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Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review

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ABSTRACT

The fourth industrial revolution (Industry 4.0) is changing not only the manufacturing industry but also the construction industry and its connected supply chains. Construction supply chains (CSCs) have specific characteristics, such as being temporary organizations that require high coordination efforts to align the processes of supply chain actors. The concept of proximity is used to analyze synchronization between suppliers and the construction site. This article presents a framework for explaining Industry 4.0 concepts that increase or reduce proximity. We find that Industry 4.0 technologies mainly influence technological, organizational, geographical and cognitive proximity dimensions. This presents benefits and challenges for CSCs. This framework is based on the results of a systematic literature review of scientific papers and analysis of applicability through practical publications and examples from industrial case studies.

1. Introduction and motivation

One decisive characteristic of construction supply chains (CSCs) is that all involved actors have different distances, both physical and cognitive, to the location of production [1]. These distances affect planning and directing of discrete quantities of materials to the construction site where the object is assembled [2]. Management of CSCs is widely understood as essentially supply chain management (SCM) applied to a specific kind of cooperation. However, Dainty and colleagues [3] identified distinct features that are unique to CSCs and require specific management tasks. Most notable is the temporality of construction projects.

This feature facilitates narrow-minded "win-lose" attitudes between suppliers and manufacturers, who focus on short-term gains and are unwilling to invest in long-term relationships. Thus, information flow between general contractors and subcontractors often is poor, due to low transparency, inadequate information exchange and limited communication. This may lead to false expectations and unrealistic and uncertain lead times for materials and equipment [1]. CSC managers, then, face particular challenges. These challenges, as we will show, are associated with so-called proximities that account for inefficiencies in CSCs.

We will argue in this paper that many challenges in CSCs relate to distance or closeness between actors in the supply chain. For instance, motivation, commitment and engagement all are factors influenced by proximity to the decision-making unit [4]. In a similar vein, communication barriers, or exclusion from information flows, negatively impact commitment and involvement in solution-finding [5]. Many concepts have emerged to deal with these challenges since the advent of Industry 4.0 and digitization technologies.

These concepts have the power to bridge objective geographic distance. As such, they are viewed as promising for improving inter-organizational collaboration among actors in the CSC. In addition, these concepts also are known to change subjective distances. These include organizational, cognitive, social, cultural, institutional, and technological proximities. By drawing on proximity theory, we are able to show that Industry 4.0 concepts foster what Getler calls "de-territorialization of closeness" [6]. In many instances, construction firms and suppliers coordinate their actions by means of digitization, creating a sense of proximity regarding major processes, routines and procedures.

However, maximum geographical closeness facilitated through face-to-face interactions, for instance long has been seen as more conducive to efficient collaborations than technology-mediated interactions. Several authors have been critical of these assumptions about closeness, arguing, for example, that closeness between actors is less straightforward than often assumed [7–9]. In other words, some argue that the relevance of high proximity tends to be exaggerated and that there are trade-offs between distance and closeness.

In our study, we address four related research questions. We first answer the question, "Do Industry 4.0 concepts mitigate problems

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resulting from proximity (i.e., distance/closeness) in CSCs?". We specify our answer to, "Which concepts in particular enable solving of proximity related challenges?". However, we also explain, "How and to what extent do Industry 4.0 concepts contribute to solving these challenges?". Second, by referring to efficiency trade-offs between distance and closeness, we adopt a critical position to address the question, "What are the conceptual limitations of too much or too little proximity and how does this effect CSC efficacy?".

This paper is among the first to introduce proximity theory, which is widely discussed in innovation studies as well as construction SCM (CSCM) and is undergoing a deep digital transformation [10–13]. We contribute to a better understanding of inter-organizational challenges in the area of Industry 4.0 in CSCs and how to face them. We further analyze Industry 4.0 concepts and their coordination mechanisms with respect to the efficiency of CSC collaborations. We show that not all Industry 4.0 concepts affect all proximities to the same extent. Specifically, technological, organizational, geographical and cognitive proximity are most likely to be changed by Industry 4.0 concepts.

In addition, we demonstrate how closeness and distance are two extrema on one continuum and how efficiency gains are realized with a balanced interplay between both dimensions. This effect suggests the value of more fine-grained management of Industry 4.0 concepts within CSCs. Addressing this need for management strategies, we present practical recommendations for businesses to better manage proximity through Industry 4.0 concepts. In particular, we provide a framework to study efficiency gains that result from considered application of these concepts.

We develop our arguments based on a systematic literature review (SLR), which is outlined after the following section on basic concepts. The SLR is a detailed overview of current research on technology use in CSCs. We then build on our evaluation of the impact of Industry 4.0 concepts on proximities in CSCs. Finally, we refer to the extended literature on proximity to critically question the benefits of efforts to increase proximities. From our analysis, we find (*Key Finding 1*) that Industry 4.0 concepts applied without reflection on context can lead to over-embeddedness.

2. Basic concepts

2.1. Proximity

Research on proximity has identified the distance between two or more entities as a major determinant of knowledge transfer, innovation, and inter-organizational cooperation [14,15]. For the purposes of our study, we refer to proximity in its widest sense, as "distance". It has been known for a long time that distance impacts relations. However, one major achievement of the so-called *French School of Proximity* [11,16,17] was to show that proximity comprises more than just geographic distance between two actors.

Today, distinctions most often are made between geographic and organizational proximity. However, some authors differentiate between three to five dimensions of proximity, depending on the scope of their research. If we understand proximity as a multi-faceted concept, we can see it as a construct involving geographic, organizational, cognitive, social, cultural, institutional, and technological dimensions [10]. The heterogeneity of these dimensions accounts for diverse and sometimes incommensurable features of proximity.

Theoretical frameworks to investigate the effects of proximity range from Marshallian theories regarding industrial distinctions and externalities [18–20] to more recent theoretical concepts like research and development (R&D) spillover [21,22], innovation ecosystems [23,24], organizational networks [13], and strategic alliances [25]. Accordingly, models today, as Moulaert and Sekia [26] note (see further [13]), suffer from conceptual ambiguity. However, there are some aspects of proximity that are commonly agreed upon; for example, that actors attempt to reduce uncertainty when making decisions.

Another consistent finding in previous studies is that the search for knowledge happens most often in close proximity to an existing knowledge base [8] as this increases the likelihood of similarity between the cognitive bases of actors and organizations. This then increases the potential to identify, interpret and exploit external knowledge [27]. It also is commonly accepted that most knowledge is tacit, path dependent, and embedded in idiosyncratic contexts.

Thus, learning and innovation often require the capacity to combine diverse knowledge bases with complementary capabilities of heterogeneous actors within and between organizations [28]. Contextualization, therefore, is easier if actors are close in proximity. The core dimensions of proximity explain the reduction of uncertainty through the process by which organizations search for external information. Proximity also has the power to solve the problem of coordination. This, in turn, may facilitate inter-organizational learning [15,29].

As our underlying assumption is that Industry 4.0 concepts may affect cooperation between suppliers and the construction site, we do not analyze proximity exclusively on a global level. Instead, we are interested in investigating if and how Industry 4.0 concepts change interactions on alternative sublevels. Accordingly, we consider proximity to be a compound concept [8,16] that is, according to prior studies, best analyzed with respect to its building blocks. These types of buildings blocks can be subdivided into external and self-chosen proximity dimensions. Examples of dimensions of external proximity include the geographic distance between supplier and contractor, both parties' level of technical knowledge, and how cooperation is organized.

Other proximity dimensions, such as culture, social norms, or institutional environments are not, or at least not easily, amenable to external influence. The focus of our paper is managerial implementations of proximity. As such, it is consistent with existing research that our paper focuses solely on dimensions of proximity that are capable of being influenced. Table 1 shows our general definitions of these dimensions, as well as some examples from CSCs.

Boschma et al. [8,9] and others [30,31] have attempted to deepen the concept of proximity through the so-called "proximity paradox". They argue that, while proximity may be crucial for actors to connect and exchange information and knowledge, too much proximity may hinder innovative solution-finding. In other words, a high degree of proximity is a prerequisite for connection but not necessarily for increasing novel problem-solving. In what follows, we outline the specifications of CSCM and how Industry 4.0 affects these supply chains. Based on the claim that there is an optimal level of proximity in cooperation [9], we show how these levels may increase efficiency in CSCs.

2.2. Construction supply chain management

SCM aligns upstream and downstream companies to create value for the customer [32]. More specifically, SCM "regulates the material, information and cash flows among a set of aligned companies" [33]. CSCs face specific challenges that result from different types of proximity. For this reason, SCM in construction has attracted scholarly interest since the late 1980s [34]. For instance, CSCs typically are Make-to-Order (MTO) supply chains, converging all materials to the site where the building is assembled from incoming materials [35–38].

Moreover, according to the type of material assembled, different supply chain configurations with different lead times should be considered. These configurations include Make-to-Stock (MTS) for consumables such as bolts; Assemble-to-Order (ATO) for doors and windows; MTO for cast-in-place concrete or prefabricated panels; or Engineer-to-Order (ETO), which is common in the field of high-class design façades [39]. The main aim of CSCM is to plan and direct specific quantities of materials to the site where the final assembly takes place [2].

For the purposes of our study, we understand CSCs as temporary