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# A collaborative system for capturing and reusing in-context design knowledge with an integrated representation model

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ABSTRACT

Current research on design knowledge capture and reuse has predominantly focused on either the codification view of knowledge or the personalisation view of knowledge, resulting in a failure to address designers' knowledge needs caused by a lack of context of information and insufficient computational support. Precisely motivated by this gap, this work aims to address the integration of these two views into a complete, contextual and trustworthy knowledge management scheme enabled by the emerging collaborative technologies. Specifically, a knowledge model is developed to represent an integrated knowledge space, which can combine geometric model, knowledge-based analysis codes and problem-solving strategies and processes. On this basis, a smart collaborative system is also designed and developed to streamline the design process as well as to facilitate knowledge capture, retrieval and reuse as users with different roles are working on various tasks within this process. An engineering case study is undertaken to demonstrate the idea of collaborative knowledge creation and sharing and evaluate the effectiveness of the knowledge representation model and the collaborative technologies employed. As evidenced in the development and evaluation, the methods proposed are effective for capturing an integrated knowledge space and the collaborative knowledge management system not only facilitates problem-solving using knowledge-based analysis but also supplies in-context tacit knowledge captured from the communications between users throughout the design process.



## 1. Introduction

Engineering design is a knowledge-intensive process and designers need a lot of informational support throughout this process. A recent study has shown that engineers spend nearly 60% of their working time engaged in all types of information-related activities [1]. These activities include using software packages to process information and facilitate knowledge-based engineering analysis as well as sharing knowledge with colleagues to improve decision making. In this sense, design knowledge takes the form of both tangible objects that can be edited, copied, transferred and programmed and precious experience that can only be learnt through a community of expertise, i.e. the codification view and the personalisation view of design knowledge [2]. Knowledge Management (KM), as a key enabling technology for distributed enterprises in the 21st century, has attracted considerable attention in recent engineering design research [2]. Previous research on KM for engineering design tends to be very diverse, ranging from understanding engineering designers in design activities in terms of their information needs, information organisation and usage, and information-seeking behaviours [3–10], to the development of structured models to represent design knowledge [11–16] as well as the development of methods and tools for knowledge capture, retrieval and reuse [14,17–21].

However, there still exist a few barriers to effectively applying KM tools to design projects. First, a recent study has revealed an apparent failure to satisfy designers' knowledge needs due to the variety of the needs and current knowledge models' particular emphasis on formal design knowledge [7]. Second, knowledge capture tools are quite intrusive in the sense that they are not used as an integral part of the design process, resulting in a lack of design context [21]. In addition, knowledge retrieval research is far from being enough, making the tools hard to use especially when a large amount of knowledge records have accumulated [22]. Third,

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current research has a particular focus on either designers or knowledge objects while an integrated approach to addressing both the knowledge objects and the processes whereby these objects are created and designers' communications largely take place [21].

These barriers are to some extent ascribed to a separation of the personalisation and codification views in the current research on KM for engineering design [2,22]. The emerging collaborative technologies have great potential for addressing these barriers by providing a smart collaborative computing environment and facilitating designers' knowledge acquisition and sharing activities. This research precisely aims to address this gap by developing a novel knowledge representation model that emphasises placing designers in the very centre of the knowledge creation and sharing process. The capture of informal knowledge created and shared during design communication can provide important design context for formal knowledge objects. Additionally, it is also focused on exploring the potential of the collaborative computing technologies towards the development of next-generation collaborative knowledge management systems.

The rest of this paper is organised as follows. Section 2 reviews related work on knowledge management, knowledge representation and designers' collaboration and communication during the design process. In Section 3, a knowledge model for representing an integrated knowledge space is described with a particular focus on the integration of different kinds of knowledge with different forms and granularities of information. Section 4 details a method for knowledge-based engineering analysis which, based on knowledge of domain experts, can transform customers' needs and expectations into detailed functional requirements. In Section 5, the design, development, and evaluation of a smart collaborative system for design knowledge management is explained. Finally the discussions and conclusions are given in Section 6.

## 2. Literature review

### 2.1. Data, information and knowledge

Knowledge engineering is critical to research and development of enterprises [23]. In the context of engineering design, knowledge management specifically aims to reuse useful knowledge in new design tasks and this reuse is realized through transferring knowledge in the form of information. As such, the terms 'knowledge' and 'information' are often used interchangeably while 'knowledge' is particularly used to emphasise reusing knowledge [1,3,4,7,12,16,20,24–27]. A differentiation of the terminologies can help researchers identify the particular focus of research to achieve an appropriate scope of definition [2,7]. Specifically, data refer to raw data in the form of numbers, words, symbols, etc. to describe basic facts, which can be created, copied, edited and deleted. Information usually takes the form of structured data, which is more tangible than knowledge. The terms 'information' and 'information management' are often used in the context of knowledge and knowledge management as information is a necessary medium or material for eliciting and constructing knowledge [2]. Information in itself does not necessarily embody knowledge which is more about beliefs and commitment and is usually associated with actions and particular business processes [2].

Knowledge is difficult to assimilate and has a personal aspect which demonstrates the key difference between knowledge (as a 'competence notion') and information (as tangible objects that can be managed) [2]. In this sense, the terms 'tacit knowledge' and 'explicit knowledge' have proposed as a way of differentiating between personal knowledge and that which has been codified as a company information resource. Tacit knowledge resides in a community's know-how which can be market-based (in products), infrastructure-based (in systems), personal (concerning staff and competence of suppliers) or administrative (concerning workflow and processes) [2]. The term 'knowledge model' has been used to refer to an information representation scheme for facilitating codification [12,16,28–30]. In this paper, unless otherwise stated, formal knowledge is used to describe engineering know-what and know-how embodied in codified information sources such as a 3D geometric model, a simulation model, a data-accessing source (e.g. material and manufacture data) or a computer routine (e.g. parameters optimization); and tacit knowledge refers to engineering know-how and know-why in relation to personal knowledge and experience (within a community) of understanding an issue, developing a problem-solving strategy, considering necessary constraints and options, and reasoning on possible decisions. These are within the scopes of term definitions identified in literature. A knowledge model is used as a scheme of representing an integrated knowledge space covering both the formal and tacit aspects.

### 2.2. Knowledge management for engineering design

Engineering design is heavily informational [9] and designers require a variety of information and knowledge from various sources to support their decision-making [2,7]. Therefore, understanding the knowledge needs and information usage behaviours of engineering designers has long been a focus of KM research for engineering design [3–6]. It is a common practice for designers to use formal knowledge in various forms such as sketches, CAD models, calculation sheets and simulation results [10,24]. In addition, a good design largely depends on the experience relating to design strategies generally possessed by experienced designers. This kind of experience is often termed 'internal knowledge' or 'informal knowledge', which provides the basis for developing a 'corporate memory' bank [31]. Research on KM for engineering design generally falls into two categories in terms of the two focuses on different knowledge types, namely personalisation and codification [2]. The former is more focused on informal knowledge, emphasising a range of organisational issues such as the communication between designers in a distributed design team, while the latter involves technological issues such as the application of Information and Communication Technologies (ICTs) to the codification of formal knowledge. Work on understanding through-life knowledge and information represents one of the trends for recent research in this area [27,32]. In addition, despite it is difficult to codify informal knowledge, its importance has been highlighted by many researchers [14,22,33]. It has been indicated that, in terms of reuse, KM needs to focus on the experiences pertaining to the decision processes associated with the various design phases, e.g. the utilisation of new technologies and the specification of engineering components [25]. However, the valuable knowledge of experienced departing staff is not readily captured [22]. This is in part ascribed to the particular focus of existing KM research for engineering design on either the personalisation view or the codification view, e.g. ICTs are typically only used for codification [2,33]. Therefore, an integrated approach to KM can facilitate capturing and reusing informal knowledge and thus can achieve improved design quality and efficiency.

### 2.3. Knowledge representation, retrieval and reuse

Research in this area aims to develop enabling technologies for KM tools. For instance, the organisation and storage of design information has been explored [10,25,34], and its computer support has also been developed [26,35,36]. Various models have been developed to represent formal knowledge such as the knowledge model for an artefact repository [37], the