A Visual Transactive Memory System Approach Towards Project Information Management

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Abstract
The Architecture Engineering Construction - Facilities Management (AEC/FM) industry is currently plagued with inefficiencies in access and retrieval of relevant information across the various stakeholders and actors, because the vast amount of project related information is not only diverse but the information is also highly fragmented and distributed across different sources and actors. More often than not, even if a good part of the project and task related information may be stored in the distributed information systems, the knowledge of where what is stored, and how that information can be accessed remains a tacit knowledge stored in the minds of the people involved in the project. Consequently, navigating through this distributed and fragmented information in the current practice is heavily reliant on the knowledge and experience of the individual actors in the network, who are able to guide each other to relevant information source, and in the process answering questions such as: who knows what? What information is where? Etc.

Thus, to be able to access and effectively use the distributed knowledge and information held by different actors and information systems within a project, each actor needs to know the information access path, which in turn is mediated by other actors and their knowledge of the distribution of the information. In this type of distributed-knowledge network and "actor-focused thinking" when the key actor or actors leave the project, the access path to the relevant knowledge for the associated queries may also disappear, breaking the chain of queries. Therefore, we adopt an "information-focused thinking" where all project actors are considered and represented as computational and information storage entities in a knowledge network, building on the concepts and theories of Transactive Memory Systems (TMS), which primarily deal with effective management and usage of distributed knowledge sources.

We further extend the explicit representation of the information entities to visual objects such that the actors can effectively understand, construct and recognize contextual relationships among the information entities through visual management and communication. The merits and challenges of such an approach towards visual transactive memory system for project information management are discussed using a prototype information management platform, VisuaLynk, developed around graph and linked-data concepts, and currently configured for the use phase of a project.

Keywords: Construction Management, Facility Management, Knowledge Networks, Transactive Memory, Project Information Management

1 Introduction

Effective information access, delivery and management have remained one of the major challenges in Architectural, Engineering, Construction and Facility Management (AEC/FM) industry for decades. Despite of the increasing digitalization of the AEC/FM data and the increasing role of information and communication technologies in the AEC/FM projects, the information management challenges continue to grow with the growing volume and variety of digital information sources and advanced computing solutions. More often than not, the industry actors seek the advice of other actor(s) by considering the other as an access path/link for the answer to various types of queries through the actor's expertise and knowledge. The reason for this can be two-fold. First, there is a limit to the amount of information that people can process, and consequently effective documentation and representation of data and information is critical for communication and collaboration between people. This is evident in different data documentation and formats such as CAD/BIM files, PDF documents, spreadsheets, emails, etc. Second, despite the wide variety of documentation, a significant part of the generated knowledge remains stored in the minds of individuals as memories and experiences. In particular, most of the meta-knowledge of where the information is stored, how to read different data formats, how to build connections and links between the data and information stored and documented across different sources, etc. remain as tacit knowledge of the individuals. That is, the effective usage of the documented information requires human cognitive capacity and interpretive problem solving, together with the power of digitization and computing for processing and making sense of the large amounts of information. Consequently, information systems need to be user friendly for effective information exchange and transactions between users as well as between users and information systems.

At the same time, the increasing variety, accessibility and availability of information sources has triggered the development of a range of data search, retrieval and visualization tools which enable the end-user to access, analyze and process the information. Nonetheless, it may be detrimental if users take the output of the analysis without understanding how the information was processed or analyzed. That is, it is desirable that users either personally engage in the discovery and evaluation of the output or at least be explained about the relationships between information entities and outputs presented to them. This engagement can lead to the discovery of new relationships beyond what computational systems can detect and present. Any potential new relationships emerge through the variety of backgrounds, experiences and perspectives of the actors which are valuable in the creative generation and analysis of information. However, once again these relationships typically remain hidden and stored within the minds of the key actors and they are not accessible directly to others (individuals, teams) in the organization. There should be some mechanism to manage this as an organizational knowledge, which could also potentially be recorded and/or backed up by computational systems.

As in many other industries, in the AEC/FM industry effective sharing and use of organizational knowledge depends to a large extent on the organization's ability to create, allocate and share its collective memory with the individuals in the organization. The concept of Transactive memory systems (TMS) is built on these three aspects of knowledge management. A TMS is "... a set of individual memory systems in combination with the communication that takes place between individuals" (Wegner et al. 1985). It assumes that individuals play the role of external memory for other individuals, in other words, meta-memories. Hence, they benefit from each other's knowledge and expertise as an access path to the relevant information and its relationships by developing a shared understanding of who knows what. However, when one of these key actors leaves from the organization, the associated access path to the relevant information also disappears. This creates a gap in collective storage, allocation and retrieval of the relevant information and its dependencies in actor-focused-thinking.

Therefore, we propose an information-focused-thinking where all project actors are considered and represented as a computational (data integration) and visual (user-interface) information entity among the other information entities in a knowledge graph/network. The contribution of this paper is twofold. First, the potential "access path" bottlenecks associated with the key actors is eliminated and distributed among all information entities which allows members of an organization to access the relevant information through various paths. Second, we present a prototype computational environment, VisuaLynk, which can help individuals to capture, understand, construct and recognize contextual relationships among information items (including the key actors) and the relationships of other individuals with those information items. Hence, the knowledge created in this platform does not only reside in the minds of individuals, but is computationally created, administered and represented, to provide a so-called visual transactive memory system (V-TMS).

2 Background

2.1 Knowledge Management Practices in Construction Industry

Knowledge management practices have been extensively studied across various domains over the years. The knowledge management literature can be grouped across diverse themes such as knowledge creation (e.g. Nonaka & Takeuchi 1995), knowledge sharing (e.g. Dyer and Nobeoka 2000), knowledge diffusion and networks (e.g. Cowan and Jonard 2003), social capital (e.g. Tsai and Ghosal 1998), distributed knowledge management (Wegner 1987), etc. This paper focusses on the management of distributed knowledge, and hence, the other perspectives are not covered in this paper.

As one of the major industries which operates in an information-intensive environment, the construction industry relies heavily on the use of distributed knowledge sources as one of the most essential elements to ensure the success of a project. The tasks associated with the project can be performed effectively and efficiently by the project team members on when they are able to effectively use and manage the distributed knowledge. However, due to the fragmented nature of construction industry, the success rate of managing the project knowledge is typically very low, and processes are quite often ad-hoc at the best. In addition, considering the different stages involved in each phase of the project lifecycle, the amount of knowledge to be captured and managed can be overwhelming. A significant part of the project knowledge such as technical procedures, project-related problems and solutions, best practices and lesson learned experiences often reside in the heads of the key actors as a tacit knowledge.

At the same time, majority of the existing ICT solutions developed to document the information store the explicit digital data in a siloed manner within digital files and folders; and share them with such cloud-based services and/or intranets. This approach prevents and limits the opportunities to capture the critical knowledge about connection between siloed information, which remains as tacit knowledge known to the project team members. This tacit knowledge cannot be extracted or shared through classical and siloed IT systems. As mentioned in (Nonaka & Takeuchi 1995), the process of uncovering this hidden knowledge can be achieved by means of capturing the social interaction of individuals. However, this approach assigns a “key actor” role to the individuals, which makes them an access path/link to the relevant knowledge for other individuals. This also brings a new challenge for actors to identify who knows what, in other words the right “key actor” who is able to meet the specific task requirements and at the same time facilitate the process of knowledge sharing in which TMS is built on this notion.

2.2 Transactive Memory Systems (TMS)

Transactive memory is a meta-knowledge of the memory structure in an organization or group of people (Lewis 2003; Wegner 1987). It is also defined as the group’s shared awareness of who knows what in the group, which is based on attributions of responsibility, skills, or expertise in different domains (Wegner et al. 1991). TMS is composed of internally and externally encoded knowledge. Internally encoded knowledge refers to memory that resides in the minds of individuals (Lewis 2003). Externally encoded knowledge refers to external representations such as documents or knowledge held by other individuals. In other words, every individual holds some unique knowledge as well as some meta-knowledge (Moreland et al. 2002). The primary benefit of a TMS is that it can reduce the rehashing of shared information and foster the pooling of unshared information (Mohammed & Dumville 2001).

Three stages are involved in the creation and maintenance of TMS: directory updating, information allocation and retrieval coordination (Rulke & Rau 2000). At the first stage, group members create directories of meta-memories containing information about the memories held by others. These meta-memories usually include not only the information about the subject and location of knowledge but also some perceptions about the individual's own and others' expertise on the subject. When new knowledge enters the group, it is allocated to the person who is perceived by the group as the expert on the topic. This expertise differentiation can develop naturally within the group or be imposed by defining roles and allocating responsibilities. Finally a group member wishing to retrieve some knowledge will first assess his/her own perception on the topic and then will evaluate other group members that may possess this knowledge (Wegner 1987).

2.3 Challenges and Issues to Consider with TMS

Although the TMS is quite helpful and effective in organizational learning, there are still some of challenges associated with establishing and maintaining TMS during the project/organization's lifetime. These challenges can be defined as:

Long time investment: In a TMS, individuals must be in direct communication with each other, and take time to explore each other's backgrounds and expertise. This task is often time consuming during the initials stages of a group effort, particularly in situations where group members do not already know each other (Ancona & Caldwell 1992).

Individuals' expertise/backgrounds: The backgrounds and expertise of participants should neither be too similar nor too diverse so group members can cover a wide range of expertise while still being able to efficiently communicate and develop a shared understanding of issues.

Number of Individuals: The complexity in the operation of TMS increases with the number of participants. There are fewer opportunities to leverage group cohesion in large groups and organizations where people only maintain effective knowledge about each other. Bigger groups often depend on individuals that focus on administering memory differentiation and task coordination by directing the communication exchange among individuals (Ancona 1990; Ancona & Caldwell 1988).

Departure of an individual: As discussed earlier, TMS are susceptible to the turnover of its members. While departure of a single individual can cause the loss of essential group knowledge, the integration of knowledge of new members requires time and effort (Ancona & Caldwell 1992).

Lack of dependencies: With regards to the above challenges, information systems/technologies (IS/IT) researchers have suggested that IT can be useful in supporting organization-wide TMS for various aspects of knowledge management activities (Alavi & Leidner 2001). Such systems should be designed (Jackson & Klobas 2008; Nevo & Wand 2005) to include intranets, search engines, document repositories and collaboration tools that allow virtual communities of practices to be organized (Hansen & Haas 2001; Wasko & Faraj 2005; Wegner et al. 1991). However, TMS are difficult to maintain within highly dynamic, remotely distributed and organizationally decentralized environments. Individuals may collaborate remotely, contribute to multiple tasks and workgroups simultaneously and dynamically regroup based on their availability and expertise. While the technological solutions enable individuals to gain task specialization, independence, initiative, speed and effectiveness (Keel 2007), many of them are not capable of capturing the hidden dependencies of the entire knowledge network. This creates conditions and limitations where individuals have limited knowledge about the people they are working with, and are thus less effective in coordinating and benefiting from the knowledge and experience of their colleagues. Therefore, it is desirable to have clearer visibility and explicit mapping of the relationships of information and associated actors.

3 Background

As discussed, the interaction of individuals with each other and with the outputs (e.g. digital documentation) of their work collectively creates the organizational knowledge. The existing IT-systems are configured to organize actors, systems and information in a siloed manner. The generated knowledge is stored in structured files, folders, databases, etc. With such an approach, the hidden interactions within the information ecosystem cannot be captured and remains ignored. Therefore, there are two key driving principles of the proposed computational and visual-transactive memory system:

(1) A dynamic and network based configuration should replace the existing static and silo-based information repository systems, and

(2) An interactive visualization of the knowledge sources and their mapping should be considered to allow the users to access the relevant information/knowledge without the need to find a "key actor".

The first requirement for a V-TMS is a different approach to data configuration compared to existing IT solutions. Instead of structuring and categorizing the project information only in structured files and folders, the "relationships" identified during the project lifecycle are also considered such as:

- Relationships of a single actor with other actors and,
- Relationships of actors with information entities, files, folders, and systems.

This approach enables two essential features: (1) elimination of constraints associated with the hierarchical and sequential organizational structure of team members, files, folders and associated systems and, (2) creation of a knowledge network in which each entity (actors, systems and information) of the organization is linked with each other. These two major features are further enhanced with the system configuration allowing capturing, creation and maintenance of the project related information created by the actors or the systems. The built-in user management module assigns an ownership attribute, a timestamp and the descriptive tag in the system to the generated information entity; and combines these with the actors' pre-defined background, expertise, interests and objectives in a shared digital repository.

The second feature is for the creative and incremental discovery of these relationships among pieces of data, information and knowledge. Typical solutions for this can be brainstorming, decision making and problem solving which can include the collection and visualization of task-relevant information (Furnas & Russell 2005). Typically this step accumulates large amounts of information, a lot of which is independently extracted from different sources, found in different formats and stored in different directories, represented through different visualization (notes, graphics, diagrams) styles (Marshall & Bly 2005). All these factors increase the difficulty level for contextual understanding of the overall output. Therefore, we aim for an information navigation and access platform that:

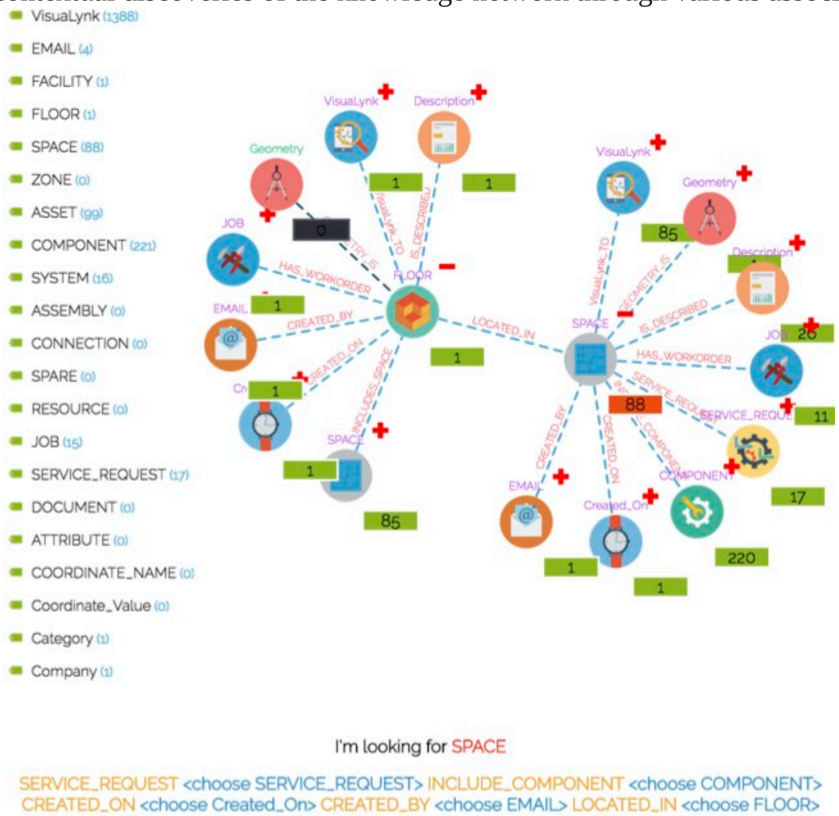
- allows quick comprehension and evaluation of the information item/set or piece of knowledge with the ownership attribute,
- provides relevant information sets and alternative paths to access the information associated with the specific task,
- provides a peer to peer (P2P) knowledge exchange platform to develop a shared understanding with other users (this feature is under development)

Regarding the above requirements and features, an interactive visualization interface has been developed as a V-TMS which is: (1) able to allocate the fragmented project information, instantly check and update the directory of existing information, and merge the newly generated information with the existing knowledge network; and (2) facilitates navigation to retrieve and explore relationships among information items through spatial organization of pre-attentive figures assigned to information entities. In this visualization, each actor is represented as another information entity, which are in direct relationship with other actors as well as other information entities. The relationships between the information entities are explicitly represented and presented to the end-user to be able to identify alternative paths to reach specific information entities/sets or knowledge exploration.

The proposed V-TMS promotes the representation of information and knowledge in an abstract format and common location. The visually abstract information can be quickly and easily understood. The pre-attentive figures which are assigned to each information entity can represent and remind the broader meaning/classification of that entity rather than presenting the knowledge item in detail. Explicitly represented relationships among the information entities summarize the details using the ontological structure of the generated knowledge. Therefore, while using the system the end-user does not need to remember specific content of an information item or the associated key-actor to access the relevant knowledge. Explicitly represented alternative paths (relationships) provide alternative access ways for the associated information sets or knowledge.

4 VisuaLynk: A Prototype V-TMS Platform for Construction Information Management

Although the above-specified principles of V-TMS are broadly defined, they outline the merits and challenges of such an approach towards a V-TMS which have been implemented and tested in VisuaLynk, a prototype development for facility management phase of project information management. VisuaLynk engages the end-users in the visual organization and management of information through the spatial arrangement of knowledge network, configuration of information entities with graph and linked-data based technologies; and representation in a dynamic visualization platform showing explicit relationships (Figure 1). There are two basic levels on VisuaLynk: (1) data integration based on graph and linked-data technologies which can dynamically update, allocate and retrieve new/existing knowledge entities (2) user interface which allows the end user a non-interruptive interchange of contextual discoveries of the knowledge network through various associated paths.



In VisuaLynk information is organized in a granular network (graph) in which individual entities,

Figure 1 The user interface of VisuaLynk

their properties and relationships with other entities can be saved and accessed. The user-interface of VisuaLynk presents the visual connection and spatial organization of information in a visually space-saving and abstract "node-link" diagram. The information is categorized in pre-defined list located near the node-link diagram which allows end-users to access to each knowledge category. Each information entity is represented as a node and is visualized with representative picture (icon) and a descriptive tag (text) to support the easy recognition and recollection of information which has the associated descriptive text (label). The label may be the name of a key-actor, components or any numerical value. The semantic relationships of the graph-data model are represented as a dashed-line between the associated two nodes and represented with a descriptive label as well.

There are two types of nodes in VisuaLynk to enhance the knowledge discovery (1) a root-node which can be expanded to see the relationships/alternative-paths associated with other root-nodes in the proposed V-TMS. For example, a *Component* and *Manufacturer* root-nodes with a *Manufactured_By* relationship and, (2) entity-node which shows specific information entity such as Ventilation_Component_101 node. To see the alternative paths in the proposed V-TMS, root-nodes hold a "+" sign. When the end-user clicks the sign, the other related root-nodes are appeared with their unique relationship links. The related root-nodes can include systems, actors, detailed descriptions etc.

Since all the root-nodes are semantically related with each other, the end-user can create a chain-of-paths during knowledge discovery. Both root and entity nodes as well as relationships may involve some specific semantic properties which may refer to another property and/or external information source. For this need, hyperlinks can be assigned to the tags (text) of the nodes and/or relationships directly which can forward the end-user to the relevant knowledge source. The ownership attribute of the "actor" root-node collects, allocates and semantically interrelates the interactions of the associated actors with other actors, information entities, systems, etc.

The use of a dynamic node-link diagram in VisuaLynk offers variety of benefits for a V-TMS such as:

- The abstract representation of complex knowledge networks engages the human's cognition in ways that allows for processing of large amounts of information (Byrne 1993).
- Dynamic and collapsible node-link consumes little space and offers a good balance between visual and textual reminders thus allowing users to easily recall the contents of associated knowledge entity (Robertson et al. 1998).
- Semantic hyperlinks enable users to easily manage, store and distribute information in different formats and external locations.
- Explicitly represented relationships between each nodes hold the most essential role for a V-TMS by providing alternative paths to reach the associated knowledge entities. So end-user is not binded to a key-actor to access to the relevant knowledge.
- Visual features such as icons of nodes and colors of textual components greatly enhance information access time (Lewis et al. 2004).
- Spatial arrangement of nodes and combining relationships between these nodes help end-users to develop a contextual understanding of a knowledge subset.

5 Limitations and Future Studies

A TMS is built on the distinction between internal and external memory encoding, storage and retrieval from the collective memory through various transactions between actors, based on the meta-memories. In this research, we aimed to eliminate the "key-actor" factor of traditional TMS by integrating actors into the knowledge network, and developed the VisuaLynk platform for construction project information management. Nonetheless the following limitations of this research need to be considered while reviewing the findings.

Since the construction industry is based on a highly fragmented network, the interactions of actors in a construction project vary significantly based on the project task. Therefore, the overall interaction network among actors and systems is like a living organism which is difficult to capture and track all the details. In VisuaLynk, we developed an initial network structure for facility management (FM) phase and tracked the interactions within this predefined network. VisuaLynk has been designed as a scalable V-TMS platform to be extended to other phases of construction projects.

6 Conclusions

In this paper, we specified the fundamental aspects of a V-TMS platform and introduced VisuaLynk, a prototype computational environment for construction project information management that engages the end-users in the visual organization and management of knowledge through the spatial and abstract arrangement of graphical entities. We further outlined the potential advantages of such a platform in terms of user interaction, cognition and knowledge discovery. The primary contribution of this research lies in the design concepts and information structure that enable a non-interruptive interchange of contextual discoveries between individual actors and systems. The paper presents a proof-of-concept, which is currently being used for pilot studies to test its usefulness.

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