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REQUIREMENTS FOR A MOBILE KNOWLEDGE MANAGEMENT SYSTEM IN ENGINEERING DESIGN

Christopher L. Spiteri[1], Jonathan C. Borg[1], Ernest Cachia[2] and Mark Vella[2]
[1]Department of Manufacturing Engineering, University of Malta
[2]Department of Computer Science and Artificial Intelligence, University of Malta

ABSTRACT
As products become more complex, a significant amount of design knowledge support is required by designers during the design process. However, given that design activity is not only confined within a design office, knowledge support must be provided to designers even when away from their usual workplace. This provision of knowledge is essential to the successful product development, and is also important to the enhancement of a company's competitiveness. Furthermore, design knowledge is dynamic in nature, and this implies that practicing designers require continuous learning resources. This growing synergy between knowledge management and learning will eventually result in better engineering design support. With the ever-increasing popularity of mobile devices (such as PDAs, smartphones and pocket PCs), access to information, knowledge and learning resources can be greatly facilitated. The contribution of this paper consists of the identification of a set of requirements and system functions necessary for the development of a mobile Knowledge Management (mKM) system that integrates mobile devices within the knowledge management loop to support engineering designers situated in mobile work settings with design knowledge and learning.

Keywords: Collaborative design, mobility, knowledge management, mobile learning

1 INTRODUCTION
Engineering design is considered to be a knowledge-intensive activity [1], and managing it is an important concern for the engineering design industry [2]. This can be achieved by adopting a knowledge management (KM) approach to systematically structure expertise and make it more accessible and easily shared.

However, the engineering design environment is highly distributed in nature [3], and as a result engineering designers are frequently outside the design office to carry out other tasks away from their usual working place [4-6]. This mobility is seen as a disadvantage to engineering designers as they occasionally find themselves without the knowledge support required to take the necessary decisions. On the other hand, collaboration between designers is even more necessary nowadays as companies are expected to deliver high quality products at shorter lead times and lower costs. This brings together a number of actors from various realms of expertise, who may be geographically distant but whose tasks are inter-reliant. With the ever-increasing popularity and computational power of mobile devices (such as PDAs, smart phones and pocket PCs), access to information and knowledge can be greatly facilitated. This paper aims at identifying the requirements and system functions for the development of a mobile Knowledge Management (mKM) system that integrates mobile devices within the knowledge management loop. These requirements are based on the knowledge needs emanating from designer activities situated in mobile work situations. The development of a mobile Knowledge Management system in the engineering design domain is proposed as a promising way to support engineering designers situated in mobile work situations.

The paper is structured as follows: section two will describe the design activities of the design process and derive the respective knowledge requirements. Section three describes mobile knowledge management and presents the main work done so far on the subject. Section four presents all the major mKM systems developed so far and highlights the design activities that are (not) supported by the evaluated mKM systems. Section five presents a set of general mKM system requirements, and a set of more detailed activity-based requirements, whilst section six defines the mKM system functions derived from the system requirements. Finally, section seven discusses the contribution of a mKM system in engineering design, and section eight concludes this paper.

2 DESIGN ACTIVITIES AND ASSOCIATED KNOWLEDGE REQUIREMENTS

The design process is assumed to be divisible into a finite number of partial processes, i.e. activities. There are many different kinds of activities when designing: analyzing, creating design, making representations, evaluation, etc. These design activities have been categorized by many authors, but this research considers the categorization made by Roozenburg and Eekels [7], i.e. *analysis*, *synthesis*, *simulation* and *evaluation*. These design activities have the associated knowledge requirements, tools and methods to support them, and these knowledge requirements are presented in Table 1.

Table 1 – Knowledge requirements associated with design activities

Activity	Description	Methods/Tools	Knowledge Requirements
Analysis	Observing, Describing, Explaining, Predicting, Identifying and Formulating goals and objectives.	• Product Design Specification (PDS) • Quality Function Deployment (QFD) • Means End Tree	• Knowledge of goals, functions, constraints to produce a successful product / process • Knowledge of product attributes in relation to customer requirements from market research, documentation on complaints and repairs, and trend analyses
Synthesis	The generation of a provisional design proposal, where ideas are externalized in any form. Ideas are integrated through human creativity.	• Sketches and Drawings *Creativity Methods* • *Association Methods* (Brainstorming, Checklists) • *Creative Confrontation Methods* (Analogies, Synectics) • *Analytic-Systematic Methods* (Function Analysis, Morphological Method)	• Knowledge of creativity methods • Knowledge on other design solutions • Knowledge on product functions / characteristics • Knowledge on theoretical conceivable solutions to a problem
Simulation	Predicting the properties of a design before the actual manufacturing and use of the product.	• Simulation Models (Structure Models, Scale Models, Analogue Models, Mathematical Models) • Failure Mode and Effect Analysis (FMEA) • Fault Tree Analysis • Design for X (DfX)	• Knowledge of likely properties of the product designed: technical, functional, ergonomic, aesthetic, commercial etc. • Knowledge on simulation techniques: mathematical models, FEA, RPs, etc.
Evaluation and Decision	Evaluation of the design of a product by determining its value by deciding among a set of alternatives.	*Ordinal Methods* • Majority Rule • Rank-Sum rule *Cardinal Methods* • Weighted Objectives Method	• Knowledge on design alternatives, consequences and effective decision methods to determine the design's value

The knowledge requirements identified in Table 1 cover both the *operational* and *substantive* knowledge elements that are used in design [7]. The operational knowledge is composed of knowledge related to *design activity* concerned with how to carry out design activities, and *design process* knowledge, concerned with the organization and execution of design activities [8]. On the other hand, *substantive knowledge* is design knowledge that is concerned with the nature of the artefact (i.e. what is its use, how does it work and how is it constructed). After the identification of the knowledge requirements related to the design activities, the next section defines mobile Knowledge Management and presets the most important works carried out in this area of study.

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"* [9]. 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. Mobile Knowledge Management systems attempt to integrate the technical progress in the area of mobile computing, such as mobile networks and mobile devices (mainly PDAs, smartphones and pocket PCs), into IT-solutions to support KM in organizations [10].

There has already been a considerable body of research on mobile Knowledge Management. Various issues were explored, such as to how to create and share knowledge within groups and organizations, and how to coordinate and share knowledge in dispersed and mobile groups. Table 2 below illustrates a list of the salient work that has been carried out on mobile Knowledge Management.

Table 2 – Work carried out in mobile Knowledge Management

Year	Author	Work
1996	Bellotti and Bly [4]	Established that although there is significant work which is mobile, there are no applications that support this type of work
1996	Kristoffersen and Rodden [11]	Listed specific requirements for information systems and applications
1997	Kristoffersen and Ljungberg [12]	Explored how they could facilitate sharing and coordination in the dispersed, mobile and networked group by means of IT
1998	Kleinrock [13]	Argued the vision of mobility as being able to work "anytime, anywhere"
2000	Fagrell [14]	Focused on how to provide mobile workers with timely knowledge
2003	Shen and Jones [15]	Provided system design implications focusing on how rich data captured in situ can be used to enhance the integration of knowledge management process into everyday work activities
2003	Saugstrup and Henten [16]	Put forward a preliminary framework for implications of mobility on the use and development of mobile and other wireless technologies
2005	Grimm, Tazari and Balfanz [17]	Identified the basic functionalities for knowledge Management Systems in mobile environments and proposed a reference model for such systems.
2005	Lehmann, Berger, Remus and Lehner [18]	Focused on mobile knowledge portals and implemented a mobile KM portal for university staff

4 STATE-OF-THE-ART MOBILE KNOWLEDGE MANAGEMENT SYSTEMS

There are many research efforts focusing on enabling technologies that assist designers to collaborate, coordinate and make decisions during collaborative design [19]. This section presents a detailed research review on the work related to mobile Knowledge Management requirements in engineering design, whereby the most notable mKM systems developed over the last decade are compared and contrasted, including state-of-the-art mKM systems.

4.1 mKM System Comparison

The scope of the mKM system comparison and evaluation was to understand whether any of the existing mKM systems can be adapted and used in engineering design. To achieve this objective, these systems were analysed with respect to the four main activities that take place in Roozenburg's Basic Design Cycle [7]: Analysis, Synthesis, Simulation, and Evaluation and Decision.

Table 3 below compares and contrasts ten mKM systems that were evaluated. Since the reviewed mKM systems were not designed to support engineering design activities, a mapping of the system functions to each design activity was carried out. It can be observed that the design activities are not completely supported by these mKM systems.

Table 3 – Comparison of mobile Knowledge Management systems

***mKM* system / authors**	**Application**	**Design Activity**			
		Analysis	**Synthesis**	**Simulation**	**Evaluation & Decision**
Darwin [20]	Pharmaceutical industry	✓ Goals and objectives can be input in an appropriate data entry section, and analyzed by group members	✓ Supports the process of sharing experiences ✓ Exchange of tasks	✗ Simulation activities are not supported	✓ Coordination between group members
NewsMate [21]	News journalism	✓ Goals and objectives can be input in a *To Do* entry section, and analyzed by group members	✓ An archive contains past articles ✓ Notification for overlapped tasks	✗ Simulation activities are not supported	✓ Location (office or field) of journalists who have been involved in similar tasks
FieldWise [22]	News journalism, sales, real estate brokering	✓ Goals and objectives can be input in a data entry section, and analyzed by group members	✓ A commonly shared list of potentially interesting tasks is accessible to all clients ✓ Overview of record extracts ✓ Shared task list	✗ Simulation activities are not supported	✓ Location of available expertise
Shen J., Jones Q. [15]	Repair technicians	✓ Onsite data capture with pocket PCs to enhance knowledge transfer	✓ Exchange and retrieval of case-stories with sound, image and text from a web interface	✗ Simulation activities are not supported	✗ Evaluation and Decision activities are not supported

Mobile Home Care [16]	Home care workers (nurses, doctors)	✓ *To-Do* list, ideal for goal/objective statements ✓ *Search* function used to find information	✓ *Question and Answer* function with general information ✓ *Library* function containing elaborated information regarding work procedures	✗ Simulation activities are not supported	✓ *Yellow Pages* function containing relevant contact information
mummy [17]	Facility management at construction sites, mobile health care support, video-based e-learning	✓ Examination of site plans to define critical conditions ✓ Defines *To-Do* and appointments	✓ New recordings are recognized and are automatically correlated with descriptive information	✗ Simulation activities are not supported	✓ Automatic generation of hyper-reports
KnowWork [23]	Technical sales, construction and production	✓ Search Engine facility for document retrieval	✓ Search Engine facility for document retrieval	✗ Simulation activities are not supported	✗ Evaluation and Decision activities are not supported
PHOENIX [24]	Advanced education and industry	✓ Dynamically queries data from a wide range of data sources	✓ INDEX search facility	✗ Simulation activities are not supported	✓ Support of collaborative data applications
CogniQ [25]	Healthcare and medicine	✓ To-Do list for goals and objectives	✓ A list of journals is available ✓ Provide context-sensitive hints or tips ✓ Link to in-depth resources on the Web for information	✗ Simulation activities are not supported	✓ Alphabetical search mode with updates
U-KNOW [18]	Education	✓ *Information* and *Search* services for simple information management	✓ *Frequently Asked Questions* function with general information for new staff members	✗ Simulation activities are not supported	✓ *Yellow Pages* function containing relevant contact information ✓ Collaboration between staff members through a virtual teamspace

The main design activity that is not supported is the simulation activity. Simulation activities depend on the design stage of the design process, and vary from elaboration of design specifications, identification of properties of the designed product, analysis of potential reliability and safety problems of the designed product, checking of errors and cost effectiveness, and testing and development. From the authors' viewpoint, the existing mKM systems fail to address such simulation activities, and the reason can be attributed to the fact that these mKM systems were not intended to be used by engineering designers. Furthermore, even other design activities (i.e. analysis, synthesis and evaluation & decision) are not fully supported by such systems, and Table 3 only shows subsets of the activities that are supported. This literature review has resulted in the identification of a need for a set of requirements for a mKM system that will support designers through the design activities during the different life-phases of the design process.

5 MOBILE KNOWLEDGE MANAGEMENT SYSTEM REQUIREMENTS

Although various mobile Knowledge Management systems have been developed in different domains, none were so far developed in the area of engineering design. The state-of-the-art literature review of these mKM systems has identified gaps that such mKM systems have, and a set of requirements necessary for the development of a mobile Knowledge Management system have emerged. Since design activities take place a number of times during the design process, these requirements must ensure that all the design activities carried out by designers situated in mobile work are adequately supported.

A set of high-level requirements for a mobile Knowledge Management system for engineering designers are presented below. The requirements are classified as either *designer oriented*, *knowledge oriented*, or *technically oriented*. The list of requirements is not exhaustive, and only the salient points are listed.

Designer Oriented Requirements

- <u>User profiling</u>: A user profile of all the engineering designers making use of the system is required. The user profile will contain relevant information on the designers, such as the area of expertise, work on design projects, contributions and contact information. The user profile is necessary to identify domain experts and also to automatically notify users with the latest announcement related to the interests of the users.
- <u>Contextual annotations</u>: When submitting or updating knowledge elements to the system, it must be ensured that contextual annotations are added either manually or automatically. Annotations must include the author of the knowledge source, the name of the person who made any updates and/or modifications, what other projects, documents, drawings etc. are related to the new knowledge elements, and in what mobile situation was the knowledge requirement encountered. The contextual annotations are very useful when a designer situated in a mobile setting is given guidance based on the contextual setting. This means that if a designer is situated in a particular design stage performing a specific design activity, the provided knowledge should only be related to that particular instance, thus not overloading the designer with irrelevant knowledge.
- <u>Support of design activities</u>: The designer must be supported through all the design activities, in every design stage. See Table 5 for a more detailed set of activity-based requirements.
- <u>Designer guidance</u>: It is important to guide the designer by providing design guidance pertinent to both the design process and design product knowledge. Design product knowledge is concerned with the artefact to be designed (such as product specifications and associated design data), whereas process knowledge is concerned with the activity of designing itself (such as knowledge about how to carry out tasks and approach problems) [26].
- <u>Continuous learning</u>: Engineering design is a dynamic discipline, and continuous learning is a necessity in order to stay abreast of the ongoing developments in the ever-changing work environment of engineering design. A mobile Knowledge management system with links to appropriate learning material such as m-learning courses can certainly aid designers with on-the-job training through mobile devices.

Knowledge Oriented Requirements

- Modularized Knowledge: The captured and codified design knowledge should be modularized in appropriate levels of granularity that can be transferred to/from appropriate channels. This implies that a proper indexing of the knowledge content is required, so that only the required knowledge is provided when this is required. The use of contextual annotations is important when indexing knowledge.
- Knowledge Elements: The stored knowledge elements should include both structured and unstructured knowledge. This should include product or process knowledge, procedural or declarative knowledge, and tacit or explicit knowledge. Examples of these knowledge elements are design theories, design catalogues, design guidelines, design methods, rules and facts etc.
- Knowledge Search: Due to the high diversity of products designed and engineered, and the advances in design-related areas, searching for the most relevant aspects has become a time-consuming activity. A precise search facility is thus essential, to help the designer find the required knowledge effectively and efficiently.
- Knowledge Sharing and Reuse: Designers must be provided with the facility of sharing and reusing already existing knowledge. The reuse of already existing knowledge avoids designers wasting time 'reinventing the wheel'. This is especially the case in routine design when designing similar products, such as product variants reuses already established design concepts.

Technically Oriented Requirements

- Intuitive User-Interface: An intuitive and user-friendly user-interface that does not interfere with the designer's cognitive thinking during the design process is essential. Furthermore, a platform-independent user-interface is ideal, thus enabling knowledge and information to be easily accessed from different existing and predicted devices. This can be achieved by utilizing a web interface, such as a web portal that can be accessed from a selection of mobile devices (such as tablet PCs, PDAs, smart phones and pocket PCs) through a suitable web browser. The interface must support the addition of knowledge apart from extracting knowledge.
- On-line and Off-line access: A mKM system must not rely entirely on an "always-on" wireless network connection. Quite the opposite, the mKM system should also be able to synchronize knowledge content between the knowledge repository and the mobile device(s), thus permitting knowledge to be stored on the mobile device and be accessed even when there is no wireless connection.
- Knowledge repository: A knowledge repository that contains valuable knowledge (both tacit and explicit) based on the unique user experiences as well as the know-how that has been tried and tested in practical work situations is required. The knowledge repository must consist of both structured knowledge (such as Design Documents and Catalogues, CAD drawings, Links, and User Profiling) and unstructured knowledge elements (such as Weblogs, Wikis and News).

5.1 Activity-based requirements

The requirements of a mobile Knowledge Management support system vary, depending on the design stage that the designer is situated in, and also on the design activities performed by the designer. In engineering design, the design process follows more or less the same four stages: clarification, concept, embodiment and detail design [7, 27], and design activities take place a number of times during the design process. Table 5 below illustrates the requirements for every design stage and for every design activity. These requirements were derived from prescriptive literature of the design process.

Table 4 – Legend for mKM system requirements

Requirement	Description
R1	Access (read/write/manage) to a knowledge repository containing project information, previous design drawings/sketches, documents with customer requirements for a particular design problem, indexed product and process knowledge (implicit, explicit, tacit) captured during previous design processes, and design catalogues for consultation.
R2	Access to the worldwide web for project-related information and knowledge that can be accessed online.
R3	Synchronous and asynchronous communication tools for sharing of ideas, designs/sketches, documents, and expertise, and other design collaboration activities in general. These include e-mail, forum, chat, SMS and MMS.
R4	Access to engineering design software tools to generate CAD drawings, run simulation tests and generate computer/physical prototypes. A *thin-client* architecture permits such software tools that cannot be stored onto a mobile device's memory due to memory size restrictions to still be accessible from a server.
R5	Methods, methodologies or tools used during a particular design activity that can be utilised on mobile devices.

Table 5 – Activity-based mKM system requirements

Design Stage	Design Activity	Steps involved	Description	Require-ments
Task Clarification	Problem Analysis	Market and problem analysis	View document containing problem statement and customer requirements	R1
		Establish the state-of-the-art	Search for current established products, processes, tools, etc	R1, R2
		Establish the main objectives and functions	Create a Means End Tree	R5
	Solution Synthesis	Identify similar design solutions	Search for similar design solutions from existing database or from the web	R1, R2
		Generate new or alternative ideas	Search for similar products from existing database or web	
	Simulation	Elaborate design specifications	Decide upon likely properties of product: technical, functional, ergonomic, aesthetic, commercial etc.	R3, R4
	Evaluation and Decision	Evaluate and disseminate PDS	View generated design solutions and compare and disseminate	R3
Conceptual Design	Problem Analysis	Identify essential problems	Search for solutions related to the design problem	R1, R2
		Collect information on similar products	Search for similar products from existing database or from the web	
		Search for alternative design solutions	Search for alternative design solutions from existing database or from the web	

	Solution Synthesis	Sketch preliminary design solutions	Generate preliminary design sketches on paper and share them between design team	R3
		Develop creative solutions to the design problem	Generate and evaluate ideas in a Brainstorming session	R5
		Generate new or alternative design solutions	Search for similar products from existing database or from the web	R1, R2
		Generate preliminary drawings	Generate a provisional design proposal, and share it between design team	R1, R3
		Generate variant design specifications	Generate variant design specifications, and share them between design team	
	Simulation	Identify properties of designed product	Decide upon properties of the designed product: technical, functional, ergonomic, aesthetic, commercial...	R1, R3
	Evaluation and Decision	Preliminary evaluation	Evaluate against technical and economic criteria	R3
Embodiment Design	Problem Analysis	Categorize and prioritize requirements	Establish customer and design requirements	R1, R3
			Create a Quality Function Deployment (QFD)	R5
		Select best preliminary layout	Analyze and establish the best preliminary design solution	R1, R3
	Solution Synthesis	Identify product functions / characteristics	Generate a Function Means Tree	R5
			Generate a Transformation Process Model	
			Generate a Morphological Chart	
		Design for X (function, safety, manufacture)	Use dfX design guidelines	R1, R2, R3
	Simulation	Analyze potential reliability and safety problems	Carry out a Failure Mode and Effects Analysis (FMEA)	R5
			Carry out a Fault Tree Analysis	
		Check for errors and cost-effectiveness	Test design properties through simulation techniques, such a FMEA, mathematical models and RPs	R4
	Evaluation and Decision	Evaluate design of a product	View generated design solutions and compare	R3
Detail Design	Problem Analysis	Finalize details	Finalize all product design details based on PDS	R1
		Check all documents	Review and check all documentation related to product designed	R1, R2

	Solution Synthesis	Complete detail drawings and production docs.	Finalize drawings and documentation related to production	R1, R2, R3
	Simulation	Testing and Development of product	Test design properties through simulation techniques, such a FMEA, mathematical models and RPs	R4
	Evaluation and Decision	Decide among a set of alternatives	Identify any design alternatives and the corresponding consequences	R3, R4
			Rank-Sum rule	R5
			Weighted-Objective Method	

6 MKM SYSTEM FUNCTIONS

Based on the set of requirements presented in section five, several main functions of a mobile Knowledge Management system that support engineering designers have emerged. These functions take in consideration the fact that knowledge capture, provision, dissemination and application will take place through mobile devices, with the advantages and limitations associated with them. The main mKM system functions should:

- Support knowledge capture in several formats (such as text, graphics, pictures, speech, audio and video) and indexing of the captured knowledge;
- Support continuous updating of stored knowledge;
- Provide codification and structuring of tacit knowledge to explicit knowledge;
- Provide modular, just-in-time, context-sensitive knowledge support through attached meta-data to design knowledge elements;
- Provide design guidance and assistance throughout the design process;
- Identify previous design knowledge that permits design reuse;
- Provide a knowledge dissemination/sharing facility that includes best practice, lessons learned and expertise location;
- Support integration with other CAD tools and systems;
- Support integration with simulation tools that allow engineering designers to model, analyze, and optimize design products and processes;
- Provide continuous learning material through m-learning courses.

7 DISCUSSION

The fundamental argument of the research reported in this paper has been the identification of a set of requirements to develop a mobile Knowledge Management system that supports engineering designers situated in mobile work during the design process. From these set of requirements emerged a number of functions that the mKM system is expected to support.

This research takes into account the fact that the popularity and level of computing power of mobile devices is constantly on the rise, whilst designers are frequently away from their usual design workplace. Furthermore, given that designers encounter situations where design activities give rise to knowledge creation and/or knowledge support required, a mobile Knowledge Management system that is capable of supporting a designer through the various design activities can result in improved product development. Moreover, the importance of continuous learning is increasing proportionally with the increase in complexity of products designed and developed. This fact can be addressed by providing access to learning material such as m-learning courses with the mKM support system, thus providing also on-the-job training.

From the set of identified requirements, it can be observed that the requirements vary, depending on the design stage and also on the design activities of the design process. Considering how the requirements vary with respect to design activities, access to a knowledge repository and access to the world-wide web is required more during the early activities of the design cycle. Synchronous and asynchronous communication tools are required throughout all the activities whilst engineering design software tools are required during the later design activities. The requirements for methods, methodologies or tools also decrease as the design cycle progresses. Considering how requirements vary with respect to the design stages, access to a knowledge repository is required mostly during the conceptual design stage, whereas access to the worldwide web is seen to be required in all of the design stages. Synchronous and asynchronous communication tools are more required during the conceptual and embodiment design stage than during any other stage. Engineering design software tools are required more during the later stages of the design process, as are the methods, methodologies and tools.

8 CONCLUSIONS

Engineering Design is a knowledge intensive activity, and engineering designers require continuous knowledge support, especially when carrying out design activities away from the design workplace. It is observed that although various mobile Knowledge Management systems have been developed, none have so far been specifically dedicated to support the engineering design process and the associated activities and knowledge requirements. After identifying the knowledge requirements pertaining to the different design activities, a state-of-the-art review of mKM systems was carried out to identify whether currently developed mKM systems would be capable of supporting a designer through all the design activities throughout the design process. After recognizing gaps in the design activities supported, a set of mKM system were specified, taking into consideration the advantages/disadvantages associated with mobile devices (mainly PDAs, smartphones and pocket PCs). The identified system requirements are the basis for the design and development of a prototype mKM system in engineering design named MOKMED (Mobile Knowledge Management support in Engineering Design) that supports engineering designers through the activities involved in the design process.

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Contact: Christopher Spiteri
University of Malta
Faculty of Engineering
Department of Manufacturing Engineering
Concurrent Engineering Research Unit
Tel: Int +356 2340 2448
Fax: Int +356 2134 3577
Email: chspit@eng.um.edu.mt
URL: http://www.eng.um.edu.mt/~chspit