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TOWARDS A CONCEPTUAL FRAMEWORK FOR MOBILE 'KNOWLEDGE MANAGEMENT' SUPPORT

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1. Introduction

This paper proposes the concept of providing *modular*, *just-in-time* knowledge support to engineering designers engaged in *mobile work* through the use of portable devices. In this context, the paper contributes a conceptual framework that supports and improves the existing knowledge communication and work between designers in mobile design situations. This framework is the basis of ongoing research carried out at the Concurrent Engineering Research Unit (CERU) at the Department of Manufacturing Engineering (DME), University of Malta, in order to investigate and support the role of mobile Knowledge Management (*mKM*) in engineering design.
The paper is structured as follows. Section 2 outlines the problem that this research attempts to address in the context of designer mobility in product design. This is followed by a state-of-the-art literature review on mobile knowledge management, where a number of state-of-the-art mobile knowledge management systems are compared and contrasted. Furthermore, designer activities that can be supported by portable devices during mobile work are identified. Section 4 highlights the requirements necessary for mobile knowledge management in engineering design to be supported. This leads to the development of a conceptual framework by which engineering designers engaged in mobile work can be provided with modular, just-in-time knowledge support, presented in section 5. Finally the paper discusses the proposed framework, and concludes by highlighting the contribution that this developed framework has on the engineering design domain.

2. Designer mobility problem background

Design is considered to be a central activity in engineering. However, given that design is a problem solving activity, and that engineering designers tend to solve problems based on the available knowledge, knowledge must be presented timely and in the right format and quantity during the design process. Otherwise the optimum result in the context of product design will not be obtained. Furthermore, engineering designers are frequently outside the design office to carry out other tasks away from their usual working place [Bellotti V. 1996; Kristoffersen S. 2000]. This *mobility* is seen as a detriment to engineering designers as they occasionally find themselves without the knowledge support required to take the necessary decisions.
This paper argues that adequate knowledge support is required by engineering designers whilst being *mobile*, i.e. when away from their usual workplace (Figure 1b), as opposed to design situations in which the designer is in the office, where knowledge is readily available (Figure 1a). Consequently, designers are effective in their work both when in their design office as well as when in mobile work situations.

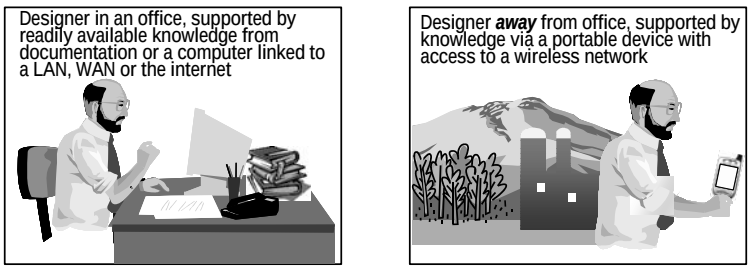

Figure 1. Adequate support needs to be provided to designers even when away from their office

3. Current state-of-the-art mobile knowledge management

Designers constantly require knowledge support during the design process. This is confirmed from the large amount of knowledge management systems designed and developed with the main purpose of supporting designers with critical decision-taking. However, designers also need to be adequately supported when they are in a *mobile* setting. Perhaps the fact that nowadays a host of new mobile technologies (such as portable devices) is more accessible than ever before, this should make it easier for the mentioned knowledge support to be realised. This section addresses two important issues: *'knowledge management'* and *'mobility'* in the context of engineering design, in order to render how and why designers must be provided with *modular*, *just-in-time* knowledge support.

Just-in-time knowledge provision implies that knowledge is provided immediately when it is required. This ensures that correct decisions are taken in unpredictable design situations, and *before* the contextual setting of the design problem changes. This knowledge support has to be presented in a ***modular*** format, such that knowledge is structured into components that can be transferred in adequate chunks of knowledge, which can also be *reused* in other similar design situations.

3.1 Knowledge management

Knowledge management (KM) started to address the problem of structuring expertise in organisations, where this expertise is made more accessible and easily shared. Knowledge management supports users by making knowledge-intensive work, such as design activity, more effective. Although there are many interpretations and versions of KM, a definition relevant in this context is the one defined by Holsapple and Joshi [Holsapple C.W. 2003]: *"… KM is to ensure that the right knowledge is available to the right processors, in the right representations and at the right times, for performing their knowledge activities"*. In other words, Knowledge Management envisions providing the right knowledge within the right context to the right person at the right time.

3.2 Supporting mobility in design

The challenge of providing timely knowledge can be alleviated by means of new communication technologies that have been recently developed. These technologies, such as the internet and wireless media, have transformed the way knowledge is experienced. Through such technological advances, everyone is more connected and expected to be *'online'* all the time. Workers find themselves in *mobile* situations more than ever, and the engineering design domain is no exception. As a matter of fact, design teams have become more mobile than ever. From a number of empirical research studies on mobile work, it is evident that most members of a product design team very often are away from their usual workplace [Bellotti V. 1996; Kristoffersen S. 2000]. Depending on the design situation, engineering designers may either be:

- *Co-located*: performing design activities face-to-face;
- *Mobile*: such as when visiting laboratories, the shopfloor, testing departments, other buildings, or to participate in meetings with other designers or with customers;

- *Distributed*: there are different scales of distribution, from designers being separated by different floors in a building to different countries and different time-zones. In contrast, *mobility implies* that a designer D_i is away from the usual workplace and is constantly moving from place to place x_{ij+n} (Figure 2). Therefore, being distributed does *not* imply being mobile; however it is possible to be mobile whilst being distributed.

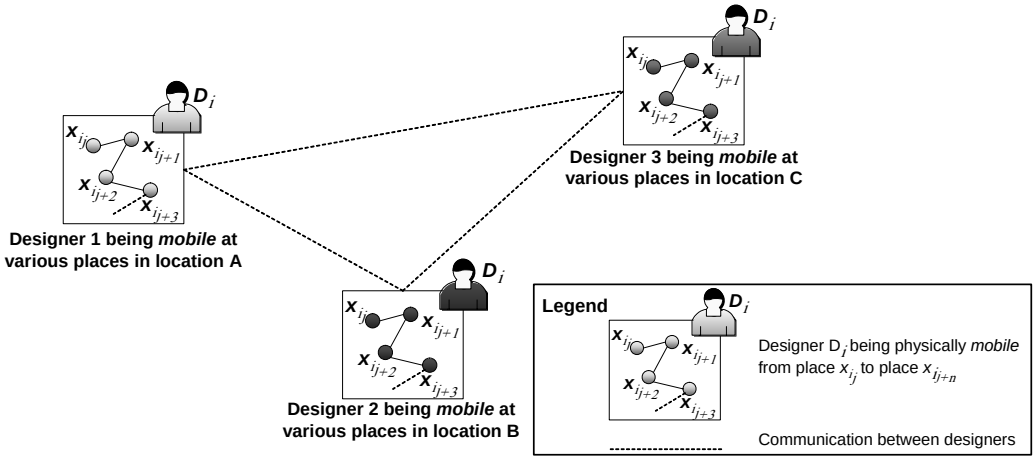

Figure 2. Mobility in a distributed environment

Fagrell [Fagrell H. 2000] argues that since mobile work is a human activity, it is difficult to define in a meaningful way. The Oxford English dictionary defines mobility as *"the quality of moving or being moved easily from place to place, or of having ease and flexibility of motion"*. Literature that addresses mobility, such as that of Kristoffersen *et al.* [Kristoffersen S. 2000], distinguishes instances of mobility as follows: *wandering* (i.e. extensive local mobility in a building or local bounded area), *visiting* (i.e. spending time in one place for a prolonged period of time before moving on to another place) or *travelling* (i.e. going from one place to another in a vehicle). Therefore designers must be adequately supported even throughout these instances of mobility, and this can be succeeded by means of new communication technologies. The next section will explore this possibility by determining the essential qualities of *mobile Knowledge Management*.

3.3 Mobile Knowledge Management

Mobile Knowledge Management (*mKM*) can be defined as "*a management process in the course of which mobile communication techniques in conjunction with mobile devices are employed for the creation, validation, presentation, distribution or application of knowledge*" [Derballa V. 2004]. Even though mKM does not augment the KM loop, mKM must still be integrated within the KM process. It is agreed that the main advantage of mKM is the increase in the access to knowledge, regardless of temporal and spatial constraints.

When engaged in *mobile work*, engineering designers require performing various activities pertaining to the main stages of the design process, as these necessitate out-of-office work. These activities can vary from requesting access to CAD (Computer Aided Design) drawings, access to knowledge about a product or a process (such as from a knowledge database or a design expert), communicating with other designers or with clients, etc. These activities all have the possibility of being supported by portable devices, as illustrated in Table 1 below.

Table 1. Designer activities supported by portable devices during mobile work

Design stage	Activities	Current possibilities of utilising a portable device
Task Clarification	Clarify task	*Communication with designers and customers to analyse and compile information and knowledge on the design problem, by:* ▪ Using messaging features such as SMS (short messaging service), e-mail*, MSN Messenger* (an instant messaging client), MMS* (multimedia messaging service) or even fax* ▪ Using phone ▪ Using embedded applications to generate a PDS (product design specification)
	Elaborate specifications	
Conceptual Design	Identify essential problems	*Generate design concepts by:* ▪ Using embedded facilities on portable device to help with capturing ideas, notes, sketches, drawings and thoughts by either using written and typed text, drawings and video/audio recordings ▪ Using an integrated camera to capture sketches and/or drawings, and share them by utilising the MMS* or e-mail* feature ▪ Using a stylus to draw sketches on the touch screen of a portable device ▪ Searching for information on websites* from internet, or from a knowledge base on a corporate network* directly from a portable device
	Establish function structure	
	Search for solution principles	
	Combine concept variants	
Embodiment Design	Develop and optimise preliminary layouts and form design	*The chosen concept is elaborated into a definitive design product model:* ▪ A CAD application can be installed on a portable device for the creation and editing of CAD drawing(s) ▪ Drawings can be stored on a portable device, to be shared* in neutral formats (such as DXF) between designers / customers ▪ Utilise embedded design tools to generate QFDs, FMEAs, and morphological charts ▪ Communicate with product modelling tools to generate and/or analyse the product model (e.g. RP, FEA etc) ▪ Communicate with other designers and product development teams through phone, SMS, MMS*, MSN*, email* or fax* to decide upon best preliminary layouts
	Select best preliminary layouts	
	Refine and evaluate against technical/economic criteria	
Detail Design	Finalise details	*Full specifications of design concept are achieved:* ▪ Design drawings and documentation may be refined / completed directly on a portable device, and shared between design team(s) for approval through e-mail* or fax*
	Complete detail drawings and production documents	
	Check all documents	

** This requires networking functions such as GPRS, Wi-Fi (wireless LAN) or Bluetooth*

3.3.1 mKM systems

Research on mobile Knowledge Management (*mKM*) in the engineering design domain is still evolving. Although Knowledge Management systems have been developed, these cannot be directly adapted to mobile work, as stationary and mobile work differ in their characteristics of knowledge requirements, and mobile environments cause different predicaments from stationary situations. It was observed from the state-of-the-art literature carried out that the need to understand mobility and to develop knowledge management systems that support mobile work is constantly increasing. Furthermore, although a number of *mKM* systems have been developed, these are applicable to domains other than engineering design. These facts provide scope for further research in the area of mobile knowledge management in the engineering design domain. To this end, Table 2 compares and contrasts a number of leading state-of-the-art mobile Knowledge Management systems.

Table 2. Mobile Knowledge Management Systems

mKM system / author(s)	Application(s)	Fundamental approach of mobile client support	Type of support
Darwin **[Kristoffersen S. 1998]**	Pharmaceutical industry	*Darwin* supports the distribution and exchange of lessons learnt within a dispersed IT-support group, by specifically using an early PDA	▪ data entry editing of tasks ▪ sharing of experiences ▪ support of *to-do* list ▪ coordination of tasks
FieldWise **[Fagrell H. 2000]**	News journalism, sales, real estate brokering	*FieldWise* is a generalized knowledge management architecture implemented for mobile news journalism by using Pocket PCs and mobile phones	▪ data entry and editing of tasks ▪ sharing of information ▪ support of to-do list ▪ location of available expertise ▪ evaluation of records
NewsMate **[Fagrell H. 2001]**	News journalism	The *NewsMate* prototype provides mobile and distributed news journalists with timely knowledge via a PDA with network access using a mobile phone	▪ support of a to-do list, matched with internal archives ▪ provides information on people involved in similar tasks ▪ provides matching between predefined external sources ▪ SMS facility to alert people with overlapping activities
Shen J., Jones Q. [Shen J. 2003]	Repair technicians	This system allows data capture *in situ* by using mobile devices (pocket PCs with integrated digital cameras) and retrieve the information from the internet	▪ uploading of photos and voice recordings via wireless transmission
mummy **[Grimm M. 2005]**	Facility management at construction sites, mobile health care support, video-based e-learning	*mummy* research focuses on capturing context to enhance intra and inter-individual knowledge transfer processes, such as remembering, reconstruction and communication	▪ retrieval and presentation of relevant information in photographic and textual format

It is not possible for these mKM systems to be adapted to the engineering design domain, as many of the activities associated with the later design stages listed in Table 1 are not collectively supported. Furthermore, product modelling, the language by which a designer can elaborate, synthesize, evaluate and communicate [Andreasen M. 1994] is not supported either. Some kind of product modelling must be supported, such as CAD models, Rapid prototyping (RP), Finite Element Analysis (FEA), assembly modelling, etc. Hence research is currently being carried out at CERU to fully investigate the requirements of *mKM* in the engineering design domain in order to understand the role and requirements of engineering designers engaged in *mobile* design situations.

4. Requirements for mobile knowledge management in engineering design

As a first step, the requirements for a mobile knowledge management support tool were identified. Based on the state-of-the-art review, it can be observed that no such *mKM* system exists which fully supports *all* the design activities encountered in mobile situations. There is a need that designers in mobile work are supported with a mobile knowledge management tool which manages the complex, information-overloaded design work environment. The elicited requirements are summarised below:

- Automatic classification of captured knowledge in KB (knowledge base) repository, categorised according to the design stage – CBR (Case Based Reasoning) techniques are useful in this respect;

- Automated modular knowledge structuring / indexing which permits effective storage and searching;
- Knowledge retrieval mechanism which supports the knowledge clients through different means, including textual, audio, graphical and multimedia formats – Data Mining techniques provide useful in this respect;
- Interaction with 3D CAD drawings and other design product modelling applications that support the generation and analysis of product models directly from portable device;
- A reliable wireless network infrastructure that provides access to internet – 2G (e.g. GSM) networks are optimised for voice transmission, whereas 2.5G (e.g. GPRS and EDGE) and 3G (e.g. UMTS) networks are more suited for audio and video transmission;
- A reliable wireless network infrastructure that provides access to an organisation's network services – WLAN (wireless local area network) technology and Bluetooth are standard wireless technologies;
- Portable communicating devices that are capable of displaying graphics and provide powerful information processing and data entry capabilities - PDAs (personal digital assistant) and Pocket PCs (mobile hand-held computing devices) are the most suitable.

The requirements listed above are not comprehensive, however they have resulted in the development of a high-level conceptual framework for mobile 'Knowledge Management' support.

5. Conceptual Framework of mobile 'Knowledge Management' support

This conceptual framework has been developed with the aim of providing designers engaged in mobile work with *modular*, *just-in-time* knowledge support during the design process (Figure 3). This conceptual framework is based on the following four frames:

1. *Knowledge Capture Frame:* this concerns the acquisition and storage of valuable knowledge generated by designers engaged in mobile work. The acquisition of this valuable tacit knowledge can be achieved through various means, such as in textual, audio or video format. This knowledge is stored in a knowledge repository, together with other pre-obtained explicit knowledge. This frame facilitates the *reuse* of knowledge by other designers working on similar design projects, thus enhancing knowledge contribution to the whole organisation.
2. *Knowledge Modelling Frame:* this concerns the modularization of the captured knowledge. Knowledge can be retrieved from various sources, such as from the expertise of other designers, or from books or electronic sources. Once this knowledge (explicit, tacit or implicit) is captured and classified according to the design phase, it is then organised by codifying and structuring it into *modular* elements, such that it can be transferred in the right amount and can be also *reused* by the knowledge recipients, i.e. the designers. Modular structuring of the knowledge elements permits easier indexing and searching facilities, hence accelerating the generation of new knowledge.
3. *Knowledge Representation Frame:* this concerns the method by which the modularised knowledge is externalised and presented to *mobile* designers in different formats, such as textual, graphical, video, audio, or a hybrid of these. An essential component of this frame is the detail of knowledge transferred, depending upon the current design stage that the designer is situated in (refer to Table 1). This frame also takes into consideration the way that knowledge transfer takes place: the represented knowledge can either be transferred upon request (knowledge *pull*), or provided proactively (knowledge *push*). This frame addresses also the predicament of adequately adapting the transferred knowledge in a compatible format with different types of portable and handheld devices.
4. *Mobile Operational Frame:* this concerns the main operating principles of the approach. A fundamental operating principle is that designers are engaged in a *mobile work* design situation (i.e. wandering, visiting or travelling), whereby adequate knowledge support is required. This frame depends upon the availability of portable devices together with a *wireless* network infrastructure, without which knowledge support is not possible. The wireless network infrastructure will permit the mobile designer to remotely connect to the knowledge repository mentioned in the Knowledge Capture Frame. This permits the adequate support

within a specific timeframe, such that the *contextual* setting of the design situation does not change.

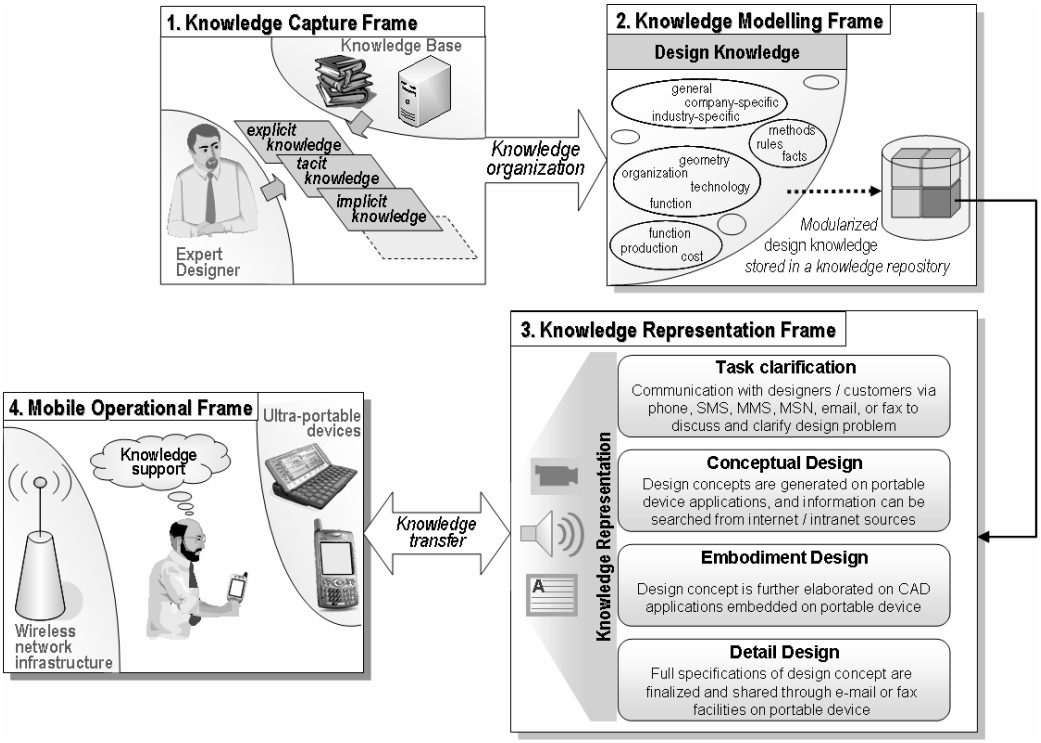

Figure 3. Conceptual framework for mobile 'knowledge management' support

6. Discussion and future work

This paper argued that designers are more mobile than ever, and may need to take decisions based upon knowledge which is not available instantly. Hence the provision of *modular*, *just-in-time* knowledge support is essential to ensure that designers are as effective in their work both when in their design office as well as when in mobile situations. This knowledge support can be attained through the implementation of a *mKM* system based upon the disclosed conceptual framework, specifically adapted to the engineering design environment, process and goals.

The main advantage of using a *mKM* system in engineering design is that the issue of distance to experts and resources in industrial organisations is resolved through the use of portable devices to effectively share design intents between the organisation's extended design teams. However, it was observed that no such *mKM* systems exist in the engineering design domain. This is the main motivation behind this research. The disclosed framework aims to give the freedom required by mobile engineering designers whilst simultaneously providing *modular, just-in-time* knowledge support.

Since research in *mKM* in engineering design is still in it infancy, this implies that further research is required to investigate in detail the *mKM* requirements in the engineering design field. Furthermore, since the field of mobile knowledge management is constantly evolving, this framework will continue to be optimised in order to include the latest technological developments and ideas. Research in the near future at CERU will include empirical studies that will specifically identify activities and knowledge requirements by engineering designers engaged in mobile work, and the actual design and development of a prototype *mKM* system based on the disclosed conceptual framework.

7. Conclusion

To conclude, it can be stated that this paper contributes towards a conceptual framework that supports and improves the existing knowledge communication and work of engineering designers in mobile work. The motivation behind this research is that although a number of mKM systems were developed in various fields, none were so far developed specifically for the engineering design domain.

As discussed, future work is required to specifically identify the knowledge support required by engineering designers engaged in mobile work. This is necessary to closely map the developed conceptual framework with the real-world requirements of engineering designers carrying out-of-office activities. This will lead to the development of a prototype *mKM* system.

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