building elements	<i>Locate (focus: items)</i>
		Identify appropriate activities	<i>Identify (focus: correlations)</i>
		Create activities listing	<i>Configure (focus: classification)</i>
	Activities duration estimation	Consult activities	<i>Visualize (focus: data)</i>
		Understand activities consistency	<i>Configure (focus: filtering)</i> <i>Determine (focus: means)</i>
		Estimate activities duration	<i>Infer (focus: hypotheses)</i>
	Activities sequencing	Consult activities and durations	<i>Visualize (focus: data)</i>
		Study relationships and dependencies among activities	<i>Identify (focus: correlations)</i> <i>Identify (focus: dependencies)</i>
		Verify conflicts	<i>Infer (focus: trends)</i>
		Associate start/end dates	<i>Configure (focus: classification)</i>
		Define site planning	<i>Configure (focus: normalization)</i>
	Schedule development	Consult activities listing	<i>Visualize (focus: data)</i>
		Consult actors listing	<i>Visualize (focus: data)</i>
		Associate actors and activities	<i>Identify (focus: correlations)</i>
		Include planning	<i>Infer (focus: trends)</i>
		Realize project plan	<i>Configure (focus: classification)</i>

**Table 2:** Actors' visualization tasks for each sub-practice



**Fig. 4:** Some visualization modes

	3D representation	2D plan
Technique structure	3D	2D
Graphical elements	Volumes	Lines, surfaces
Retinal attributes	Size, Shape, Colors, Form	Size, texture, Form
Known level	Very known	Very known
Business use level	Quite used	Very used
Data Nature	Physical Data	Physical data
Data spatiality	Spatial	Spatial
Temporality	No temporal	No temporal
Comprehensibility	Easy	Difficult
Concrete-Abstract	Concrete	Abstract
Attractivity	Attractive	Less attractive
Focus	Emphasizes whole	Emphasizes parts
Numericity	Non numeric	Non numeric
Dynamism	Static	Static
Possible interactions	Interactive zoom, Dynamic projection, Interactive deformation, Link&Brush	Interactive zoom, Interactive filtering, Link&Brush

**Table 3:** Visualization modes description

Criteria	Proprieties	3D rep.	2D plan
Technique	Structure	0	-1
	Graphical elements	1	0
	Retinal attributes	1	0
	Business use	0	1
	<b>Nc<sub>1</sub></b>	<b>0,5</b>	<b>0</b>
Content	Data Format	1	1
	Mental perception	0	-1
	Data nature	0	-1
	<b>Nc<sub>2</sub></b>	<b>0,33</b>	<b>-0,33</b>
Interaction principles	Interaction level	0	-1
	Interaction type	0	-1
	<b>Nc<sub>3</sub></b>	<b>0</b>	<b>-1</b>
Visualization tasks	Visualisation tasks	0	-1
	<b>Nc<sub>4</sub></b>	<b>0</b>	<b>-1</b>
	<b>As</b>	<b>0,21</b>	<b>- 0,58</b>

**Table 4:** Example of visualization modes adaptation score

Table 3 shows a comparison between two visualization modes that could be used to represent building elements. For example, 3D representation is

easy to understand and more attractive than 2D plan. More interactions are possible with 3D representations than with 2D plan. At the contrary, 2D representation is widely known and used compared to 3D.

Using the adaptation score formula enables to establish that it's rather to choose a 3D representation for this specific sub-practice (table 4). Same work for each other sub-practices will lead to know which visualization modes are appropriate. So, for each actor, we can know all modes he needs to achieve his usage. In order to compose multiple views and to coordinate them, we need to make sure that the selected visualization modes are compatible with other ones. That is the subject of the next step.

#### **4.4 Step 4: Composing adapted business multi-visualization**

After selecting visualization modes, we need to compose into multiple coordinated visualizations according to the need of each actor. This will include defining visualizations coordination mechanisms and how to associate and to manage adapted interaction principles. As said, this step is not well defined yet. So we will devote to this work in the future.

### **5. Conclusion and perspectives**

In this paper, we presented the pre-construction phase, site preparation activities and related simulation needs. We focused particularly on collaborative simulation activities and showed how to describe collaborative simulation practices in the framework of a visualization adaptation method. 4D CAD appears to be an innovative simulation tool for construction projects, particularly in pre-construction phase. Its collaborative use is very interesting according to the AEC industry characteristics. But the adaptation of the visualization to actors' business needs in such 4D collaborative tools remains a challenge.

A method and related models were presented to design business views in collaborative 4D tools. A case study showed how to use the method to compose the most adapted views for actors' business requirements.

Future work will strengthen the method, operationalize the ranking formula and deepen the fourth step related to multiple views coordination. We will also develop a tool to support the method and validate both the method and the tool.

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