Taxonomy of the Visualization Techniques of Project-related Interactions

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SUMMARY*: All construction projects can be considered as cooperative undertakings. Their strategic management and daily operations causes numerous interactions to occur, either among persons or among persons and resources. These interactions have been studied from various viewpoints but few researchers have focused on their visualization. The graphical representation of the cooperation is however a powerful tool to help the project participants to get a correct understanding of the situation. This paper proposes a structuring framework (IVF - Interaction Visualization Framework) of the visualization techniques used to display such interactions. Three basic axes of classification are used to organize the study. Which objects are visualized? In which context of use are they visualized? How are they visualized? For each axis, several properties have been identified and the permitted values have been specified. The paper then explains three major applications of the IVF: the characterization, the comparison and the design of visualization techniques. This work can be considered as a first step towards a structured view of the 'visualization of cooperation' domain.*

KEYWORDS*: Cooperation, project management, information visualization, taxonomy.*

1. INTRODUCTION

Any construction project can be considered as a cooperative undertaking, with groups of people working towards the project goal. The three basic functions of cooperative situations are: communication, co-production and sharing, and coordination (Lonchamps, 2003), all of which are present during a construction project. In order to produce the promised deliverables, numerous interactions occur throughout the project life cycle, either among persons or among persons and material or immaterial objects. In this dynamic context, several communication channels are used according to various factors such as the nature of the transferred information, user preferences and available communication tools. In fact, these interactions can really be considered as the visible face of the cooperation, and it is therefore not surprising that many researchers have studied them in a range of contexts.

In the Architecture, Engineering and Construction (AEC) industry, the interactions among the participants of a project have been studied from various viewpoints such as: supplier management (Clark et al. 1999), trust (Mohamed 2003), distribution of communication media (Howard & Petersen 2001), modes of information dissemination (Otjacques et al. 2003), influence of communication media on design performance (Kvan & Gao 2004), as well as distributed cognition (Perry 1997) or information flow turbulence (Fyall 2002).

Nevertheless, notably few researchers have focused their work on the specific challenges associated with the visualization of these interactions, or in other words, on the visualization of cooperation. This viewpoint is, however, really worth investigation. Indeed, human beings have known for centuries the power of using graphical representations to solve a problem. This view is best summarised by the following famous citation '*A* *picture is worth a thousand words*'. This paper proposes a global framework that aims to characterize the visualization techniques used to represent some interactions such as those arising during a construction project.

2. MOTIVATION OF THE RESEARCH

The intended result of this work is to propose a framework that could be used as a basic tool by researchers studying or designing some visualizations of interactions. Indeed, to the best of our knowledge no taxonomies of visualizations of cooperation currently exist. However, such a framework would be of substantial interest to researchers in the field as the following discussion illustrates. Herbert Simon stated that '*the first step to understanding any set of phenomena is to develop a taxonomy*' (1969). In the information visualization domain, several researchers have also drawn attention to the reasons why taxonomies, classifications or frameworks (these terms are sometimes used with quite similar meanings) are required. According to Lohse and his colleagues (1994), '*Classification lies at the heart of every scientific field. Classifications structure domains of systematic inquiry and provide concepts for developing theories to identify anomalies and to predict future research needs.*' Wehrend and Lewis (1990) explain that, with a common conceptual framework, '*workers in any area can place their techniques, so that abstract similarities among problems in different application areas can be identified, and new techniques can be readily transported across application lines*'. Gruia-Catalin and Cox (1992) mention that a taxonomy is a '*vehicle through which we carry out a systematic review of current systems, techniques, trends, and ideas …*'.

In any scientific domain, taxonomies are necessary for several reasons, among which the most important are:

- Allowing a systematic and rigorous review of current techniques and ideas.
- Positioning specific works in the whole research field.
- Clarifying the concepts of the field, which is a required step before elaborating a new theory.
- Identifying similarities and differences among the research findings.
- Pointing out new research directions.
- Highlighting flaws in research proposals.

While not exhaustive the above list provides an indication of the most significant elements and acts as a starting point upon which to develop a new taxonomy.

3. VISUALIZATION IN AEC RESEARCH

Card, Mackinlay and Shneiderman (1999), who are among the most renowned authors in this field, define '*visualization*' as '*the use of computer-supported, interactive, visual representations of data to amplify cognition*'. They also propose a list of working definitions that aim to clarify the relationships among the concepts related to information visualization. Among the most important aspects is the difference between scientific and information visualisation. '*Scientific visualization*' concerns '*the use of interactive visual representations of scientific data, typically physically based, to amplify cognition*'. '*Information visualization*' deals with '*the use of interactive visual representations of abstract, non physically based data to amplify cognition*'.

The generic definitions discussed above can be instantiated in the specific case of the AEC research field. According to the above-mentioned definitions, the visualization of physical artifacts(e.g. steel structure, heat transfer properties of a building, building site spatial organization) belongs to the *scientific visualization* discipline. This domain encompasses most of the research works on visualization in AEC. For instance, numerous papers can be found on Computer Aided Design, Virtual Reality, Building Rendering or Lighting Simulation (cf. for instance, ITCon 2003; eCAADe 2004).

The *information visualization* domain has a completely different purpose, and explores how to graphically represent abstract objects, such as meetings, document storage systems, e-mails or access to shared documents. Information visualisation has been less studied in the AEC research field, and is frequently tackled as a by-product of the study of information exchanges. For instance, project web sites (PWS) obviously include some *information visualization* (*InfoVis*) techniques however, in almost all the cases, PWS has been studied in terms of real usage, efficiency, or cost (e.g. Andresen et al. 2003) rather than in terms of *InfoVis* techniques. Similarly, workflow systems provide some graphic means to represent the steps of the construction process (e.g. Autodesk, 2006; Briscnet, 2006) but most of the research in this domain addresses the workflow engine instead of the visualization techniques. Project planning has also been intensively explored with various techniques, such as Petri nets (Rueppel et al. 2004), knowledge based systems (Castro & Dawood 2004), and *scientific visualization* techniques (e.g. adding temporal properties to a 3-D representation to show the state of the building site at a given moment of time). Few researchers however have focused on the best way to graphically represent abstract information such as the interactions between the actors or between the actors and the project resources. Furthermore, the use of traditional representations, such as Gant charts, is often taken for granted and is rarely questioned, also their appropriateness when used as an *InfoVis* technique for a particular domain is rarely discussed. This paper intends to explore these and other related issues.

The research work described in this paper relates to the *information visualization* field. It aims to study the visualizations techniques used to display the interactions occurring during a project. First of all, we have to propose a model of what a project is. We have modelled a project as a set of entities and a set of interactions among those entities. The set of entities is composed of the project participants and the resources of the project (e.g project web site and project documents etc.,). An interaction is any transfer of information among some entities. Typical examples of interactions are: a phone call between an architect and a contractor, an e-mail exchanged between a project manager and the project members, a face-to-face meeting between the project manager and the client, the upload of a document on a project-specific web site or the acceptance of a meeting summary. As this paper deals, to some extent, with the design of human-computer interfaces, it is important to mention that the concept of '*interaction*' defined in this paper is completely different from the definition of '*interaction*' usually encountered in the 'Human-Computer Interaction' discipline. Indeed, in our definition, it basically refers to the interactions between the members of a group and not to the interaction between a user and a computer.

4. IVF FRAMEWORK

4.1 General approach and formalism

A global framework, called IVF (*Interaction Visualization Framework*), has been designed to underpin the design and the analysis of the visualization techniques, that aim to display some interactions (called *InterVis* techniques in this paper). The IVF framework is not specific to the AEC industry but it is generic by nature and can be applied in any sector.

First of all, we must clearly define the concept of a visualization technique. From the IVF viewpoint, a visualization technique is a means to represent conceptual objects with graphical objects. Moreover, IVF handles atomic visualization techniques, i.e. techniques that can be conceptually considered as a homogeneous and cannot be broken down into independent parts. For instance, a software application that visualizes a data set either as a 'nodes-links' graph or as an adjacency matrix must be studied with IVF as the union of two distinct visualization techniques. The graph and the matrix have to be characterized independently.

The IVF framework has been designed according to the following methodology and it was decided to study the visualization techniques from three viewpoints:

- The nature of the objects to be visualized (What?)
- The context in which the objects are visualized (Where?)
- The means used to visualize the objects (How?)

Numerous papers have been collected about information visualization in general, about taxonomies of information visualization techniques, and about visualization of interactions (e.g. Bertin 1998; Card & Mackinlay 1997; Card, Mackinlay and Shneiderman 1999; Chi 2000; Grinstein et al. 2001; Grinstein & Ward 2002; Lohse et al. 1990; Lohse et al. 1994; Pfitzner et al., 2003; Roth & Mattis 1990; Shneiderman 1996; Tufte 2001; Tweedie 1997; Ware 2004; Wehrend & Lewis 1990). On the basis of this material, a set of properties was identified in each of the three above-mentioned aspects, and the values allowed for each property were specified. Many properties (e.g. ***Entity Retinal Variables***, ***Entity Covering Level***) derive from previous taxonomies in the information visualization domain (Bertin 1998; Card & Mackinlay 1997; Roth & Mattis 1990; Tweedie 1997). Other properties come from previous research in the field of Computer-Suported Cooperative Work (e.g. Johansen, 1988 for ***Interaction Mode***). These properties were however adapted to the study of *InterVis* techniques. Finally, some properties (e.g. ***Display Space Boundaries***, ***Integration***) do not belong to a previous taxonomy. They result from the analysis of current visualization techniques and from conceptual reflections on the properties of interactions. In fact, the focus on *InterVis* techniques is probably the most original aspect of IVF, which is justified by the lack of previous taxonomy in this specific domain.

The design of the IVF framework was underpinned by the motivation to build a conceptual tool that could survive without modification when some new *InterVis* techniques appear in the research community. Therefore, the framework does not propose a list of different types of visualisation techniques (e.g. nodes-links diagrams, adjacency matrices or Pert charts, etc.). Rather it aims to identify the basic dimensions of the design space of *InterVis* techniques. From this point of view, a new technique is considered as a proposal covering an unexploited subspace of the design space.

In order to facilitate and to allow an unambiguous understanding of IVF, a simple formalism has been adopted to describe the properties and the values that they can take. The properties are written in bold italic font (e.g. ***Property A***) and the values of the properties in italic font (e.g. $value_1$).

Some IVF properties can take a single value at a time (uni-valued) while others can take simultaneously several values (multi-valued).

The uni-valued properties will be referenced as follows:

$$\textbf{\textit{Property A}} :\{value_1 – value_2 – value_3\}$$

This expression means that for a given *InterVis* technique, the ***Property A*** can take one single value: $value_1$ or $value_2$ or $value\ _3$.

The multi-valued properties will be referenced as follows:

$$\textbf{\textit{Property A}} :\{value_1, value_2, value_3\}$$

This expression means that for a given *InterVis* technique, the ***Property A*** can take any combination of the values: $value_1$, $value_2$, $value\ _3$.

Some expression may be built on the basis of this formalism. For instance, if the ***Property A*** can take either the $value_1$ or any combination of the values of the following set $\{value_2, value_3\}$ then this will be expressed as follows:

$$\textbf{\textit{Property A}} :\{value_1 – \{value_2, value_3\}\}$$

4.2 Objects to be visualized: what?

First we have to discuss the objects to be visualized. In accordance with our previous definition, two kinds of objects are concerned: the interacting entities (persons and / or resources) and the interactions themselves. Therefore the associated properties are grouped in two distinct sets: the entities in the interaction and those describing the interactions.

4.2.1 Entities in interaction

Two kinds of entities are distinguished: ‘*persons*’ and ‘*resources*’. In this approach, the persons are not considered as resources, resources being limited to inanimate objects (e.g. document, project web site, shared calendar etc.). Two values are allowed for the ‘***Interacting Entities***’ property, namely ‘*only persons*’ and ‘*persons and resources*’, according to which kinds of entities are visualized. The IVF framework is basically designed for studying the cooperation among persons. Therefore, the *InterVis* techniques representing only interactions between resources (e.g. internal message from server A to server B) have not been included.

The ‘***Entity Visualized Objects***’ property specifies whether the visualization technique displays entities and/or attributes of these entities. It may take two values: ‘*entities*’ or ‘*entity attributes*’. For instance, in this context a project participant is considered as an entity while the role of this participant in the project (e.g. architect) is an entity attribute.

The ‘***Entity Time Position***’ property specifies whether the visualization technique shows the time positioning of some events associated with the entities. Three values are admitted: ‘*no time positioning*’ means that the *InterVis* technique does not represent it in any way; ‘*relative time positioning*’ means that the sequence of occurrence of the events is represented; ‘*absolute time positioning*’ means that the events are displayed in such a way that the absolute time of their occurrence (e.g. date, time) is explicit. For instance, the participants in an online chat are displayed on the vertical axis (without time scale) according to the order in which they login and the '*relative time positioning*' value is set. This property can simultaneously take several values, if those values concern different kinds of events that are visualized in different ways.

The next property, called '***Entity Covering Level***', expresses the level of covering of the data space. It can take three values: '*one entity*' (i.e. visualization of one specific object), '*some entities*' (i.e. a specific subset of all objects) and '*all entities*' (i.e. all objects). The example of project participants can still be used to illustrate this property. If one specific participant is displayed, the property takes the value '*one entity*'. If the visualization concerns the subgroup of all participants employed by a given company, the property takes the value '*some entities*'. Finally, if all participants of the project are showed, the property is set to '*all entities*'.

The '***Entity Granularity***' property refers to the level of data aggregation allowed by the visualization technique. If only individual entities can be displayed, the property value is set to '*individual entities*' but if groups of entities can be visualized the property is set to the '*aggregated entities*' value. For instance, if the visualization technique only allows displaying documents as separate graphical objects, the '***Entity Granularity***' property gets the '*individual entities*' value. If it allows showing a group of documents as a single graphical object, the property is set to '*aggregated entities*'.

TABLE 1: IVF properties describing the entities in interaction

IVF properties describing the entities in interaction	
Interacting Entities	{*only persons – persons and resources*}
Entity Visualized Objects	{*entities, entity attributes*}
Entity Time Position	{*no time positioning, relative time positioning, absolute time positioning*}
Entity Covering Level	{*one entity, some entities, all entities*}
Entity Granularity	{*individual entities, aggregated entities*}

4.2.2 Interactions among entities

The '***Interaction Visualized Objects***' property specifies whether the visualization technique displays interactions and/or attributes of these interactions. It may take two values: '*interactions*' or '*interaction attributes*'. For instance, if the visualization technique shows only the presence of e-mails without any other information, the '*interactions*' value is adequate, however if the priority of the e-mails is visualized, the '*interaction attributes*' value must also be set.

The '***Interaction Time Position***' property specifies whether the visualization technique indicates the time positioning of events associated to the interactions. Three values are permitted: '*no time positioning*' means that the *InterVis* technique does not represent it in any way; '*relative time positioning*' means that the sequence of occurrence of the events is represented; '*absolute time positioning*' means that the events are displayed in such a way that the absolute time of their occurrence (e.g. date, time) is explicit. For instance, if the meetings occurring among the members of a working group are displayed in a calendar the '*absolute time positioning*' value is set. This property can simultaneously contain several values if those values concern different kinds of events that are visualized in different ways.

The next property expresses the level of covering of the data space. The '***Interaction Covering Level***' property can take three values: '*one interaction*' (i.e. visualization of one specific interaction), '*some interactions*' (i.e. a specific subset of all interactions) and, '*all interactions*'. The example of e-mail exchanges can also be used to illustrate this property. If the technique displays a specific e-mail, the property takes the value '*one interaction*'. If the visualization concerns all the e-mails sent by a specific participant, the property takes the value '*some interactions*'. Finally, if all e-mails exchanged during the project can be displayed, the property is set to '*all interactions*'.

The '***Interaction Granularity***' property refers to the level of data aggregation allowed by the visualization technique. If only individual interactions can be displayed, the property value is set to '*individual interactions*' but if some sets of interactions can be visualized, the property gets the '*aggregated interactions*' value. For instance, if the visualization technique visualizes each individual e-mail as a single graphical object, it gets the ‘*individual interactions*’ value. If it allows representing all the e-mails exchanged between two project participants with a unique graphical object, the property is set to ‘*aggregated interactions*’.

The ‘***Interaction Mode***’ property refers to the tool(s) supporting the interactions. The communication media can be synchronous or asynchronous and the property will be set accordingly to ‘*synchronous*’ and/or ‘*asynchronous*’. For instance, e-mail is an asynchronous media while videoconferencing is synchronous.

The ‘***Interaction Arity***’ property is defined by the number of entities that take part in the interaction. Two values are allowed for the interaction arity: ‘*binary*’ (i.e. interaction between two entities) and ‘*multiple*’ (i.e. interaction between more than two entities).

The ‘***Interaction Centricity***’ property specifies whether the interactions that are visualized are relative to a given central entity (‘*egocentric’*) or concerns all interacting entities without favouring a specific one (‘*sociocentric*’). For instance, an e-mail client is typically ‘*egocentric*’ as it shows all interactions between the connected user and the other persons.

The ‘***Interaction Temporality***’ property is used to specify if the visualized interactions occurred in the past, are still ongoing or are planned in the future. The property can take three values: ‘*past interactions*’, ‘*ongoing interactions*’, and ‘*future interactions*’. It must be noted in this context that the ‘*ongoing interactions*’ value will be set when the *InterVis* technique shows ongoing interactions and/or interactions that occurred in a recent past. An example would be a technique which progressively fades out visualizations of interactions which have passed and removes those which are more than one hour old.

TABLE 2: IVF properties describing the interactions among the entities

IVF properties describing the interactions among the entities	
Interaction Visualized Objects	{*interactions, interaction attributes*}
Interaction Time Position	{*no time positioning, relative time positioning, absolute time positioning*}
Interaction Covering Level	{*one interaction, some interactions, all interactions*}
Interaction Granularity	{*individual interactions, aggregated interactions*}
Interaction Mode	{*synchronous, asynchronous*}
Interaction Arity	{*binary, multiple*}
Interaction Centricity	{*egocentric – sociocentric*}
Interaction Temporality	{*past interactions, ongoing interactions, future interactions*}

4.3 Context of use: where?

The context of use of the visualization is the second aspect upon which the *InterVis* techniques are based. Three properties are associated with this viewpoint.

The ‘***Visualization User Role***’ property specify whether the technique is dedicated to be used by an actor which takes part in some of the interactions (‘*participating actor*’) or by someone who is external to the interactions (‘*external observer*’).

The ‘***Visualization Purpose***’ property indicates the essential purpose of the visualization. Two basic goals are identified: ‘*interaction support*’ and ‘*interaction analysis*’. The first value concerns the case where the basic purpose of the visualization is to support the users when they interact with other entities and the second value applies when the visualization is used to analyze the interactions between some entities. For instance, the ‘*interaction support*’ should be set for the visualization of some e-mail threads within an e-mail client while ‘*interaction analysis*’ is appropriate for a sociogram used by a social network analyst.

The ‘***Integration***’ property explains whether the visualization technique is integrated with the interaction tool (‘*integrated*’) or not (‘*independent*’). For instance, an e-mail visualization module can be integrated within an e-mail client (‘*integrated*’) or it can be used to display an e-mail log file issued from an external application (‘*independent*’).

TABLE 3: IVF properties describing the context of use of the InterVis technique

IVF properties describing the context of use of the *InterVis* technique	
Visualization User Role	{*participating actor, external observer*}
Visualization Purpose	{*interaction support, interaction analysis*}
Visualization Integration	{*integrated – independent*}

4.4 Visualization Technique: how?

The third classification axis concerns the visualization techniques themselves. Intentionally, no property is defined to specify what might be called the 'visualization type' (e.g. *pie chart*, *tree* or *parallel coordinates*). In fact, such a property would not be consistent with the framework philosophy that aims to characterize the *InterVis* techniques in a way as generic and lasting as possible.

The properties are grouped in three sets: those that refer to the description of the *InterVis* technique in general; those that relate to the visualization of the entities; and those relating to the visualization of the interactions.

4.4.1 Description of the *InterVis* technique in general

The '***Display Space Dimensions***' property is used to indicate how many spatial dimensions are used to represent the data graphically. Three values are allowed: '*1-Dimension*', '*2-Dimensions*' and '*3-Dimensions*'. This property is defined as the number of coordinates necessary to position any data in the visualization display space. It may be useful to point out that it does not refer to the number of dimensions of the data. In Bertin's terminology (1998) this property refers to 'planar variables'. It is not concerned with retinal variables such as colour or size. For instance, a timeline has '*1-Dimension*', a planar tree has '*2-Dimensions*' and a virtual reality representation has '*3-Dimensions*'. It may be useful to note that in IVF, a so-called 4-D representation that shows the evolution with time of a 3-D scene is considered as a '3-D' visualization. Other IVF properties are specifically added to handle the time-related aspects of such a representation.

The '***Display Space Boundaries***' property is used to specify whether the graphical representation uses a fixed ('*fixed*') or variable ('*variable*') display space, depending on the size of the data set. It should be noted that increasing the display space resolution in order to be able to show more data is equivalent to increasing the size of the display space. In such a case, the '*variable*' value should be set. For instance, this property is set to '*fixed*' for a treemap (Johnson & Shneiderman, 1991) and to '*variable*' for a classic node-link graph.

The '***Geometrical Distortion***' property specifies whether the visualization technique shows distorted views of the data ('*distorted*' vs. '*not distorted*'). In a distorted view, the values of the data are not all equally mapped with their geometrical representation within the display space. The fisheye view (Furnas, 1986) is a famous example of distortion technique.

4.4.2 Visualization of the entities

The '***Entity Graphical Mapping***' property indicates which kind of graphical object is used to represent the entities in interaction. The possible values are '*point object*', '*linear object*', '*surface object*' and '*volume object*'. For instance, in a 'node-links' graph, this property takes the value '*point object*' because the entities are displayed as point-like nodes. If the project documents are visualized as 3-D spheres in a virtual world, the '*volume object*' value is set. Note that all types of entities do not need to be represented by the same kind of graphical objects.

The '***Entity Display Position***' specifies if the spatial position of the graphical objects representing the entities is meaningful ('*meaningful position*') or not ('*meaningless position*'). For instance, if the project participants are represented by icons that are grouped on the display space according to their affiliation (e.g. company, organization, etc.), the '*meaningful position*' value is set because the spatial position of the icons conveys some semantics.

The '***Entity Retinal Variables***' property specifies which retinal variables ('*colour*', '*grey level*', '*shape*', '*orientation*', '*size*', '*grain*' and '*texture*') are used to represent the entities or their properties in the visualization technique. For instance, in a 'nodes-links' graph, the role of the participants in the project can be represented by the ‘*shape*’ of the nodes (e.g. circle for the architecture team members, square for the structural engineers…). If the *InterVis* technique does not use any retinal variable, the ‘*not used*’ value is set.

The ‘***Entity Abstraction Level***’ property indicates whether the graphical elements used in the representation of the entities are purely abstract shapes (‘*abstract*’), are based on metaphors (‘*metaphorical*’) or mimic reality (‘*pseudo-real*’). For instance, if the project participants are represented by a photograph, the ‘*pseudo-real*’ value is set, where as if they are associated to single points, the ‘*abstract*’ value is appropriate.

The ‘***Entity Animation***’ property indicates whether some movement or animation is included in the graphical representation of the entities. Two values are allowed: ‘*animated*’ or ‘*static*’. For instance, if the graphical objects visualizing the project participants appear in the display space when they connect to a shared workspace and disappear when they leave it, then the ‘*animated*’ value must be set.

The ‘***Entity Interactivity***’ property refers to the presence or absence of means for the user to interact with the graphical representation of the entities. In this context, a visualization technique is called interactive if the user can dynamically select the entities to be displayed (‘*select entities*’), the displayed properties of these entities (‘*select entity properties to display*’), or a parameter of the graphical output used to display them (‘*select entity graphical rendering*’). In the other cases, the technique is said to be not interactive (‘*no interactivity*’).

4.4.3 Visualization of the interactions

The ‘***Interaction Graphical Mapping***’ property indicates which kind of graphical object is used to represent the interactions among the entities. The possible values are ‘*point object*’, ‘*linear object*’, ‘*surface object*’ and ‘*volume object*’. For instance, in ‘node-links’ graphs, this property takes the value ‘*linear object*’ because entities are displayed as links.

The ‘***Interaction Display Position***’ specifies if the spatial position of the graphical objects representing the interactions is meaningful (‘*meaningful position*’) or not (‘*meaningless position*’). For instance, if the e-mails concerning a specific topic are represented by icons that are grouped in a specific part of the display space, the ‘*meaningful position*’ value is set because the spatial position of the icons conveys some semantics.

The ‘***Interaction Retinal Variables***’ property specifies which retinal variables (‘*colour*’, ‘*grey level*’, ‘*shape*’, ‘*orientation*’, ‘*size*’, ‘*grain*’, and ‘*texture*’) are used to represent the interactions or their properties in the visualization technique. For instance, in a ‘nodes-links’ graph, the frequency of the interactions can be represented by colouring the links (‘*colour*’) or increasing the link width (‘*size*’). If the *InterVis* technique does not use any retinal variable, the ‘*not used*’ value is set.

The ‘***Interaction Abstraction Level***’ property indicates whether the graphical elements representing the interactions are purely abstract shapes (‘*abstract*’), are based on metaphors (‘*metaphorical*’) or mimic reality (‘*pseudo-real*’). To illustrate these values, representing e-mails by arcs takes the ‘*abstract*’ value; using expressive faces to display e-mail priority takes the ‘*metaphorical*’ value.

The ‘***Interaction Animation***’ property indicates whether some movement or animation is included in the graphical representation of the interactions. Two values are allowed: ‘*animated*’ or ‘*static*’. For instance, if the interactions are represented by links that appear and fade out in time to render the dynamics of the real operations, then the ‘*animated*’ value is appropriate.

The ‘***Interaction Interactivity***’ property refers to the presence or absence of means for the user to interact with the graphical representation of the interactions. In this context, a visualization technique will be called interactive if the user can dynamically select the interactions to be displayed (‘*select interactions*’), the displayed properties of these interactions (‘*select interaction properties to display*’), or a parameter of the graphical output used to display them (‘*select interaction graphical rendering*’). In the other cases, the technique is said to be not interactive (‘*no interactivity*’).

TABLE 4: IVF properties describing the InterVis technique

IVF properties describing the *InterVis* technique	
Display Space Dimensions	{*1-Dimension – 2-Dimensions – 3-Dimensions*}
Display Space Boundaries	{*fixed – variable*}
Geometrical Distortion	{*distorted – not distorted*}
Entity Graphical Mapping	{*point object, linear object, surface object, volume object*}
Entity Display Position	{*meaningful position – meaningless position*}
Entity Retinal Variables	{*not used – {colour, grey level, shape, orientation, size, grain, texture}*}
Entity Abstraction Level	{*abstract – metaphorical – pseudo-real*}
Entity Animation	{*static – animated*}
Entity Interactivity	{*no interactivity – { select entities, select entity properties to display, select entity graphical rendering}*}
Interaction Graphical Mapping	{*point object – linear object – surface object – volume object*}
Interaction Display Position	{*meaningful position – meaningless position*}
Interaction Retinal Variables	{*not used – {colour, grey level, shape, orientation, size, grain, texture}*}
Interaction Abstraction Level	{*abstract – metaphorical – pseudo-real*}
Interaction Animation	{*static – animated*}
Interaction Interactivity	{*no interactivity – { select entities, select entity properties to display, select entity graphical rendering}*}

5. APPLICATIONS OF THE IVF FRAMEWORK

The interactions within a construction project team are highly dynamic, complex and in some cases unpredictable. In fact, they are intimately linked of the very nature of each project and research is required to better understand this important phenomenon. The graphical representation of these interactions offers substantial potential in this context but most of the time the researchers lack a clear overview of the range of possibilities provided by the *InterVis* techniques. The IVF framework aims to fill this gap by structuring this multi-dimensional space. A previous section (see section 2.) explains why taxonomies are required in any scientific field. While we think that all the reasons mentioned there are relevant to justify the IVF approach, we limit the discussion here to three of the most important applications: the positioning of a given *InterVis* technique in the whole research field (characterization issue), the identification of similarities and differences among research findings (comparison issue) and the generation of new ideas (design issue).

Firstly the use of the IVF makes it possible to characterize a given *InterVis* technique with a structured methodology. Without such a framework, the researcher might neglect some important components of the visualization technique. For instance, novices in Information Visualization often focus on how the objects are represented (cf. *How?* Properties) and forget some fundamental properties of the objects to be visualized (cf. *What?* properties).

Secondly, the IVF provides a checklist that allows easy comparison of visualization techniques this offers several advantages for the researcher. First, as it results from a global review of information visualization techniques, it is probably more complete than an ad-hoc checklist built by a researcher studying some specific *InterVis* instances. The second advantage of IVF relates to the comparability of results among researchers. Using the same reference framework greatly facilitates the discussion of research works and IVF might become this standard framework.

IVF also offers the potential to support the design of new *InterVis* techniques. Indeed, it basically identifies the dimensions of the design space (i.e. IVF properties) and the possible values for each of them. Going through the IVF specification can stimulate researcher creativity by highlighting some design subspaces that they may not have explored otherwise.

The next three sections illustrate the applications of the IVF when applied to 'nodes-links' graphs in the context of construction projects.

5.1 Characterization of an *InterVis* technique

Sociograms, imagined by Moreno in the early 1930's (Freeman, 2000) are considered as the most ancient example of visualization of social interactions. They are graph-like drawings in which the individuals are represented by points and the relations between them by lines. They became the most popular technique to display 'interaction' data and, for this reason, will be taken as example to illustrate the use of the IVF framework.

Fig. 1 is an example of a very simple sociogram that might be drawn by a researcher to study the e-mail interactions between the members of a project team. It will be considered as our reference basic 'nodes-links' diagram.

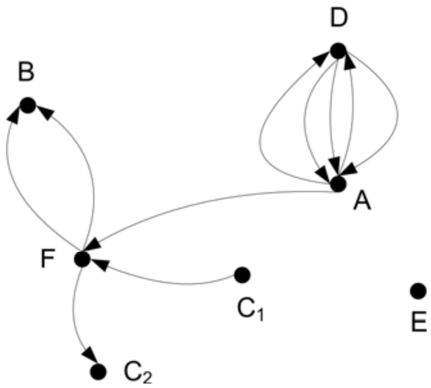

FIG. 1: Reference' nodes-links' diagram.

The IVF framework can be used to characterize this simple *InterVis* technique.

This diagram shows only persons and the interactions among them (⇒ ***Interacting Entities*** = *only persons*). The entities are displayed but none of their properties (⇒ ***Entity Visualized Objects*** = *entities*). There is no reference in the diagram to the time position of events associated to the entities (⇒ ***Entity Time Position*** = *no time positioning*). All interacting entities are visualized (⇒ ***Entity Covering Level*** = *all entities*) and they are represented individually (⇒ ***Entity Granularity*** = *individual entities*).

The diagram shows the entities but none of their properties (⇒ ***Interaction Visualized Objects*** = *interactions*). The events related to the interactions are not represented nor time positioned (⇒ ***Interaction Time Position*** = *no time positioning*). All interactions are displayed (⇒ ***Interaction Covering Level*** = *all interactions*). They are represented on a individual basis (⇒ ***Interaction Granularity*** = *individual interactions*). The interactions that are concerned are e-mail exchanges (⇒ ***Interaction Mode*** = *asynchronous*) that can involve several receivers (⇒ ***Interaction Arity*** = *multiple*). The view of the dataset does not favour a given participant (⇒ ***Interaction Centricity*** = *sociocentric*). Finally, the diagram shows past interactions (⇒ ***Interaction Temporality*** = *past interactions*).

The sociogram under study is intended to be used by a researcher that does not take part in the visualized interactions (⇒ ***Visualization User Role*** = *external observer*). His main purpose is the study and the analysis of the interactions (⇒ ***Visualization Purpose*** = *interaction analysis*). Moreover, the *InterVis* technique is based on the log file of an e-mail application (⇒ ***Visualization Integration*** = *independent*).

The display space is obviously bi-dimensional (⇒ ***Display Space Dimensions*** = *2-Dimensions*) and its size should grow if the number of persons/interactions increases (⇒ ***Display Space Boundaries*** = *variable*). The diagram does not use any distortion technique (⇒ ***Geometrical Distortion*** = *not distorted*).

The entities are represented by points (⇒ ***Entity Graphical Mapping*** = *point object*), which are randomly placed (⇒ ***Entity Display Position*** = *meaningless position*). This sociogram does not use any retinal variable to convey information (⇒ ***Entity Retinal Variable*** = *not used*). The graphical objects that visualize the entities are purely abstract (⇒ ***Entity Abstraction Level*** = *abstract*) and are not animated (⇒ ***Entity Animation*** = *static*). The user of the diagram cannot modify the selection or the rendering of the entities that are displayed (⇒ ***Entity Interactivity*** = *no interactivity*).

The interactions are represented by lines (⇒ ***Interaction Graphical Mapping*** = *linear object*). The position of the lines within the display space does not convey any semantics (⇒ ***Interaction Display Position*** = *meaningless*). The diagram does not express any property of the interactions with retinal variables (⇒ ***Interaction Retinal Variables*** = *not used*). The lines representing the interactions are abstract (⇒ ***Interaction Abstraction Level*** = *abstract*) and static (⇒ ***Interaction Animation*** = *static*) objects. There is no possibility for the user to select neither the interactions displayed nor the way that they are rendered (⇒ ***Interaction Interactivity*** = *no interactivity*).

Table 5 summarizes the values of the IVF properties for this sociogram.

TABLE 5: IVF properties of the reference 'nodes-links' diagram

IVF properties of the reference 'nodes-links' diagram	
What? properties	
Interacting Entities	*only persons*
Entity Visualized Objects	*entities*
Entity Time Position	*no time positioning*
Entity Covering Level	*all entities*
Entity Granularity	*individual entities*
Interaction Visualized Objects	*interactions*
Interaction Time Position	*no time positioning*
Interaction Covering Level	*all interactions*
Interaction Granularity	*individual interactions*
Interaction Mode	*asynchronous*
Interaction Arity	*multiple*
Interaction Centricity	*sociocentric*
Interaction Temporality	*past interactions*
Where? properties	
Visualization User Role	*external observer*
Visualization Purpose	*interaction analysis*
Visualization Integration	*independent*
How? properties	
Display Space Dimensions	*2-Dimensions*
Display Space Boundaries	*variable*
Geometrical Distortion	*not distorted*
Entity Graphical Mapping	*point object*
Entity Display Position	*meaningless position*
Entity Retinal Variables	*not used*
Entity Abstraction Level	*abstract*
Entity Animation	*static*
Entity Interactivity	*no interactivity*
Interaction Graphical Mapping	*linear object*
Interaction Display Position	*meaningless position*
Interaction Retinal Variables	*not used*
Interaction Abstraction Level	*abstract*
Interaction Animation	*static*
Interaction Interactivity	*no interactivity*

5.2 Comparison of *InterVis* techniques

The ‘nodes-links’ diagrams have been adapted in many ways by researchers of IT in the AEC domain to represent some kinds of interactions related to a construction project. From an information visualization viewpoint, one may question in which way they differ and to which extend they are similar. The IVF framework can be valuable in this context. Indeed, once the *InterVis* technique to be compared have been characterized (cf. previous section), it becomes very easy to compare the associated values for each dimension of the design space (i.e. the value of the IVF properties).

In order to illustrate an application of the IVF framework, such a comparison has been carried out for three distinct *InterVis* techniques that were recently proposed in the literature of IT in the AEC discipline. For each of these three techniques, some significant differences with the reference ‘nodes-links’ diagram are pointed out.

5.2.1 Howard & Petersen: Sociograms

Howard & Petersen (2001) studied the information flows within four housing projects. They proposed to graphically represent communications with sociograms (see Fig. 2).

The IVF characterization of Howard & Petersen’s work rapidly highlights in which sense it differs from the reference ‘nodes-links’ diagram.

The first axis of comparison concerns the dataset to be displayed (cf. *What?* properties). From this viewpoint, the diagrams differ in several ways as the following examples point it out.

- The interacting entities that are displayed are not only occurring among the project participants but also among the participants and some resources (e.g. project web) (***Interacting Entities*** = *persons and resources*).
- The H&P sociograms visualize some entities and some of their properties (e.g. affiliation) (***Entity Visualized Objects*** = *entities* ⊕ *entities attributes*).
- The interactions are visualized in an aggregated manner. Indeed, all interactions between a given person A and a given person B are represented by a unique arc (***Interaction Granularity*** = *aggregated interactions*).

It should also be noted that the diagrams (Fig. 1 and Fig. 2) are similar in many respects. For instance, they do not take time into account (***Entity Time Position*** = *no time positioning* and ***Interaction Time Position*** = *no time positioning*). They also adopt both a sociocentric point of view (***Interaction Centricity*** = *sociocentric*).

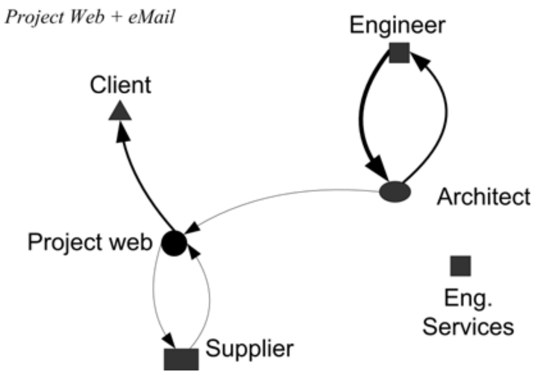

FIG. 2: Adaptation of the reference nodes-links diagram to be similar to Howard & Petersen’s proposal

The second axis for the comparison relates to the context of use of the sociograms. For this aspect, both *InterVis* techniques are very similar. For example, they are designed to be used by an external observer (***Visualization User Role*** = *external observer*) for analysis purposes (***Visualization Purpose*** = *interaction analysis*). In addition, they are independent of the tools that really support the interactions (***Visualization Integration*** = *independent*).

Third, the visualization techniques themselves are basically similar (cf. *How* properties). They are both bi-dimensional visualizations (***Display Space Dimensions*** = *2-Dimensions*). The entities are represented by points (***Entity Graphical Mapping*** = *point object*) and the interactions by lines (***Interactions Graphical***

Mapping = *linear object*). They are composed of abstract graphical objects (***Entity Abstraction Level*** = *abstract* and ***Interaction Abstraction Level*** = *abstract*).

However, at least one difference should be highlighted. Howard & Petersen use some retinal variables while the reference diagram does not. Indeed, on one hand, the width of the lines depends on the number of interactions that occurred between the connected entities (***Interactions Retinal Variables*** = *size*) and, on the other hand, the affiliation of the entities is represented by the shape of the associated node (***Entities Retinal Variables*** = *shape*).

In conclusion, the analysis of the two proposals shows that, considering the scope of the whole design space, Howard & Petersen sociograms are quite similar to the reference diagram. Nevertheless, they visualize more information than the reference diagram by using some retinal variables. They can be seen as an evolution of the basic reference sociograms.

5.2.2 Thorpe & Mead: Network Sociograms

Thorpe & Mead (2001) studied communication flows within three projects that used a project-specific web site. They represented the communication flows with network sociograms (cf. Fig. 3). The IVF-based analysis of their work points out to which extent it differs from the reference diagram.

The discussion will only focus on the description of the *InterVis* technique itself (cf. How? Properties) as the most significant elements to consider relate to this aspect. In this context, the two kinds of sociograms share several fundamental features. They have two dimensions (***Display Space Dimensions*** = *2-Dimensions*). They are basically 'nodes-links' diagrams in which the entities are represented by points (***Entity Graphical Mapping*** = *point object*) and the interactions by lines (***Interactions Graphical Mapping*** = *linear object*). They do not use some distortion techniques (***Geometrical Distortion*** = *not distorted*) or some special algorithms to keep constant the size of the display space (***Display Space Boundaries*** = *variable*).

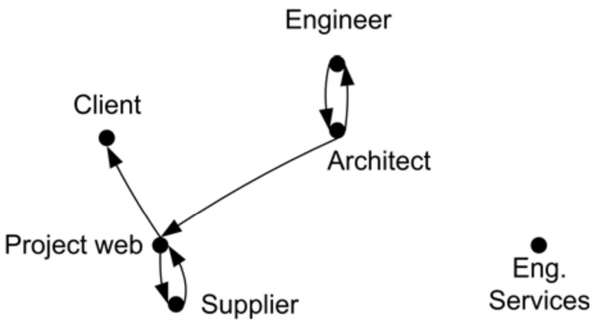

FIG. 3: Adaptation of the reference nodes-links diagram to be similar to Thorpe & Mead's proposal

Thorpe & Mead's approach introduces, however, interesting characteristics that makes their sociograms different from the reference diagram and from Howard & Petersen's sociogram. They change the value of the ***Entity Display Position*** from '*meaningless position*' to '*meaningful position*'. Indeed, in their diagrams, the more some entities interact with each other, the closer they are placed in the display space. Some clusters of entities can thus be graphically identified, which was not so easy in the two others diagrams.

Once again, the IVF framework helps us to rapidly identify the interesting features of a given technique that were not present in other ones.

5.2.3 Halin et al.: Hypergraphs

Halin et al. (2004) studied cooperative tools in architectural design. They proposed to visualize the information about the project with hypergraphs (cf. Fig. 4). In fact, this representation also appears to be a variation of the reference 'nodes-links' diagram, which can be modelled as a modification of some IVF properties.

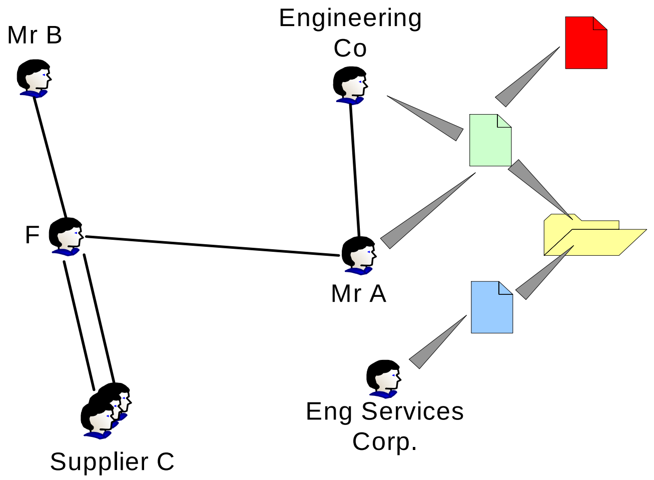

FIG. 4: Adaptation of the reference nodes-links diagram to be similar to Halin et al. hypergraph

Halin's hypergraph visualizes a different data set than the reference diagram. For instance, the representation shows the interacting persons but also some project resources, like documents or directories (***Interacting Entities*** = *persons and resources*). The hypergraph also considers time and represents the temporal precedence of some interactions (***Interaction Time Position*** = *relative time positioning*).

The purpose of the visualization basically differs from the reference diagram as it is mainly designed for the project participants, or in other words, people being involved in the interactions (***Visualization User Role*** = *participating actor*). This diagram is intended to help the participants to better manage their interactions (***Visualization Purpose*** = *interaction support*), and it is fully integrated into a cooperation tool (***Visualization Integration*** = *integrated*).

While the hypergraph technique is also an adaptation of a classic 'nodes-links' diagram, it differs in many points from the reference diagram. Some of the most important differences are listed below.

- The entities are not visualized by abstract points anymore but by characteristic icons (***Entity Abstraction Level*** = *metaphorical*).
- The current state of some entities (e.g. in progress, terminated, problem) is associated with the '*colour*' retinal variable (***Entities Retinal Variables*** = *colour*).
- Due to the usage of retinal variables, the representation of the interactions also appears richer as several attributes of the interactions are visualized. For instance, the shape of the links specify whether the relation is ordered (triangular link) or not (simple line). A temporal precedence between two documents becomes thus visible (***Interactions Retinal Variables*** = *shape*).
- The hypergraph approach offers some real interactivity. For instance, it allows the user to select the entities to be displayed according to their state (***Entity Interactivity*** = *select entities*).

In conclusion, the IVF analysis of the hypergraph points out that it fundamentally differs from the reference diagram to what concerns its context of use. Moreover, it permit to visualize a larger data set, especially in terms of the entity / interactions attributes thanks to the larger usage of the opportunities offered by the design space.

5.3 Design of *InterVis* techniques

The design of new *InterVis* techniques or the enhancement of existing ones is a third major application of the IVF framework. To illustrate it, let us assume that we want to design a new diagram that shows different kinds of interactions (e.g. e-mail, postal mail, and web-based sharing document system) that occur during a construction project. We consider that the more information displayed the better. The new diagram is designed to be used by the project participants and for this reason should be integrated in a web-based collaboration platform.

The context of use of the new *InterVis* technique is quite well defined, thus allowing us to easily set the values of the associated IVF properties (⇒ ***Visualization User Role*** = *participating actor* and ***Visualization Purpose*** = *interaction support* and ***Visualization Integration*** = *integrated*).

Considering this domain of application, we have to reflect on which objects to represent graphically. The IVF framework helps us to structure this specification step. We choose to visualize not only the interacting persons but also some project resources as well as the interactions among them. We also want to include in the diagram a representation some attributes of the entities and the interactions (⇒ ***Interacting Entities*** = *persons and resources* and ***Entity Visualized Objects*** = *entities* ⊕ *entities attributes* and ***Interaction Visualized Objects*** = *interactions* ⊕ *interactions attributes*). The sequence of the interactions between the project participants is important, we decide therefore to add this information within the diagram (⇒ ***Interaction Time Position*** = *relative time positioning*).

Considering the objects that we need to visualize and considering our previous experience with 'nodes-links' diagrams, we choose to develop an extended version of the well-known 'nodes-links' planar diagram. This decision directly determines some basic IVF properties (⇒ ***Entity Graphical Mapping*** = *point object* and ***Interaction Graphical Mapping*** = *linear object* and ***Display Space Dimensions*** = *2-Dimensions*). The IVF framework mentions the possibility to use distorted representation, which permits a 'focus + context' view of the data. We adopt this approach (⇒ ***Geometrical Distortion*** = *distorted*) and decide to add a focus lens to the diagram (see on Fig. 5 the yellow rectangle inside the display space where the graphical objects are magnified).

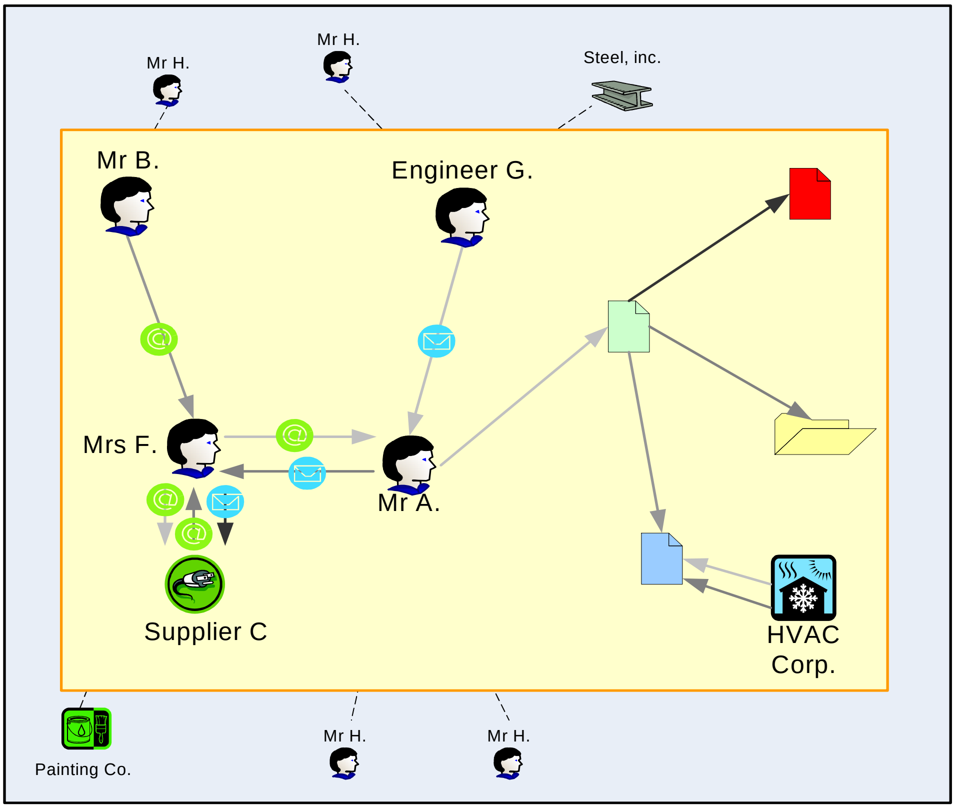

FIG. 5: New nodes-links diagram resulting from the IVF-based design process

At this point of the design process, our earlier analysis of other *InterVis* techniques via the IVF framework becomes especially useful and our observations are noted below.

- Some proposals place the graphical objects that represent the entities in a meaningful manner (cf. Thorpe & Mead) while others do not (cf. Howard & Petersen). We choose to use this graphical property to highlight the volume of interactions among the entities and therefore we adopt the first option (⇒ ***Entity Display Position*** = *meaningful position*). The closer the entities, the higher the frequency of exchanges between them.
- We also decide to use the position of the links associated with the interactions to visualize their order of occurrence. If several interactions are observed between two entities, the corresponding

arcs will be placed from top to bottom/left to right according to their sequence (⇒ ***Interaction Display Position*** = *meaningful position*).

- The metaphorical representation of the entities that Halin et al. use improves the understanding of the diagram. We adopt this approach but we decide to represent differently the persons and the organisations / companies (⇒ ***Entity Abstraction Level*** = *metaphorical*). We also choose to visualize a given attribute of the interactions, namely the medium used, with a metaphorical representation (cf. Fig. 5: envelope associated with postal mail and @ associated to e-mail) (⇒ ***Interaction Abstraction Level*** = *metaphorical*).
- The retinal variables seem to be underused in some *InterVis* techniques previously studied. We decide to convey the information about some attributes of the entities/interactions by this channel in the new diagram. The IVF framework lists the available values and helps us to realize the potential of these variables. Like in Halin et al.'s hypergraph, the state of the resources is linked to the colour of the associated icon (⇒ ***Entities Retinal Variables*** = *color*). In addition, the overall sequence of occurrence of the interactions is visualized by the grey level of the associated arcs: the more recent the interaction the darker the grey of the associated arc (⇒ ***Interactions Retinal Variables*** = *grey level*).

The result of the design process is presented in Fig. 5.

We could also include several others features like interactivity, to allow the user to select the entities to display or the interaction attributes that are visualized. However, the example is provided to illustrate the potential of the IVF framework in the design process of a new diagram. Therefore, we will not discuss in detail the possible values for each IVF property.

In conclusion, we have explained that the exploration of each IVF property provides us with quite a precise specification of the new diagram. Of course, in order to favour the final usefulness and ease-of use of the new diagram, an iterative process based on the progressive evolution of a first draft and multiple evaluations with test users is preferable.

Finally, the design of a new diagram does not demand an IVF-based analysis but we think that, thanks to the high number of dimensions that IVF identifies, it can significantly improve the creativity and the efficiency of the diagram designers.

6. CONCLUSIONS

Construction projects are basically cooperative works and several authors have studied them from various points of view. Surprisingly, few of them handle the issue of the visualization of this cooperation. This paper tackles this issue by describing a generic framework called IVF.

IVF intends to structure the domain of the *InterVis* techniques, i.e. graphic representations of interactions among persons and resources, such as those occurring during a construction project. Three basic axes of classification are used for this purpose. Which objects are visualized? In which context of use are they visualized? How are they visualized?

It has been explained in this paper that IVF offers at least three main advantages. First, it allows characterizing the *InterVis* techniques in a structured and standardized way. Second, it helps to identify similarities and differences among the proposals. Finally, it supports the design of new *InterVis* techniques. Further work will focus on refining the list of permitted values for each IVF property, this will be carried out in order to achieve a greater precision for describing the design space of *InterVis* techniques. We will also explore the potential of the IVF framework to support the assessment of *InterVis* techniques.

From an application viewpoint, the IVF framework is currently used in an ongoing project to design new graphical representations of the activity on a web-based collaborative platform.

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