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CA-FCM: Towards a formal representation of expert's causal judgements over construction project changes

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ABSTRACT

Aimed at improving the proactive benefits of Fuzzy Cognitive Mapping (FCM) for predicting construction project changes, this paper presents CA-FCM: a Context-aware Fuzzy Cognitive Mapping approach. CA-FCM's main functionality is to imitate the intuitive causal judgements of project experts over change causation in different contextual settings. Invoking the logical inference capabilities of semantic web tools, a hybrid inference mechanism is embedded within the proposed framework which enables establishing contextual connections between prospective causal factors through a semi-automated process of generating relevant causal statements. Hence, CA-FCM can assist decision-makers with (1) a shared sense-making of the domain concepts which would significantly facilitate the manual construction of FCM scenarios, (2) providing contextualized recommendations of causal information required for developing FCM scenarios, (3) dynamic modelling of causal inferences, imitating expert reasoning on change causation and propagation. Towards providing a detailed delineation of CA-FCM's effectiveness on providing assistance in planning for project changes, a partial implementation of the proposed framework was conducted within a real case scenario.

1. Introduction

Uncertainties and complexities inherent in the nature of construction projects, make these projects subject to many unforeseen changes, often resulting in significant undesired consequences. The seemingly inevitable occurrence of such changes has led to a consensus among both academia and industry that changes should be proactively managed rather than to be eliminated [1–5]. However, tackling changes proactively, requires a profound understanding of the possible mechanisms in which causal relationships between various factors result in emergence and propagation of unforeseen change events.

Fuzzy Cognitive Maps (FCMs) [6], offering visual models of causal structures are powerful tools for anticipating future states of complex and distributed systems [7–11]. Previous research has shown that FCMs are fairly effective for describing experts' belief system and representing both explicit and tacit traits of human knowledge [10–13]. This, along with other features such as expressiveness power, simplicity, flexibility, intuitiveness, and feedback inclusion [14], provide compelling justifications for FCMs to be used for generating causal accounts of change occurrences, in a way that those accounts are reasonably comparable to their corresponding ones perceived in the mind of project experts.

Nevertheless, despite their justified methodological appropriation for representation of mental models, FCMs have some considerable shortcomings in terms of *semantics* and *pragmatics*. The former one refers to the fact that individuals tend to make use of their own mental lexicons when describing a given phenomenon [15]. In the light of such lexical variations, a lack of explicit semantics would inevitably lead to word/concept-sense ambiguities within different FCM scenarios. Such ambiguities could be aggravated as the number of interchangeable terms within a domain exceeds to a certain limit, as is the case for construction project changes terminology [2,16,17]. Consequently, establishing a shared vocabulary of the relevant concepts seems to be vital when using FCMs for modelling construction project change events. On the other hand, while semantics is principally concerned with those aspects of meaning that are context-independent, pragmatics deals with contextual attributes of human utterances [15]. In this respect, Love et al. [18] have recently underlined the lack of a contextual underpinning for the accumulated knowledge about rework and change causation in construction projects. According to that study, without a clear definition of the context where reworks and changes have originated, new causal senses are probable to be adopted, which ultimately prohibits a profound understanding of the phenomenon. Such concerns are comparatively in line with philosophical arguments about

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contextual dependencies in causality knowledge: causal judgements are notably sensitive to contextual factors in two main respects: *context of occurrence*, and, *context of enquiry* [19]. In that sense, when it comes to modelling causal judgments of human individuals in the form of FCM scenarios, particular attention should be paid to these sources of context-sensitivity.

Most recently, by the emergence of context-aware computing paradigm, an increasing attention has been paid to contextual knowledge modelling for enabling the reuse of past experiences [20]. Context-aware computing promotes system's intelligence for context understanding through incorporation of contextual factors embedded in the semantics of information objects [21]. Subsequently, a plethora of studies have been conducted in various fields of research with the aim of developing knowledge-based systems which are more adaptive to the contextual essence of human knowledge utterances [22–31]. The construction research field has not been an exception [29,32–35]. To date, however, context-aware computing principles have not been specifically invoked for leveraging key potentials of FCMs for knowledge representation.

Regarding the abundant number of concepts relevant to construction project changes, the manual construction of FCMs would be neither efficient nor practicable. Thus, the central thesis of this paper is that FCMs' applicability should be enhanced from an organizational knowledge management perspective. To this end, advanced computational procedures would be required to be established for generating FCM scenarios in a semi- or full-automated order. As indicated in [36], a fair number of studies aimed at automatic generation of FCM models have been previously published. Nonetheless, those proposals are predominantly based on machine-learning techniques which does not meet the research requirements for the present study for two main reasons. First, reliability of such approaches is tremendously dependent on the amount of robust historical data available, meaning their performance could be significantly deteriorated by data-scarcity issues, as is the case for the present study. Second, in those approaches FCMs are basically derived from generalized inductions. FCMs perceived through a pattern recognition algorithm could rarely provide profound explanations required for a deeper understanding of causality which would be pivotal to the essence of proactive approaches.

Accordingly, the primary aim of this paper is to propose a knowledge-based approach for a semi-automated generation of FCMs representing the causal structure of prospective changes of a given construction project. Moreover, the research seeks to address the question that how the sources of context-sensitivity associated with human causal judgements could be addressed for a formal representation of expert's causal accounts in the form of FCM scenarios. To this end, building upon the notion of situation-aware fuzzy cognitive mapping approach (SA-FCM) proposed by Kokar et al. [37], we proposed a novel approach capable of creating more context-adaptive cognitive models: the Context-Aware Fuzzy Cognitive Mapping (CA-FCM) approach. To meet the requirements for gaining contextual awareness over change causation, the notion of context-aware recommender systems is borrowed in this paper. In particular, drawing upon the constructs of ontological engineering and semantic web technologies, a hybrid inference mechanism was designed for CA-FCM which allows for contextual derivation of relevant FCM scenarios on the basis of low-level observations. Although, ontologies and semantic web tools have previously been exploited in conjunction with FCMs [7,8,10,36,38], to the best of the authors' knowledge, no published study has explicitly attempted at coupling the FCM approach with ontology-driven context-aware frameworks.

The rest of the paper is organized as follows: First, the essential theoretical concepts and introduction to related works are presented in Section 2. Then, the four-layered architecture of the CA-FCM framework is outlined in Section 3. Section 4 gives an overview on contextual knowledge modelling processes and introduces the hybrid inference architecture designed for CA-FCM. In Section 5, the core functionality of CA-FCM is illustrated through a partial implementation of the framework. In Section 6 comparison with related works is provided. Finally, conclusions and suggestions for future directions are given in Section 7.

2. Research background

2.1. Change prediction in construction projects

To date, many studies have been conducted to investigate the underlying factors leading to change events within construction projects which in a majority of them, results were coming from statistical analysis over subjective information obtained from questionnaire surveys [16]. However, tackling changes proactively, requires a proper understanding of the possible mechanisms in which cause-effect relationships between various factors result in change occurrence and propagation. In fact, inferring cause-effect relationships on the basis of correlations observed from historical data would be a statistical fallacy when investigating causality within a phenomenon [18]. On the other hand, in recognition of the essential role of predictions in proactive approaches, a growing number of predictive models based on machine learning techniques have been proposed within the existing body of research on construction project changes [1,39,40]. Although analyses based on statistical and/or computational approaches could be beneficial to performance benchmarking at industry level [1], they could rarely provide plausible explanations for change causation in the context of singular projects. This is predominantly due to the philosophical foundations of such approaches which is based on generalized inductions.

Despite their established benefits, when data-driven approaches are adopted for the analysis of construction project changes, the scarcity and reusability of change-related data would pose serious challenges in terms of model reliability. In [41], the main causes leading to difficulties with reusability of construction defect data are listed and discussed thoroughly. Those causes include: lack of formal representations, insufficient amount of available contextual information, lexical ambiguities within textual information, and, reluctance to an effective data sharing within the community. Apparently, such issues can also be attributed to the scarcity and reusability issues with project change-related data as well. Nonetheless, when it comes to construction project changes, some issues could more severely aggravate the problem. For example, since project parties consider change data as a firm evidential basis to support their claims over unforeseen project changes, reluctance to an open culture for sharing project change-related data becomes extremely intense. In this light, access to a sufficient amount of robust data about changes occurred in previous projects, which includes essential contextual information about those change events in a way that is reasonably reliable to be used in data mining approaches, would be severely restricted. This issue, in part, has led researchers to investigate whether knowledge-based approaches, which instead of historical data rely on the acquisition of expert knowledge, could deliver more promising results with respect to change analysis within construction projects.

On top of decreasing the dependency on historical data, application of knowledge-based models with system analysis capabilities, for instance in [42,3,2], etc., have proved effective in provision of deeper insights into the change causality. As opposed to causal inductions derived from historical data, in these approaches, conclusions are explicitly or implicitly drawn through a deductive mechanism. While such approaches have certain comparative advantages in terms of expressiveness, they suffer from lower levels of formality when compared to data mining approaches. Hence, from a knowledge representation perspective, lack of careful attention paid to such issues could pose serious impediments to knowledge sharing and reuse which are of the essence when it comes to proactive approaches. Thus, creating a proper balance between the notions of *expressiveness* and *formality* would be a