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A Spatio-Temporal Perspective to Knowledge Management in the Construction Sector

KEYWORDS: Knowledge, Knowledge Management, Heuristic decision theory, Cultural historical activity theory, SECI model

The construction sector is an informative intensive one. In every project, during each phase are generated hands-on experiences, problem solving capabilities, understanding of various means and methods, and highly contextualised solutions. This knowledge represents one of the most important assets for AECO firms. In the construction process, the development of a project requires the aggregation of several stakeholders. Many times this group of stakeholders collaborate for the development of the project and once it is delivered they disband moving on to the next project. Hence, the knowledge generated during the process by a whole of stakeholders is disrupted at the end of the project. Furthermore, the experiences gained in the process are rarely, if at all documented with the consequence that knowledge remains stored in the minds of those who were directly involved.
This paper proposes a novel interpretation of the classical theories of knowledge management considering the peculiarities of the construction sector. Starting from the study proposed by Nonaka and Takeuchi and in particular the hypertext organisation schema and the SECI model, the article proposes a redesign of the schema to allow its introduction in the construction sector. This main topic is integrated with considerations derived from the cultural historical activity theory and the heuristic decision theory that represent fundamental areas of study to integrate the general model with the means to analyse distributed and decentred organisations, and the intrinsic psychological aspects involved in the management of knowledge.
Hence, the paper proposes an integrated vision of the hypertext organisation schema studied in the construction sector. Furthermore, starting from the latter, the research proposes an interpretation of the knowledge generation and consumption process in the construction sector introducing a spatio-temporal perspective that highlights the distribution of knowledge related processesin terms of both space and time during the construction process.

INTRODUCTION

The construction sector is an informative intensive one (Dave and Koskela, 2009). In every project, during each phase are generated hands-on experiences, problem solving capabilities, understanding of various means and methods, and highly contextualised solutions (Lin et al., 2005). This knowledge represents one of the most important assets for architecture, engineering, construction, and operations (AECO) firms (Deshpande, Azhar, Amireddy, 2014). In the construction process, the development of a project requires the aggregation of several stakeholders. Many times this group of stakeholders collaborate for the development of the project and once it is delivered they disband moving on to the next project. Hence, the knowledge generated during the process by a whole of stakeholders is disrupted at the end of the project. Furthermore, the experiences gained in the process are rarely, if at all documented with the consequence that knowledge remains stored in the minds of those who were directly involved (Kazi and Koivuniemi, 2006:65-79).

Because of the recognised importance of knowledge, there is a vast literature related to the concept of knowledge management (KM). KM can be defined as *"a process of acquiring, creating, sharing, utilizing and storing intellectual assets and other stimuli from the internal and external business environment that facilitates an organization to perform successfully"* (Kululanga, McCaffer, 2001). Focusing on the construction sector, e.g. Kamara, Anumba and Carrillo (2002) proposed a framework to select knowledge management strategies. Robinson et al. (2006) presented a maturity roadmap for the implementation of KM strategies. Patel et al. (2000) investigated how Information Technology (IT) can assist KM in the context of the construction sector. Kanapeckiene et al. (2010) described an integrated model for KM in construction projects including the discussion of knowledge based decision support systems. Moreover, Rezgui, Hopfe and Vorakulpipat (2010) proposed an evolutionary perspective on KM. However, the understanding of the complex interrelations generated during knowledge and learning processes in the construction sector is still an area of open discussion.

This paper proposes a novel interpretation of the classical theories of knowledge management considering the peculiarities of the construction sector. Starting from the study presented by Nonaka and Takeuchi (1995) and in particular the hypertext organisation schema and the SECI model, the article proposes a redesign of the schema to allow its introduction in the construction sector. Due to the limitation of the hypertext organisation schema highlighted in the literature (Bratianu, 2010; Engeström, 2001), it is developed an integrated vision based on the cultural historical activity theory. Furthermore, starting from this integrated schema, the research proposes an interpretation of the knowledge generation and consumption process in the construction sector dealing with the spatial and temporal distribution of the process. Hence, it is introduced a spatio-temporal perspective that highlights the distribution of knowledge related processes in terms of both space and time during the construction process.

The rest of the paper is organised as follows. The first chapter introduces the hypertext organisation schema and proposes a first expansion of the schema to represent the typical fragmented environment of the construction sector. Starting from the limitations highlighted in the first analysis, the second chapter introduces the concept of cultural historical activity theory (CHAT) and proposes an integrated vision of the hypertext organisation schema. The third chapter proposes a spatio-temporal perspective on knowledge creation and use in construction sector. Finally, the fourth chapter contains the conclusions of the work.

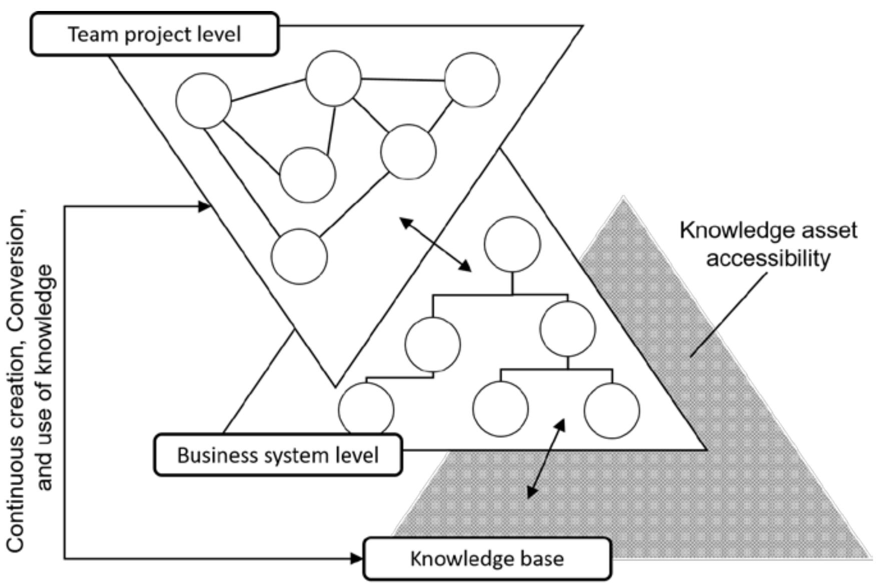


Figure 1: The hypertext organisation schema (Nonaka and Takeuchi. 1995)

KNOWLEDGE IN ORGANISATIONS

"*Sooner or later, every organization ends up creating knowledge*" (Nonaka, Takeuchi, 1995). However, the identification of where the knowledge is created, how to extract, store, share and update this knowledge, who are the subjects involved, why do they learn, what do they learn, and how do they learn represent critical questions associated to the specific environment where the learning process is introduced (Engeström, 2001). According to Nonaka and Takeuchi (1995), the knowledge creation process needs to follow a virtuous spiral moving back and forth between different mechanisms of knowledge conversion. The middle-up-down approach that they proposed highlights the importance of a knowledge conversion layer between field operators, designers and top managers. In fact, each one of these subjects has a different perception of the work and consequently a different knowledge construction in his or her mind. Moreover, each subject acts in a completely different environment (i.e. contexts) that can influence the knowledge perception (Tversky, Kahneman, 1973; Fantino, Stolarz-Fantino, 2005). Figure 1 shows the "*hypertext organisation schema*" where the continuous conversion of knowledge between different levels of an organisation is highlighted. This schema represents a fundamental paradigm in the study of organisational knowledge dynamics. Moreover, the literature is rich of studies devoted to its analysis and integration making it an ideal candidate to promote the discussion in the research community.
The knowledge base layer represents the place where the knowledge can reside and where it can be categorised and contextualised into a more meaningful product for the organisation as a whole. The individuals acting in the team project level can acquire and interpret the knowledge derived from the business system level in a complete different manner in comparison to the individuals acting on this last level. In the same way, the knowledge created in the project level is interpreted in a different context at the business system level acquiring a different value. The mobility of the knowledge and its management in the knowledge base area allows the activation of a virtuous circle of knowledge conversion allowing the creation of organisational knowledge valuable for the whole organisation.
Nevertheless, the understanding of how knowledge can be converted from one subject to another and/or from one form to another represents a crucial point. The most popular model in terms of knowledge conversion (i.e. how subjects learn) is the SECI model (Nonaka, Takeuchi, 1995; Nonaka, Toyama, Byosière, 2001; Skyrme, Amidon, 1997). It outlines four mechanisms of knowledge conversion and/or transfer:

- Socialisation: tacit-tacit
- Externalisation: tacit-explicit
- Combination: explicit-explicit
- Internalisation: explicit-tacit

Socialisation is based on direct interaction between individuals that share their experiences simultaneously, usually with analogical and practical means.
Externalisation requires the identification of means for the "translation" of experiences in a codifiable way to allow future uses. The conversion realised in a socialisation process is different from the one obtained through an externalisation-internalisation process because there is a change in time and context of knowledge usage. In fact, when tacit knowledge is shared, it still requires to be decoded by individuals (Bolisani, Scarso, 1999:209-17) and this passage is constrained by the context of interpretation.
In combination, individuals share and combine knowledge through different means including documents, meetings, and computer networks. The reconfiguration of information sorting, adding, combining and categorising explicit knowledge can produce new forms of knowledge. However, highlighting the human factor in the knowledge conversion process, Roos et al. (1998) stated that combination mechanism cannot really exist, because in this form it is a simple transfer of data and/or information without a real involvement of knowledge. For admit this mechanism, an explicit-tacit-explicit mechanism is required.

Internalisation implies the conversion of the experiences gained through socialisation, externalisation and combination in shared mental models or technical know-how for an individual. The explicit to tacit knowledge conversion is facilitated when the former can be re-experienced e.g. using

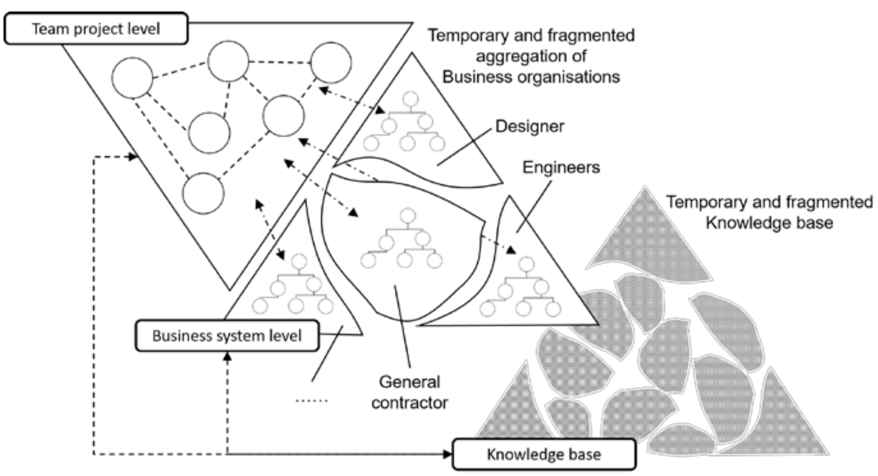


Figure 2: A simplified vision of the hypertext organisation schema for the construction sector

documents, graphical representations, or stories.

Knowledge in the Organisations of the Construction Sector

Unfortunately, in the construction sector the above-mentioned principles cannot be directly applied. The temporary aggregation between clients, designers, construction companies, field operators and the other stakeholders makes difficult the identification of the effective hierarchical roles and consequently the definition of structured KM processes. Furthermore, the conversion processes, that represent the learning activity, needto be managed in a cross organisational context. This is a critical point due to the unwillingness of the stakeholders in sharing information with other partners that are seen as competitor entities.

Figure 2 shows a possible simplified reinterpretation of the hypertext organisation schema proposed by Nonaka and Takeuchi. In this representation, the business system level is disrupted to admit the identification of the different stakeholders involved in the development of a project, each one with its own hierarchical and organisational structure. The knowledge base level is in turn disrupted representing both the knowledge embedded and generated by each subject at the business system level and the knowledge generated by the subjects as a whole at the team project level highlighting its volatility in this framework. Moreover, the coexistence of a temporary aggregation, i.e. the team project that impose defined and specific norms and rules, and of companies that can have long histories and defined processes and hierarchies can generate points of friction and consequently difficulties in the creation of an ideal learning environment.

SOCIETAL AND CONFLICTING ASPECTS: AN ACTIVITY THEORY PERSPECTIVE

As pointed out by Engeström (2001), the knowledge conversion model proposed by Nonaka and Takeuchi assumes that the assignments for knowledge creation are given from above without conflicts. Hence, the SECI model requires the creation of a friendly environment (i.e. the creation of "*sympathised knowledge*") where knowledge and learning processes are defined in a top-down approach (Engeström, Miettinen, Punamäki, 1999). This assumption is in contrast with the typical project environment in construction processes. Moreover, Bratianu (2010) critically analysed the model highlighting its limitations according to the cultural context of application. Hence, the proposed schema needs to be expanded in order to understand the societal and interpersonal relations in a distributed, conflicting and fragmented environment.

Cultural Historical Activity Theory

As proposed in other studies (Hartmann, Bresnen, 2011; Miettinen et al. 2012), cultural historical activity theory (CHAT) can be used to explicit the complex of relations and factors that rise in a construction project environment. CHAT was introduced between 1920s and 1930s by Vygotsky (Bratianu, 2010) that formed the concept of *cultural mediation*. According to Engeström and Escalante (1996), from the Vygotsky's principle CHAT has evolved through three generations of research. The first generation, centred on the cultural mediation idea, is commonly represented through a triangle of interaction where the connection between subject ("stimulus" in the original representation) and object (or response) is mediated by cultural artefacts (Figure 3, left). According to this schema, individuals and society cannot be understood without their mutual interaction and cultural means. The second generation, based on the work of Leont'ev (1978), extended the first model explicating the difference between individual action and collective activity. This concept was crystallised by Engeström (1987) that proposed the graphical representation reported in Figure 3 on the right. In this expanded

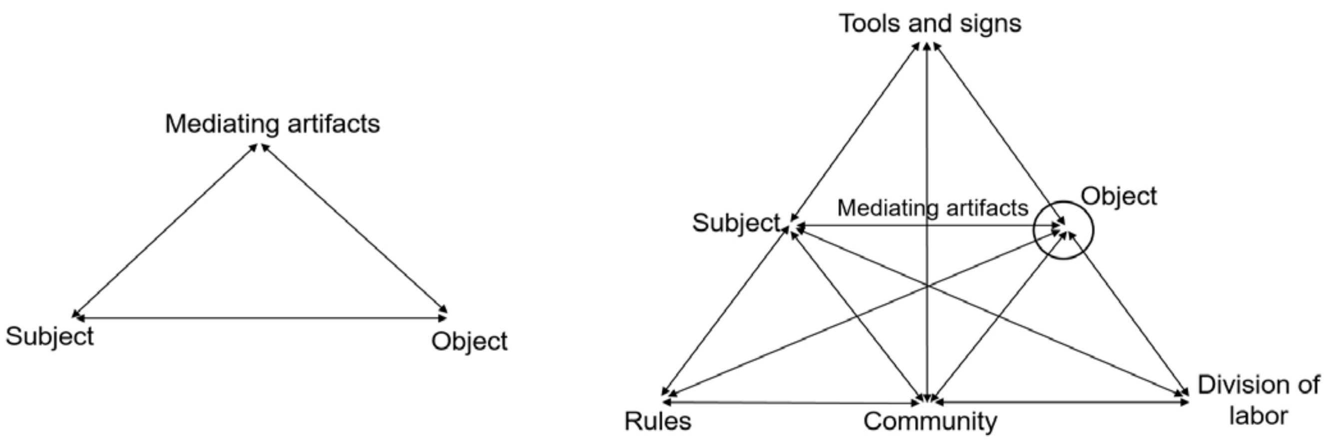


Figure 3: Reformulation of Vygotsky's model (left), and the Engeström's graphic representation of a human activity system (right)

framework, an individual subject is immersed in a complex of interrelations centred on his or her community creating a human activity structure.
The third generation of CHAT deals with the interaction between different activity-systems that can include different traditions and/or perspectives. Figure 4reports the graphical representation of two interacting activity systems proposed by Engeström (2001), highlighting the movement, the evolution and the different perspectives of the object in the interaction between the two activity systems. In the Engeström words, "*the object of activity is a moving target, not reducible to conscious short-term goals*".
Figure 4 represents a minimal model of interacting activity system. Nevertheless, it can be expanded to represent the structure of an articulated project that can include several activity systems.

Hypertext Schema and Activity Theory in the Construction Sector

Integrating the paradigm of interacting activity systems in the reviewed structure proposed in Figure 2, it is possible to define an integrated vision of the hypertext organisation schema for the construction sector (Figure 5). At the business system level, each triangle represents a specific entity (e.g. a company) that participate to the development of the project. The business system level highlights the independencies of each entity in its subjectivity and its interrelation by means of the project terms and objectives. At the team project level, each part of the entities identified at the business system level can be represented as an activity system that collaborate on a shared object (e.g. a building). According to the CHAT principles and following a recent interpretation in the construction sector proposed by Miettinen et al. (2012), the object is interpreted by each subject in a different way according to the specific interest and background of this last. Moreover, the norms and rules that regulate each activity system at the team project level are generated by the integration of the direction defined at the business system level and the directions imposed by the external environment where the construction project is embedded.
This interpretation highlights the complexity of interaction and the interpretation of the knowledge generated during the project activities. In fact, the coexistence of different communities and perspectives shape the way in which subjects act at the project level and the way in which they interpret and convert the generated knowledge.

WHEN AND WHERE KNOWLEDGE IS CREATED AND USED? A SPATIO-TEMPORAL PERSPECTIVE

While the framework proposed in Figure 5 can help in understanding the organisational structure in construction projects and the interactions between subjects, it is not able to capture the spatial and temporal distribution that characterise the construction process. Hence, it can be integrated with a spatio-temporal perspective able to express these dimensions. Analyse the spatial and time distribution of knowledge represents a critical point to understand its management and transfer processes. In fact, while knowledge moves from one place to another and while it moves forward in the time, its perception change due to the change in the context and in the availability of the surrounding information.

Figure 6 reports a qualitative representation of the impact in the production and use of knowledge during time in the different locations involved in the construction process. The graph has been empirically defined combining the evidences found in the literature and the observations of real construction processes. The proposed representation includes three locations, namely construction site (i.e. the place where the construction product is produced),

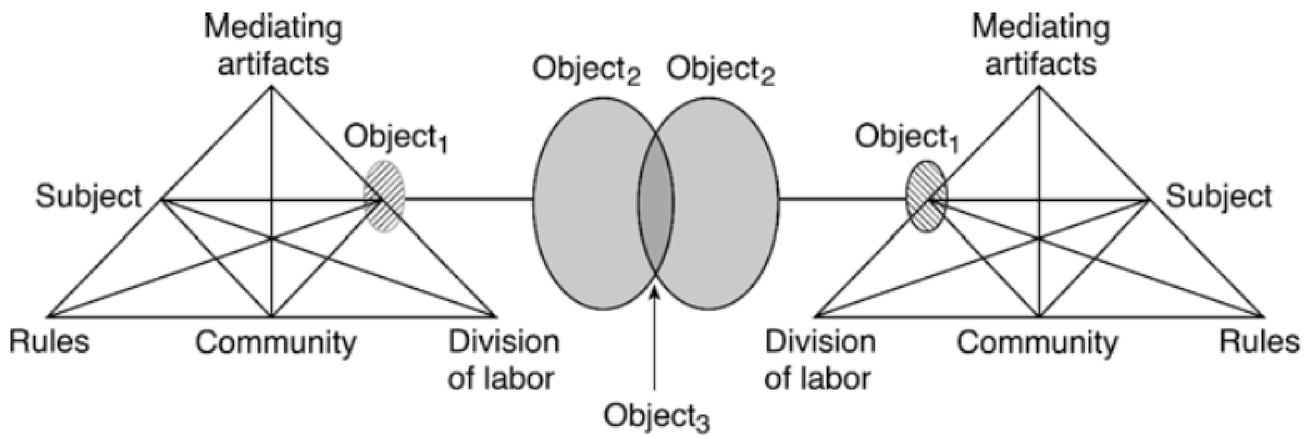
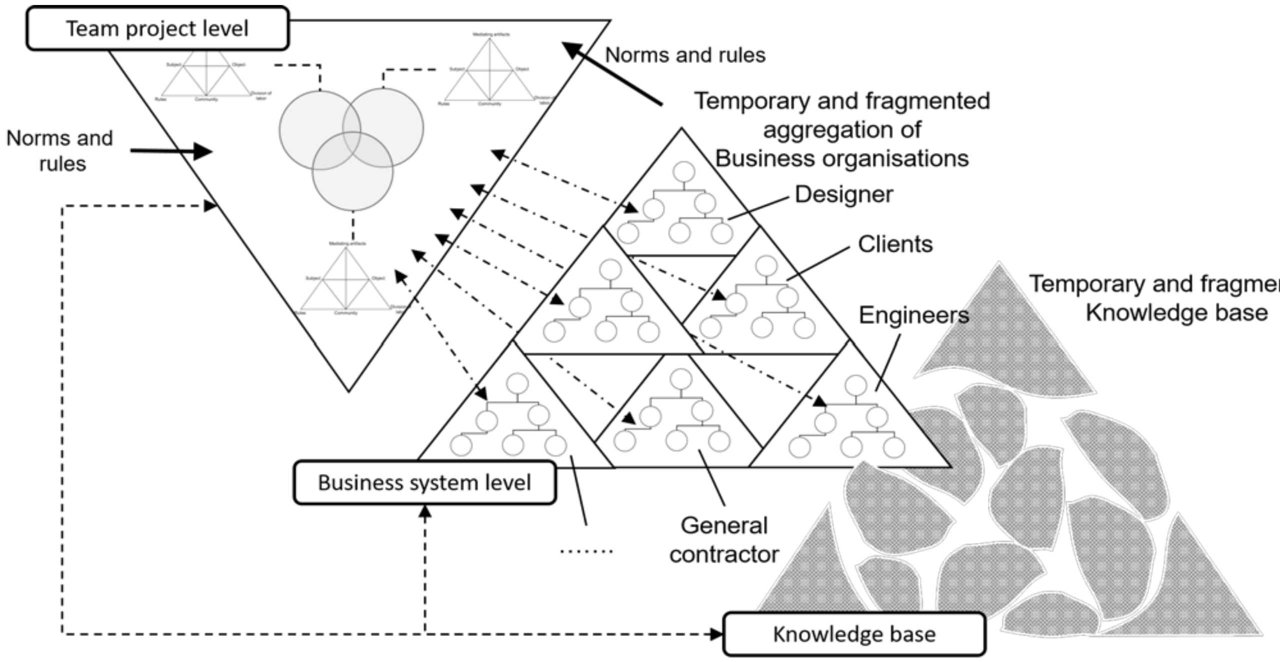


Figure 4: Representation of two interactive activity systems (Engeström, 2001)



product (i.e. the construction product such as the building or the infrastructure, once it is completed), and offices or factories (i.e. the places external to the physical location of the product where this last is designed and monitored and its components are designed, produced and monitored). The horizontal axis indicates the time correspondent to the three main phases of the construction process, namely design, construction, and operation and maintenance. The vertical axis reports the impact in terms of knowledge production and consumption, defined in qualitative fashion. According to the literature (Lin et al., 2006) in the construction phase, and especially in the construction site, there is an intensive production of knowledge as a consequence of the concentration of efforts devoted to the production of the good. Towards the end of the production, the construction site is progressively transformed in the product that will produce knowledge during its entire life cycle. Hence, the impact of construction site decrease while starts the impact of the product as a physical place. In the proposed representation, the time scale is not coherent to the real life cycle of the building due to scale problem. In fact, operation and maintenance phase can be seen as longer than it is in the graph. The oscillation of the graph in the operation and maintenance phase highlights the dynamicity of the impact along the life cycle that can change according to specific events including maintenance, and/or restoration.

In every phase and in every location can be recognised examples of both tacit and explicit knowledge. The design phase is characterised by an intensive use of regulations (e.g. national, local, hygiene), standards (e.g. fire safety, acoustic, management), and other requirements (e.g. clients requirements). Many of the solutions that can be used to fulfil these requirements can be converted in an explicit form of knowledge and can be stored and used through digital tools. For example, several studies explored the use of IT solutions to handle this explicit dimension. These include the use in energy simulations (Cheng, Das, 2014), the use of ontology-based approaches (Yurchyshyna, Zarli, 2009; Zhong et al., 2012), the evaluation of permissions from public administrations (Pavan et al., 2017), and the representation of regulatory knowledge through open standards (Dimyadi, Pauwels, Amor, 2016). Nevertheless, the identification of the correct solution between all the possible ones that can be proposed by an algorithm, the interpretation of design solutions in their context in a human perspective and the management of design teams are only some examples of the variety of tacit knowledge that can be experienced in the design phase.

During the construction phase, the stakeholders mature genuine experiences about the constructability of a specific solution, the effective applicability of the solution in the context and its alignment with time and costs hypothesized in the design phase. Hence, during the construction phase are generated problem solving, know-how, know-what and innovation (Lin, Wang, Tserng, 2006). In this phase mostly of the knowledge is tacit and its collection and transmission is a critical issue in the process. In fact, in a general contractor environment, the site

Figure 5: An integrated vision of the hypertext organisation schema for the construction sector

work is subcontracted to various trade contractors on a competitive tendering basis. Therefore suppliers have no incentive to share learning experiences (should read knowledge) for the sake of reapplying them on future projects of the main contractor (Koskela, Vrijhoef, 2001). Furthermore, in the construction phase the interaction between designers, engineers, clients, authorities, contractor, and subcontractors produce a dynamic environment of knowledge generation and conversion. However, there is not a unique business level where can be established techniques and technologies to document this knowledge asset.

The operation and maintenance is distributed in a long time span. Furthermore, once the design and construction phase is concluded, it is difficult identifying who is the subject interested in the collection, management, use and update of the information and of the experiences produced during the life cycle of the construction product. In other sectors, like the automotive one, the manufacturer can act as central collector in all phases including design, construction and monitor of the product. In the construction sector, this is hardly the case. Nevertheless, there is a substantial learning opportunity from the analysis of a construction product (i.e. building, infrastructure) during its operation. For example, the durability of a technological solution can be assessed along its life cycle, and the effectiveness of a design solution in satisfy the client's requirements can only be evaluated following the experiences of the client.

CONCLUSIONS

This paper proposes a critical analysis of the hypertext organisational schema and of the SECI model presented by Nonaka and Takeuchi to evaluate their possible integration in the construction sector. The above-mentioned paradigm presents several issues when introduced in a fragmented and conflictual organisational environment. In particular, the difficulties in creating a friendly environment and the temporal aggregation of subjects with a different cultural basis can hinder the principles of the hypertext organisational schema and of the SECI model. Hence, considering the peculiarities of the construction sector and the complex of interrelations between the possible stakeholders involved in a project, the author of this paper proposes an integrated interpretation of the hypertext organisational schema including the societal and cultural aspects derived from CHAT.

The author argues that a spatio-temporal perspective must accompany an organisational vision on knowledge because of the spatial distribution of construction sector's products (buildings, infrastructures) and the long life cycle of these last. Hence, the author proposes a qualitative graph that can represent the evolution of knowledge creation and consumption during the construction process.

Nowadays the study of collaborative means and environments supported by digital processes and instruments represents one main area in the research field. Several studies proposed frameworks and solutions related to both collaborative and KM environments. The proposed schema can help in further developing the existing frameworks starting from a theoretical comprehension of the relations between the involved stakeholders to optimise their processes of use in the practice. Hence, future research can look in the development of collaborative environments and/or KM environments frameworks based on the proposed schema answering questions such as how can we optimise the integration of new processes e.g. based on digital means in the construction sector?. Moreover, a quantitative evaluation related to the proposed spatio-temporal schema can be identified as a valuable future line of research.

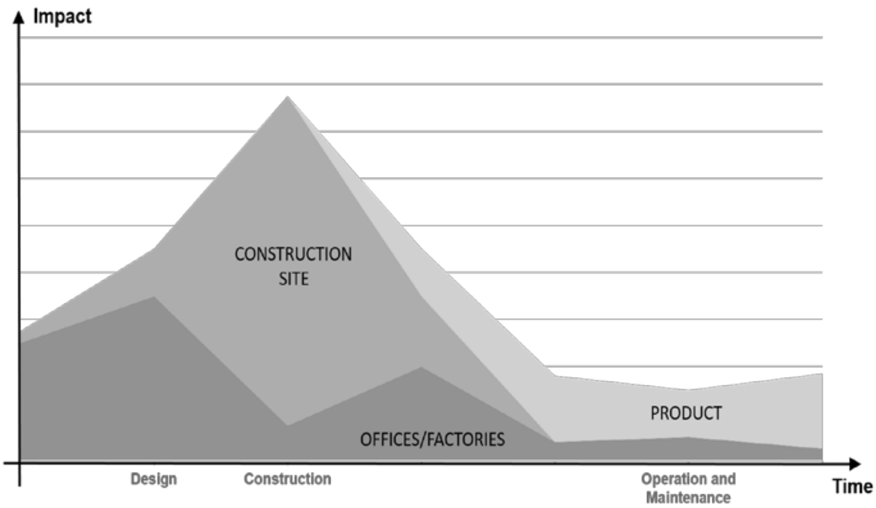


Figure 6: A spatio-temporal perspective in knowledge generation and use

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