HELSINKI UNIVERSITY OF TECHNOLOGY
Department of Computer Science and Engineering
Software Business and Engineering Institute

USER-CENTRED DESIGN IN THE DEVELOPMENT OF A MOBILE MAP APPLICATION

Annu-Maaria Nivala

Licentiate Thesis

Supervisor: Professor Marko Nieminen
Instructors: Docent, D.Sc. (Tech.) Tiina Sarjakoski, Professor Tapani Sarjakoski
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Developments in hardware and software have led to new innovative methods for visualising geospatial data and there has been a change from view-only to interactive map applications. The hypothesis of this research is that user-centred design (UCD) has a fundamental role in designing maps for new technical environments such as mobile devices, which involve entirely new ways of interacting. By using an iterative UCD approach, while simultaneously taking into account the novelty and diversity of users and their tasks together with the characteristics of maps, application developers could design products that have a higher quality of use.

The aim of this thesis was to find out how a UCD approach could be included in the development of a mobile map service. The research started with a literature review, which summarised usability engineering principles and usability-related research carried out in cartography. The review revealed that current map application projects are mainly carried out in two separate research fields: by cartographers and by software application developers. Thus, there is a need for a multidisciplinary approach that merges the knowledge developed by cartography and usability engineering. Based on the literature review, a synergy model for UCD and mobile cartography was proposed, which aimed to provide guidelines on putting the UCD approach into practice in the development of a mobile map application.

The validity of the synergy model was tested with a case study in an R&D project entitled Geospatial Info-Mobility Service by Real-Time Data-Integration and Generalisation (GiMoDig), in which a mobile map service was developed. The project followed an iterative UCD approach and different usability methods were used. The design at each phase was based on defining the different user groups and their tasks and goals in situations where a mobile map would be used.

The innovative aspects developed in the design process during the case study strongly support the suitability of a UCD approach for mobile map application design. One of the central findings was a realisation of the relevance of user-friendly map applications based on true, meaningful user requirements. This is especially important for new technology applications, since the user requirements may not be the same as in traditional application environments. Furthermore, understanding the context becomes especially critical with mobile map applications, because they can be used in various situations and for various purposes. New technological possibilities and restrictions create the potential for new design approaches, and therefore the UCD approach can be used as a method to incorporate material and increase designers' knowledge on user requirements and thus support innovativeness. Only by understanding the users and the real context of use can realistic applications for new technological environments be created. The thesis closes by identifying future research topics related to the usability, UCD and map applications.

Keywords: usability engineering, user-centred design, map, cartography, mobile device

TEKNILLINEN KORKEAKOULU **Tietotekniikan osasto**	**LISENSIAATTITYÖN** **TIIVISTELMÄ**
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Viimeaikaiset laitteisto- ja ohjelmistokehitykset ovat johtaneet siihen, että myös karttasovellusten käyttäjät, heidän tehtävänsä ja käyttötilanteensa ovat muuttuneet huomattavasti. Karttojen käyttö on nykyään usein dynaamista ja vuorovaikutteista ja käyttöympäristöt voivat vaihdella toimistosta kenttäolosuhteisiin. Perinteiset kartografian suunnittelu- ja arviointimenetelmät eivät välttämättä ota huomioon uudenlaista vuorovaikutteisuutta karttasovelluksen ja sen käyttäjän välillä.

Tämän työn hypoteesina oli, että käyttäjäkeskeinen tuotekehitys on oleellista innovatiivisten ja interaktiivisten karttasovellusten suunnittelussa ja toteutuksessa. Käyttäjäkeskeisen tuotekehityksen tavoitteena on tuoda käyttäjänäkökulma tuotekehitykseen ja iteratiivisesti testata sovelluksen käytettävyyttä koko suunnitteluprosessin ajan. Tutkimuksen tavoitteena oli selvittää, miten käyttäjäkeskeistä tuotekehitystä voitaisiin hyödyntää mobiilin karttapalvelun suunnittelussa. Tutkimus alkoi kahdella kirjallisuustutkimuksella, joissa tutustuttiin käyttäjäkeskeiseen tuotekehitykseen sekä karttojen käytettävyysaiheiseen tutkimukseen. Havaittiin, että käytettävyysnäkökulmaa ei ollut vielä hyödynnetty riittävästi karttasovellusten suunnittelussa. Todettiin myös, että tällä hetkellä sovelluksia suunnittelevat ja arvioivat toisaalta kartografit ja toisaalta sovelluskehittäjät. Karttasovellusten kokonaisvaltaisen käytettävyyden takaaminen vaatii kuitenkin sekä kartta- että ohjelmistosuunnittelun näkökulmien yhdistämistä.

Kirjallisuustutkimuksen perusteella tehtiin ehdotus mallista, joka perustui käyttäjäkeskeiseen tuotekehitykseen ja otti samalla huomioon mobiilin kartografian erityispiirteet. Mallin tavoitteena oli antaa ohjeita käytettävyysnäkökulman mukaan ottamisesta karttasovelluksen kehitykseen. Mallia hyödynnettiin ja sen toimivuutta testattiin tutkimus- ja kehitysprojektin, Geospatial Info-Mobility Service by Real-Time Data-Integration and Generalisation (GiMoDig), yhteydessä. Projektin tavoitteena oli kehittää mobiilikarttapalvelu, joka toimittaa reaaliaikaisesti kansallista karttaaineistoa mobiililaitteen käyttäjälle. Käyttäjäkeskeisen tuotekehityksen mukaisesti projektin vaiheet perustuivat yksityiskohtaiseen tietoon potentiaalisista käyttäjäryhmistä, heidän tavoitteistaan, tehtävistään ja käyttöympäristöstään. Prototyyppiä arvioitiin useissa projektin vaiheissa käyttäjäkeskeisin menetelmin hyödyntäen tietoa kartografian erityispiirteistä.

Käyttäjäkeskeisen tuotekehityksen merkitys korostui mobiilin karttasovelluksen suunnittelun yhteydessä. Se toi tuotekehitykseen vankan ymmärryksen palvelun potentiaalisista käyttäjistä ja erityisesti uudenlaisesta käyttöympäristöstä. Tämän kautta pystyttiin tunnistamaan oleelliset käyttäjävaatimukset ja saamaan innovatiivista näkökulmaa mobiilin karttasovelluksen suunnitteluun. Tulosten perusteella käyttäjäystävällisten karttasovellusten tuotekehityksessä on tärkeää huomioida myös kartografisen visualisoinnin erityispiirteet. Työn lopussa tunnistetaan karttojen käytettävyyden ja käyttäjäkeskeisen tuotekehityksen tulevaisuuden tutkimusaiheita.

Avainsanat: käytettävyys, käyttäjäkeskeinen tuotekehitys, karttasovellus, mobiililaite, kartografia

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Masala, 31st October, 2005

Annu-Maaria Nivala

LIST OF PUBLICATIONS

The thesis is based on the following research papers:

I **Nivala, A.-M., Sarjakoski, L.T., Jakobsson, A. and E. Kaasinen, 2003.** Usability Evaluation of Topographic Maps in Mobile Devices. *Proc. of the 21st International Cartographic Conference,* Cartographic Renaissance, Durban, South Africa, CD-ROM, 1903-1913.

The paper describes the arrangements and results of field tests that were arranged in order to evaluate the usability of topographic maps in mobile devices. The purpose of the evaluation was to identify preliminary user requirements and design principles for mobile maps in small displays. The author was involved in performing the tests and analysing the results and preparing the paper equally with the co-authors.

II **Nivala, A.-M. and L.T. Sarjakoski, 2003.** Need for Context-Aware Topographic Maps in Mobile Devices. In Virrantaus, K. and H. Tveite (eds.), *ScanGIS'2003 – Proc. of the 9th Scandinavian Research Conference on Geographical Information Science*, Espoo, Finland, 15-29.

The paper is a further analysis of the user requirements of mobile map users. The mobile contexts were examined from the map users' points of view based on user tests of topographic maps in PDAs. It is proposed that embedding context awareness into the maps increases the usability of mobile map applications. A new categorisation for mobile contexts in map services is proposed and discussed. The author conducted the studies, analysed the results and prepared the paper equally with the co-author.

III **Nivala, A.-M. and L.T. Sarjakoski, 2005.** Adapting Map Symbols for Mobile Users. *International Cartographic Conference 2005:* Mapping Approaches into a Changing World, A Coruna, Spain, CD-ROM: Theme 12: Internet Location-Based Services, Mobile Mapping and Navigation Systems, Session 5.

The paper describes a design implementation that was done based on the user requirements ascertained earlier. The paper demonstrates how maps for different types of mobile users can be delivered with symbols adapted for user-specific needs. A concept of a 'symbol library' is presented and the cartographic design and intuitivity of the symbols are tested by users. Recommendations for future symbol library implementations for mobile use are given. The symbol library approach is based on collaborative work. The author conducted the studies, analysed the results and prepared the paper with the advice of the co-author.

IV **Nivala, A.-M., Sarjakoski, L.T. and T. Sarjakoski, 2005.** User-centred Design and Development of a Mobile Map Service. In Hauska H. and H. Tveite (eds.), *ScanGIS'2005 – Proc. of the 10^{th} Scandinavian Research Conference on Geographical Information Science*, Stockholm, Sweden, 109-123.

In this paper an iterative UCD approach is presented through experiences gained on a mobile map application project. It contains discussion on how to integrate usability issues into map applications. The author conducted the studies, analysed the results and prepared the paper with the advice of the co-authors.

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1 INTRODUCTION

In days gone by, maps were presentations of cartographers' manual skills, and many maps were thus extremely subjective in their representation. The compilation of maps was not strictly bound by regulations and specifications, so different layouts and typographies could be used for each map depending on the artistic view of the map designer.

Computer-based map production technology changed the output and plotting of maps into an automatic process, and at the same time map visualisation became less subjective, since maps were now derived from a database according to objective rules and specifications. Clarke (2001) divided the influence of the computer on cartography into three phases. Firstly, large mainframe computers were used as analytical engines for problem solving using an algorithmic approach. Smaller desktop computers and workstations followed, allowing personal interaction with computer-based processes. In the third phase, emerging Internet solutions also allowed non-cartographers to receive maps via the Internet.

The fourth era, 'mobile computing', includes geospatial services, from which map data can be delivered to a user's mobile devices, such as a cell phone and Personal Digital Assistant (PDA), in real-time or by downloading the maps onto the device. During the initial stage of providing maps to mobile terminals, the fastest way was to simply make use of similar maps designed for desktop and Internet applications. However, the main problem with this approach is that maps on mobile devices are also used in mobile situations, which means that they should be visualised in radically different ways compared with static indoor usage situations at office desktops (Nivala et al., 2003) (Figure 1).

Figure 1. Traditional way of providing a map for a user and a map shown on the screen of a PDA.

Each map may be regarded as a representation of its time: the existing art trends, and scientific thoughts as well as the available technology. However, despite the techniques, or the decade of map-making, the central issue in map reading has always been how the map is perceived and understood by the user. A user may not always understand the cartographic visualisation of the map, the meaning of the map symbols, or the purpose of the map's content. Furthermore, the computer-based system, which produces the digital maps also brings up other issues to consider in relation to the design: multi-dimensional approaches, interaction and animation. For instance, having maps on mobile devices may cause usability problems due to the size and quality of the screen, as well as the input techniques for moving and zooming the map. However, electronic maps may offer advantages to the user by supporting a search of the user's location on the map and linking the user with location-based services (LBS).

Consequently, traditional design and evaluation methods for maps may not be valid from all perspectives. Koua and Kraak (2004) crystallised the main problem by stating that the map use studies that have been carried out over a long time in the field of cartography are not fully applicable in new interactive visualisations, which may have new representational spaces and user interfaces. In addition, Cartwright et al. (2001) stated that the technological changes involving both cartography and computer graphics have made modern cartographic representation different: a wider range of maps can be made faster and less expensively and interaction with visual displays in almost real-time is now possible. This results in moving the emphasis from static to dynamic map use and, furthermore, in new requirements for the design and interfaces of representations. But how can it be guaranteed that today's map applications using different (new) technologies will fulfil user requirements? How will it be possible to assure that the applications are easy to use and gain user acceptance and interest for investment?

1.1 Motivation for the study

As graphical user interfaces (GUIs) in software engineering, maps can also be regarded as user interfaces (UIs); e.g. Kraak and Ormeling (1996) described maps as interfaces to geographical information systems (GISs). Kraak and Brown (2001) stated that due to the multimedia nature of the Internet, maps can be seen as interfaces, or also as indices to additional information. Furthermore, Peterson (1995) suggested that the word interface can be related to maps in two ways: maps are firstly interfaces to the world and secondly are composed of UI elements. The layout of the map, its legend, colours, sectioning and folding, are all aspects of the map's UI and there is an interaction between the map and the user when the map is used.

This means that if we consider a map on a mobile device as another type of GUI, the design principles for maps should also include the design principles used in other GUI designs. *Usability engineering* is a term used to describe methods for analysing and enhancing the usability of software (Nielsen, 1993; Mayhew, 1999). *Usability* is defined in the ISO 9241 standard (1997) as "the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments." The need to consider usability issues during product design and development is nowadays widely accepted, and ISO 13407, Human-centred design processes for interactive systems, gives instructions to achieve user needs by utilising a *user-centred design* (UCD) approach during the whole life cycle of a system (ISO, 1999).

Systematic usability engineering throughout the life cycle of map applications seems to be rare, for instance, Fuhrmann et al. (2005) stated that usability inspection methods are not widely used for geovisualisation at present. Other researchers have also noticed the lack of thorough usability engineering in geovisualisation. MacEachren and Kraak (2001) referred to research challenges in geovisualisation, and one of the main topics included in their work was cognitive and usability issues. According to them, there is a lack of established paradigms for conducting cognitive or usability studies with highly interactive visual environments, and therefore one of the overarching challenges includes the need to develop a human-centred approach to geovisualisation. Fairbairn et al. (2001) also stressed that since modelling techniques are developing rapidly, there is a need to advance ways of transforming information about the world into models suited to digital and cartographic representations that lead to effective visualisation. According to them, such models “should draw on research into the cognitive issues that surround increasingly personalised and flexible possibilities for map use with an expanded range of map forms.”

Fuhrmann et al. (2005) discuss the concept of geovisualisation theory, which should be developed to include more formal design guidelines for the design process to make geovisualisation useful and usable. By etablishing this type of theory, the design would be more valid across different applications and culturally different user groups. They state that this theory could originate from different disciplines, for instance; perceptual science, cognitive science or HCI science, but the role of geovisualisation researchers would be to extend and refine it in ways that make it specific to geovisualisation.

1.2 Thesis objectives

The goal of this research is to gather information on usability research related to map applications and to develop user-centred map application design theory by studying the suitability of usability engineering methods in the development of a mobile map application service. The intention of this research is to apply the UCD concept to a specific research area, i.e. geoinformatics, by giving a concrete example of how the research methods should be selected and how to put them into use in practice. Slocum et al. (2001) stated that due to the novelty of geovisualisation and the difficulty of defining the nature of users and their tasks, applying usability engineering may be problematic. The hypothesis of this study is that *because of* the novelty and diversity of users and their tasks, the user-centred approach is *compulsory* to successfully implement usable map applications.

The research presented here is multidisciplinary: the research themes include usability engineering, cartography, geographic information science, cognitive science and computer science. Naturally, when incorporating usability methods into applied sciences such as geoinformatics, it may be necessary to adapt the methods. The objective of this thesis is to merge knowledge from cartographic research with usability methods and bring the cartographic and usability engineering research areas closer together.

1.3 Thesis structure

The thesis is structured in six major chapters (Figure 2). Due to the multidisciplinary nature of this thesis, the bridge between UCD and mobile cartography has been created by reviewing the literature on both disciplines. Special emphasis is placed on previous usability-related research carried out by cartographers. Based on these literature reviews, a synergy model for UCD and mobile cartography is proposed. This model is tested with a case study in the research and development project, Geospatial Info-Mobility Service by

Real-Time Data-Integration and Generalisation (GiMoDig, 2005). Finally, conclusions are given and the experiences from the research are discussed.

Chapter 1 Introduction - gives a short introduction to the motivation for the study, thesis objectives and it's structure.

Chapter 2 User-Centred Design - studies the principles of user-centred design (UCD).

Chapter 3 Usability-Related Research in Cartography - describes the findings of the literature review of usability studies carried out in cartographic research.

Chapter 4 Synergy Model for UCD and Mobile Cartography - proposes a model for incorporating UCD approach into the design of mobile map applications.

Chapter 5 Case Study: UCD in the GiMoDiG Project - presents the UCD process executed in the GiMoDig project and the evaluation results.

Chapter 6 Conclusions - gives conclusions and recommendations for future map application projects and discusses future research topics.

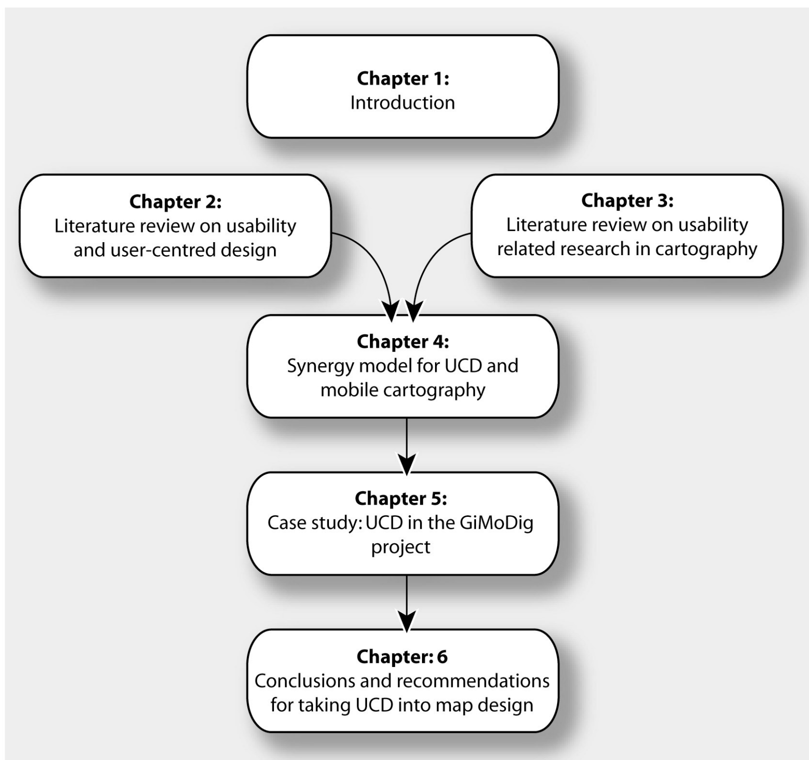

Figure 2. Structure of the thesis.

2 USER-CENTRED DESIGN

In their work in the early 1980s, Gould and Lewis (1985) stressed the three principles of design: 1) an early focus on users and their tasks, 2) empirical measurement, and 3) iterative design. First, the designers must understand who will be using the system that is being designed. Second, users should be involved in the development process at an early stage of the design by being asked to test the simulations and prototypes, and recording their performance and reactions. Third, problems found during the empirical stage must be resolved and the new designs tested.

Norman and Draper (1986) started to use the term User-Centered System Design, and nowadays this approach is widely accepted and used either under terms such as Human-Centred Design, User-Centred Design, Usability Engineering, Human Factors Engineering, or even Ergonomics. The aim of all these is to support the entire product development process with user-centred activities in order to create applications which are easy to use and fulfil the needs of the intended user groups. User-centred design is considered especially important when creating new applications which need to be accepted by users.

Due to the multidisciplinary nature of this thesis, a very general overview of usability engineering methods, user-centred design and usability aspects are given in this chapter. This has been included to help non-usability engineers 'upgrade' their knowledge on the matter and to provide a basis of understanding for the rest of the thesis.

2.1 System acceptability

The goal of User-Centred Design (herein referred to as UCD) is to ensure that a product fulfils the needs and requirements of the users. System acceptability forms a wider backdrop to product validity. According to Nielsen (1993), the acceptability of a system covers social and practical acceptability, with the latter being further divided into usefulness, cost, compatibility and reliability of the system (Figure 3). On the other hand, usefulness itself can be further divided into utility and usability, whereas usability can be described with five criteria: 1) easy to learn, 2) efficient to use, 3) easy to remember, 4) few errors, and 5) subjectively pleasing.

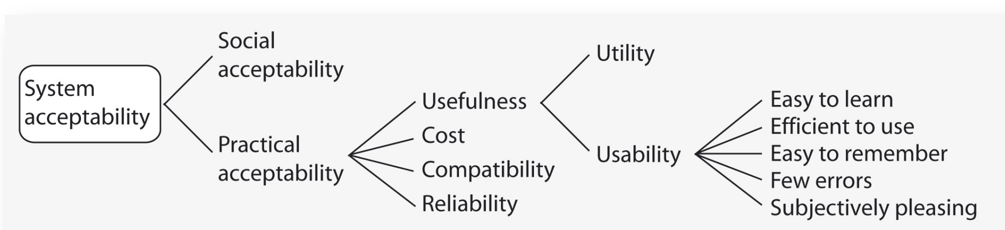

Figure 3. Nielsen's (1993) model of the attributes of system acceptability.

2.2 Usability

According to Shackel (1991), the usability of a system is “the capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and user support, to fulfil the specified range of tasks, within the specified range of environmental scenarios”, or in short “the capability to be used by humans easily and effectively.”

The ISO 9241 standard for ergonomic requirements for office work with visual display terminals (ISO, 1997) defines usability as “the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments” (Figure 4). Another definition according to ISO standard 9126 describes usability as “the capability of the software product to be understood, learned, used and attractive to the user, when used under specified conditions.” The standard has been updated and ISO 9126-1 (ISO, 2000) now uses the term “quality in use”, which means the capability of the software product to enable specified users to achieve specified goals with effectiveness, productivity, safety and satisfaction within specified contexts of use.

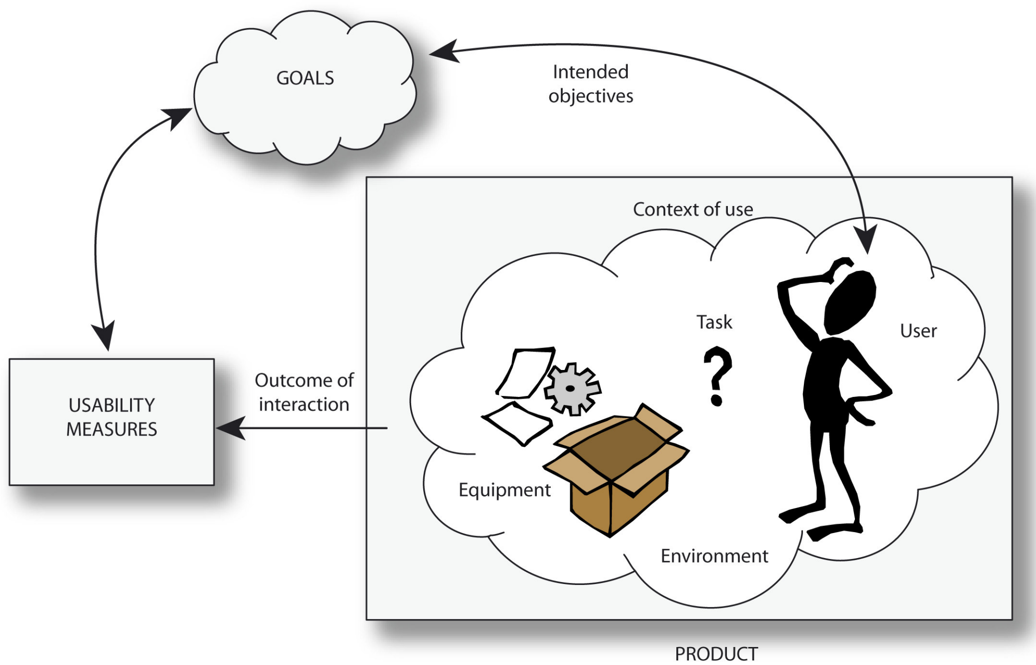

Figure 4. Usability components and their relationships (after ISO 9241, 1997).

The usability of a certain product is therefore strongly related and affected by the *users* using the product: Who are they? Shneiderman (1998) discussed the differences among users: physical abilities (height, age, left right handedness, speed of finger presses etc.), cognitive and perceptual abilities (memory, learning, problem-solving, decision-making etc.) and personality differences (attitudes to computers, habits, personality types such as extroverted vs. introverted, emotional states etc.). In some situations it may also be necessary to define specific characteristics of different types of user, for example, the users’ different levels of experience or the different roles they perform.

In addition to user characteristics, usability components include the *tasks* of the users, which are strongly related to, and also affect, the context of use. Furthermore, the context of use is strongly affected by the *equipment*: the hardware, software and other materials used for performing the tasks. The usage situation is also composed of the physical, social and cultural *environment:* e.g. workplace, temperature, work practices, organisational structure etc.

The intended objectives of the user form the *goals* (what are the users trying to do with the product) of the product and the outcome of the interaction is the result of the product being used in a specific context of use (Figure 4). According to ISO 9241, in order to specify or measure usability, it is necessary to divide effectiveness, efficiency and satisfaction and the components concerning the context of use into sub-components with measurable and verifiable attributes. In other words, the assessment of a product's usability should first identify the goals and the relevant context of use (including the users, tasks, equipment and environment involved), and then the measures of effectiveness, efficiency and satisfaction that are determined as being relevant to the goals identified.

2.2.1 Usability measures

Usability measures are the tools for studying the outcome of the interaction of a product. The ISO 9241 (1997) standard measures usability a product's attributes: effectiveness, efficiency, and satisfaction. Nielsen (1993), however, lists the following usability attributes: efficiency, satisfaction, learnability, memorability, and minimal errors.

Effectiveness is measured by assessing whether users can do what they want to do with the product: are they able to complete tasks and to achieve goals, and with what degree of accuracy and completeness? *Efficiency*, on the other hand, tries to measure how much effort and recourses are needed to use the product after the users have learned to use it (usually by measuring the time it takes for users to perform specific tasks). *Satisfaction* is a subjective measure referring to what users think about the products: are they easy to use, and in general, do users like the product? *Learnability* aims to measure whether users can easily learn to use the product. It should also be easy to remember how to use the product after a period of not having used it, which is measured using an attribute called *memorability*. *Minimal errors* means that when using the product the number of errors made by users should be low, and recovering from the error stage should be easy.

2.3 User-centred design cycle

ISO 13407, Human-centred design processes for interactive systems, provides guidelines on achieving user needs by utilising this design approach during the whole life cycle of the system (ISO, 1999). User-centred design (UCD) (often referred to as human-centred design, human factors engineering, ergonomics and usability engineering) can be seen as an iterative process (Figure 5), which starts by recognising the potential users, their contexts of use and tasks. The design process continues by using this information to set the requirement specifications and usability goals for the product. The next step is to illustrate the design to the users, and on the basis of user feedback, to evaluate the design against the goals established earlier. By doing this, the user requirements may be refined or new requirements may be identified. The feedback may also lead to changes in implementation. The iterative process continues until the usability goals are achieved.

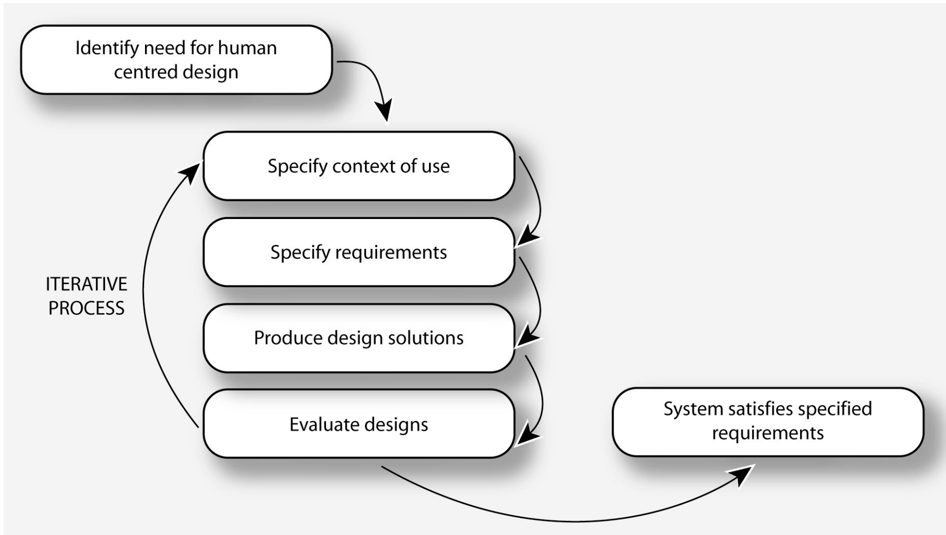

Figure 5. Human-centred design processes for interactive systems (ISO, 1999).

2.3.1 Planning the UCD project

The UCD project starts by determining what kind of usability information on the product is needed: the usability of an existing product, ideas for developing a new product, or information for comparing products already on the market. The factors affecting the project planning are related to the amount of resources available for the project: money, time, people, etc. In addition to which, it is preferable to decide at the early stages of the project by whom, how, and when the usability evaluation is to be carried out, i.e. whether to employ usability experts or users, usability tests or questionnaires, and at which stage of the project.

2.3.2 Specifying context of use

The basic concept behind UCD is to thoroughly understand the potential users of the product, as well as their tasks, and the social and physical environment in which the product will be used. A UCD process therefore often starts by identifying all the primary and secondary users and classifying them in a meaningful way according to the project's objectives.

After identifying the potential users of the product, the next step is to describe what tasks users need the product under development to perform. The description of the interaction between potential users and the product is essential in many cases, and this description may include information on what users currently do to achieve the specific goals, and what the pros and cons are of the equipment they are currently using. It is also possible to gather information about users' wishes for future products. A task analysis can be produced from the information gathered.

Furthermore, one of the crucial steps in specifying the context of use is to find out, what terminology is employed by users. The knowledge gained should also be taken into account in the design phase to avoid implementing a product with terminology specific to designers or programmers, which the user would not understand or feel comfortable with. Information on the type of environment in which users will operate the system is crucial from the usability point of view; therefore descriptions of the usage situations together with the social and physical environments are also relevant at this stage of the process.

There are several methods of collecting context of use information: surveys, interviews, contextual inquiries, or observations of users in field studies, user participation in context of use analyses, focus groups or brainstorming, or even evaluating an existing system. Questionnaires or user surveys are often used since they are relatively easy and inexpensive to compile and analyse.

By identifying user requirements and the real context of use, the preliminary requirements for the system can be determined. This is an important phase of the study, since the first prototypes will be based on these results.

2.3.3 Specifying requirements

After gathering all the relevant information related to the context of use, the data can be structured, for example, by affinity diagramming or producing scenarios of use:

- Affinity diagramming (e.g. Beyer and Holtzblatt, 1998) is used to sort large amounts of data into logical groups so that it can be analysed. The data is written on notes, which are then sorted into categories by the researchers.
- Scenarios of use, i.e. use cases, specify how users perform their tasks in specified contexts (e.g. Kulak and Guiney, 2000). These should include information about, e.g., which activities should be performed by the user and which by the computer when the user is performing a certain task with the system.

After compiling the affinity diagrams or use scenarios they can be validated according to relevance and importance, at which point a decision must be taken on which tasks or components of the use context require usability criteria. A set of key tasks representing the significant aspects of the overall task will typically be selected to evaluate usability. The user requirements can be defined from these and the first usability goals decided. It also has to be decided which usability criteria are to be emphasised in the study: effectiveness, efficiency, satisfaction, memorability, and/or minimal errors?

2.3.4 Producing design solutions

When the user requirements and the usability goals for the system have been studied, the next step is to make the first design implementations. At this point it is important for the design to answer user needs in specific tasks. Sometimes the preliminary design ideas can be very immature. The purpose is to improve the design step by step in an iterative UCD cycle. By visualising the design ideas at the early stage of the process, the evaluations can be presented to users quickly and cheaply. The feedback from users can be gathered at an early stage, and making the changes at this stage of the design may reduce the design costs.

Nielsen (1993) discusses different dimensions of prototyping. Reduced prototypes may be useful in order to save money and time, and in order to develop a design, which can be evaluated by users. According to Nielsen, prototypes can be divided into two different types: a) horizontal prototypes, which have a reduced level of functionality, or b) vertical prototypes, which have a reduced number of features (Figure 6).

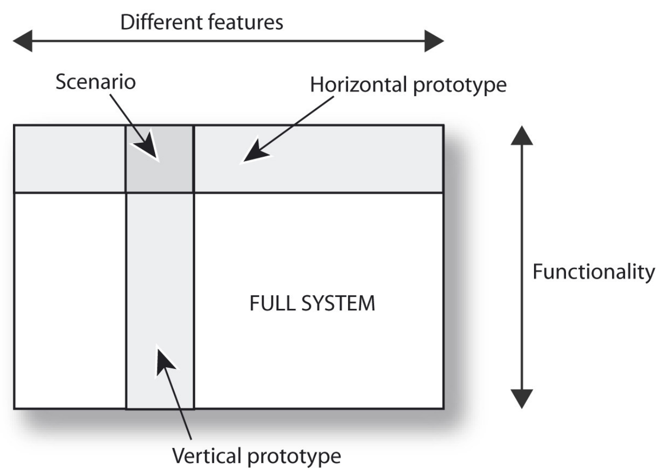

Figure 6. Two dimensions of prototyping: horizontal and vertical prototyping (after Nielsen, 1993).

2.3.5 Evaluating designs

After the design phase, and often concurring with it, the iterative UCD cycle continues to evaluate and test the implemented prototypes, to find out whether the design fulfils the user requirements and usability goals established earlier in the project. The motivation for testing and evaluating is also to find out whether there are usability problems in the design which may have a negative impact on the actual use of the system. According to Faulkner (2000), it is not enough to only gather information about the system performance, but to get a holistic picture of the system acceptability also requires qualitative information, for example, on user satisfaction. Testing can provide valuable information and feedback for further development and to help improve the UI.

There are many different usability evaluation methods that can be used when testing the design. The choice of method may depend on the project's financial and time constraints, as well as the designs that need to be evaluated, which may differ between systems and the stage of the current design. If the evaluation results indicate that the user requirements have not yet been reached, the usability problems ascertained during the evaluation can be used to improve the product, or they can be used to redefine the context of use and user requirements established earlier. New solutions will once again have to be designed and evaluated.

If no usability problems can be found, there is no need for another iterative round. At this point the design comes out of the UCD cycle and can be considered ready for the markets. User studies should not end though, since market conditions may change rapidly. Therefore, evaluations are executed for existing products accordingly, in order to obtain information, e.g., for future versions, and to make sure the product still satisfies user needs.

2.4 Usability evaluation methods

According to Whitefield et al. (1991), the classification of usability evaluation methods can be carried out according to whether the evaluations are done with real users or representational users, and with real computers or representational computers. Shneiderman (1998) calls the evaluations performed without users ‘expert reviews’, Faulkner (2000), on the other hand, calls these methods ‘analytical evaluation’, and Riihiaho (2000) uses the term ‘usability inspections’. The term ‘expert’ means that the design is evaluated either by a usability engineer, interface designer, or person who is familiar with the application area, etc.

If the evaluation involves a user, the methods are called empirical evaluations (Faulkner, 2000), or user tests (Riihiaho, 2000), or usability testing (Nielsen, 1993). Involving users is often more time and money consuming than employing usability experts, but it also provides information on real-use situations, which can sometimes be difficult for system developers to perceive.

Usability problems found during the evaluation can be used to make improvements to the UI. In other circumstances, the findings can be used to redefine the user requirements established earlier. If no usability problems are found, there is no need for another iterative round (Figure 5). However, if the user requirements are not fulfilled, the design, implementation, and evaluation continue until the objectives are reached.

2.4.1 Expert reviews

Expert reviews employ many similar methods, all based on guidelines that provide advice on how to establish the usability characteristics of an interface. According to Nielsen (1993), the guidelines can be divided into three different levels: 1) general guidelines, 2) category-specific guidelines, and 3) product-specific guidelines. General guidelines are applicable to all user interfaces; e.g. in a *heuristic evaluation* the usability of the user interface is studied by usability specialists using simple heuristics. The idea is to determine whether the interface conforms to established usability principles, called heuristics. Usability heuristics have been listed, for instance, by Norman (1988), Shneiderman (1998) and Nielsen (1993). According to Nielsen (1993), the greater the number of evaluators, the greater the number of usability problems that will be found, because different people find different problems.

Using *guideline reviews*, usability can be examined either from a category-specific point of view, where the emphasis is on what kind of system is developed, or by product-specific guidelines, where the guidelines depend on the individual product (Nielsen, 1993). In general it can be said that due to their complexity, guideline reviews require a high degree of expertise, whereas *property checklists* can normally be worked through by almost anyone. *Standards inspections* have a slightly different perspective, since they provide information on how the interface should appear to the user, and therefore are not concerned so much with usability.

The aim of a *consistency inspection* is to find inconsistencies among a set of user interface designs of a product family (Nielsen, 1993). The system designers from each of the development groups meet to see whether an interface functions consistently with its designs. Therefore, such inspections evaluate the consistency across a group of products. In *formal usability inspections*, inspections are performed by a moderator after which there follows an inspection meeting, where the lists of usability problems are presented and discussed, e.g., with the designers (Shneiderman, 1998). The *feature inspection*, on the other hand, emphasises the importance of functionality in order to achieve product usability. The method involves identifying the user tasks and the application's features that will be used for performing these tasks. The features are then evaluated against the usability measures.

A *cognitive walkthrough* is an examination of certain tasks performed by usability specialists using the user interface, but which tries at the same time to identify the role of real users and their use situations (Wharton, 1994). Cognitive walkthroughs simulate users' problem-solving processes, because the test evaluates whether the simulated user's goals lead from one action to the next in the correct way.

Another expert review is called the *GOMS* method, which is a family of techniques proposed by Card et al. (1983). The acronym GOMS stands for Goals, Operators, Methods, and Selection Rules and the aim is to model and describe human task performance. A goal defines a state of affairs to be achieved and determines a set of possible methods by which it may be accomplished. Operators are different acts (perceptual, motor, or cognitive) the execution of which is necessary to change any aspect of the user's mental state or to affect the task environment. Method describes a procedure for accomplishing a goal. If there is more than one method than can be used to achieve a goal, a selection rule is required to determine what method to choose, depending on the context.

2.4.2 User tests

User testing methods involve the use of real users who belong to the chosen user group. A *usability test* is one of the most fundamental methods in the usability evaluation, because real test users are asked to use the product. The moderator of the test gives predetermined test tasks one at a time to the test user, who in turn performs the tasks with the user interface (Nielsen, 1993). The aim is to identify possible problems with the interface. Test users are generally asked to think aloud while performing the tasks. Interviews and questionnaires are also frequently used in connection with the usability test, in order to gain more insight into the user's interaction with the interface. Usability tests can be arranged either in a usability laboratory or in the real use context, which may differ, for example, from office environments to outside conditions.

Thinking aloud is a technique used to gather information about the user's thoughts and rationale for executing the tasks in a particular way (Nielsen, 1993). This is useful especially when trying to understand the mistakes made by users and to get ideas about what might be causing the mistakes. *Interviews* between usability specialists and users are also used as a method in itself to gather information about work practices, context requirements, user preferences and opinions. *Questionnaires* are often used to capture data about users (e.g. their skills, experience and profile) for statistical purposes.

Performance measurement techniques are used to obtain quantitative data about the performance of test participants' when they perform certain tasks, e.g. during a usability test. Different measures, such as the success rate or task time are considered, and the aim is to gather the data to see, for example, if the usability goals of the product have been met.

During *pluralistic usability walkthrough* meetings, representative users, developers, and usability specialists go though a specific scenario and talk through any potential usability issues (Bias, 1994). The reason for bringing together various people from different aspects of the interface is that each one has a certain perspective, expertise, and goal in relation to the project and a greater number of usability problems can be found from the interaction between team members.

Observations can be performed either with an unobtrusive observation method, where the usability specialist observes the test users without interrupting them with questions or explanations, or by employing an obtrusive observation method, where the observer may explain design decisions and ask questions, or even engage the test users in a discussion. The *contextual inquiry* method is actually a kind of combination between an interview and an observation. The specific characteristic of this method are that the interview is executed in the real use context, where the user is performing the real tasks (Beyer and Holtzblatt, 1998).

User logging is done automatically by collecting statistics about the use of a certain system. This is a useful and easy method of collecting large amounts of data from several users working under different conditions. Log data contains information about the frequency with which each user has used each feature in the program and the frequency with which various events of interest have occurred.

F*ocus groups* are used to evaluate a system by getting user feedback and gathering initial reactions to a design. The method involves bringing several users together to discuss new concepts under the leadership of a moderator who has a pre-planned script on topics to be raised (Caplan, 1990). Focus groups often bring out users' spontaneous reactions and ideas through the interaction between the participants.

Users can be asked to keep *incident diaries* on the system, which typically means writing notes when problems occur in real use situations. On the other hand, if one wants to find out how users experience a product and how it enters their minds (what they know, feel and dream), then more empathic methods are needed (Koskinen and Battarbee, 2003). *Empathy probes* address this issue, since their purpose is to achieve an understanding of the users' thoughts, experiences and lives. The word 'probe' refers to a recording object that can be sent to the user, i.e. to the places where the researcher cannot go. The probe can be a recorder, diary or a disposable camera. Pictures and postcards can also be used to support storytelling (Koskinen and Battarbee, 2003). In order to understand why the user has documented the specific items, it is essential to go through the results together with the user after the empathy probe study (Mattelmäki, 2003).

2.5 Expected benefits of applying UCD

Making systems more usable may have noticeable social benefits for users by guaranteeing easy-to-use systems which are less stressful for the user and therefore more acceptable. For the system developer, a user-centred design can provide financial benefits in the following areas (Earthy, 1996):

- *Reduced production costs:* the overall development times and costs can be reduced by avoiding over designing a system and reducing the number of changes required late in the design stage.
- *Reduced support costs*: systems which are easier to use require less training, less user support and less subsequent maintenance;
- *Reduced costs in use*: systems better matched to user needs improve productivity and the quality of actions and decisions.
- *Improved product quality*: user-centred design results in products with a higher quality of use and products that are more competitive.

Since the benefits of applying a UCD approach are widely accepted and the methods involved are well developed, the following chapter contains a literature review on cartographic research to establish whether a usability and UCD approach has been applied to cartography and map application design.

3 USABILITY-RELATED RESEARCH IN CARTOGRAPHY

A literature review of usability-related research in cartography is presented in this chapter, which shows that actually a number of studies have been in fact undertaken relating to maps, and which can be considered ‘usability studies’ in one way or another. Montello (2002) concludes that map design research includes much of what has variously been called ‘perceptual cartography’, ‘the human factors of maps’, ‘evaluation research’, ‘usability research’, ‘communication research’ or ‘experimental cartography’.

The review is divided into five, partly overlapping, thematic entities. First, the basics of cartographic visualisation are introduced. This is followed by a description of the map reading process. The third part reviews the main studies that have been undertaken in cognitive map design research, and the fourth part discusses different usability aspects relating to GIS and digital maps. Usability-related research into maps on mobile devices is reviewed in the fifth section. Finally, a summary is given at the end of this chapter.

3.1 Cartographic visualisation

Due to the multidisciplinary nature of this thesis, a definition of *cartography* is required at the outset: “cartography is the art, science and technology of making maps together with their study as scientific documents and works of art” (ICA, 1973, p.1). *Cartographic visualisation* embodies the unique characteristics of a map, i.e. it is a generalised, symbolised and measurable document designed to meet its intended purpose. Furthermore, a map can be described as “a symbolised image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author’s execution of choices, and is designed for use when spatial relationships are of primary relevance” (ICA, 2005).

The term *geovisualisation* is sometimes preferred over the term cartographic visualisation, because a map can be considered too narrow for new representational possibilities of spatial data (perspective views, photographs, animations etc.). The term addresses the visual exploration, analysis, synthesis, and presentation of geospatial data by integrating approaches from cartography with scientific visualisation, image analysis, information visualisation, exploratory data analysis and GIScience (Dykes et al., 2005).

Objects or phenomena in reality are the visualisation sources of geospatial data. The nature of these objects can be expressed in their symbol shapes, which can be point, line, area or volume. Map design consists of the choices made by the cartographer: the choice of the graphic variables for symbols and the mapping method (Kraak and Ormeling, 2003). According to Bertin (1983), the visual (graphic) variables can be listed as: size, value, texture, colour, orientation, and shape. Furthermore, Kraak and Ormeling (2003) also write about arrangement (the random or systematic repetition of variables) and focus (the clarity with which symbols are visible). Colour can also be further divided into hue, value or chroma (saturation).

If these elements, chosen by a cartographer, are used in a map in such a way that the visualisation corresponds to the knowledge of the user and the map use situation, then the message delivered by the map can be said to correspond to the message that the map producer wanted it to. Sometimes deficiencies in the visualisation may cause interruptions in map reading, e.g. if the user does not understand the visual layout of the map, the meaning of the map symbols, or the purpose of the map's content (Nivala and Sarjakoski, 2004). Help has traditionally been provided by the map's legend, but even if the information can be found in the legend, there still remains the task of going back to the original place on the map before the interruption occurred. This can be time consuming and frustrating for the map user. Therefore, understanding the user's *map reading process* is important in map design.

3.2 Map reading process

Due to the visual nature of cartography, the underlying principles of graphical communication are critical to the good over-all visual layout of a map. People react to visual stimuli differently than they do to written and spoken communication; spoken information is received in serial fashion, i.e. words follow each other in sequence in a definite order. With graphics, people receive visual information synoptically, all at once, instead of in a sequence. According to the Gestalt psychology approach, when people open their eyes they do not see fractional particles in disorder, but instead, see larger areas with defined shapes and patterns. The whole picture that people see is more structured and cohesive than a group of separate particles. The focal point of Gestalt theory is the idea of 'grouping'; how people tend to interpret a visual field or problem in a certain way (the rules were originally set by Wertheimer, 1923, cited in MacEachren, 1995). The main factors in determining grouping are:

- **Proximity** – elements tend to be grouped together depending on their closeness.
- **Similarity** – items that are similar in some way tend to be grouped together.
- **Closure** – items are grouped together if they seen to complete a pattern.
- **Simplicity** – items are organised into figures according to symmetry, regularity, and smoothness.
- **Continuity** – items that form smooth, straight, or curved lines appear to belong together. Contours based on smooth continuity are preferred to abrupt changes of direction.
- **Connectedness** – parts of the array that appear to be connected are organised as a single unit.
- **Figure-ground** – for an item to be perceived, it must stand apart from its background.
- **Familiarity/experience** – items are more likely to form groups if the groups appear familiar or meaningful.
- **Good form, good shape, prägnänz** – items' shapes tend to continue beyond their ending points.
- **Common fate** – objects moving in the same direction tend to be seen as a unit.

The laws of perception are essentially related to the map reading process, because every map symbol is affected by its location and appearance relative to all the other symbols. Therefore, people viewing maps see the maps structurally; some marks look more important than others, some shapes will 'stand out', some things will appear crowded, some colours will dominate etc. The visual hierarchy of map symbols is a relevant issue to consider in cartographic design (Figure 7). Thus far, most of the references to Gestalt principles by cartographers have been related to figure-ground segregation (MacEachren, 1995).

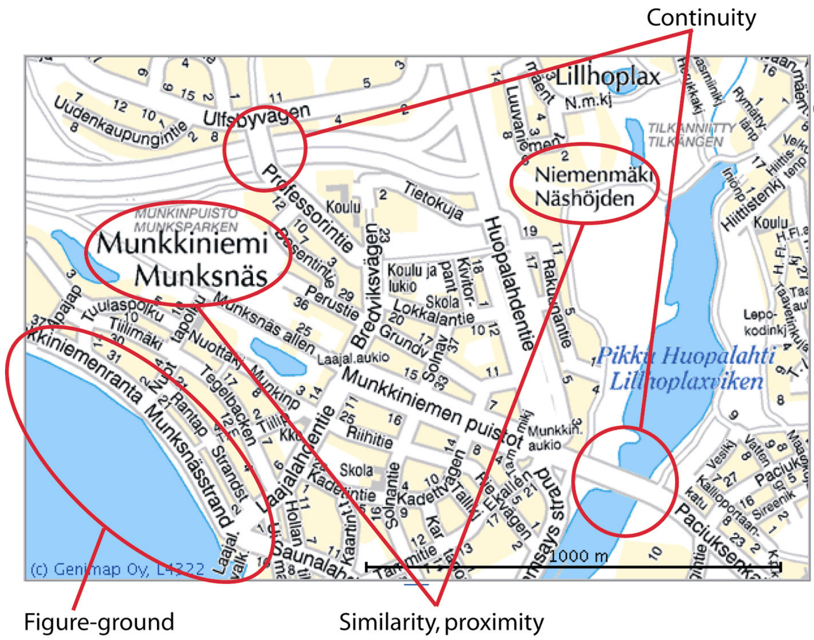

Figure 7. The laws of perception are related to the map reading process (map example available at http://www.ytv.fi/, copyrights owned by Genimap Oy).

Keates (1996) discusses the fundamental processes involved when using a map: detection, discrimination, identification, recognition and interpretation. First of all, the map user has to be able to respond to what is there, i.e. the map symbols have to be sufficiently stimulating in order to make them *detectable*. Furthermore, the map user also has to be able to make out the difference between one symbol and another, in order to *discriminate* between them. *Identification* is a more complex issue compared with the latter two processes; detection and discrimination can take a place without the user understanding what the symbols represent, whereas identification is a learned behaviour. Forgus and Melamed (1976) state that the difference between identification and *recognition* is that by identification users are able to say what a specific symbol is or name it, whereas the recognition means that the users are able to say that something looks familiar to them. In addition to these preconditions, *interpretation* is the stage where the percepted information is further processed by the user to resolve the tasks required of the map.

The map reading process is very much a personal experience, but it still remains a challenge from the map designer's point of view to ensure that everyone reading the map understands it in the way that it was meant to be understood. The final result depends, not only on the skill of the cartographer, but also on the user ability to perceive the map.

3.2.1 Communication theory

Shannon and Weaver (1949) first introduced the communication system in the classic Shannon information theory, which has been referred to by many researchers in computer science and also in cartography. In general, the communication theory divides a communication event (such as the map reading process) into five different parts:

- the source of the message
- the sender of the message
- the message
- the receiver of the message
- the interpretation of the message by the receiver

This also applies to the map making and reading processes; the source of the message equals the data used for compiling the map, whereas the sender of the message is the cartographer. The message is the map product, and the receivers are the map users and their sensory perception. Robinson (1952) emphasised that the function of maps is to communicate with people, with the message being dependent on the visual appearance of the map, which in turn depends on the design decisions made by the cartographers. In order to understand and improve a map's function, cartographers have to understand the effects of design decisions on the minds of the users, and systematically observe and measure how people study and interpret maps.

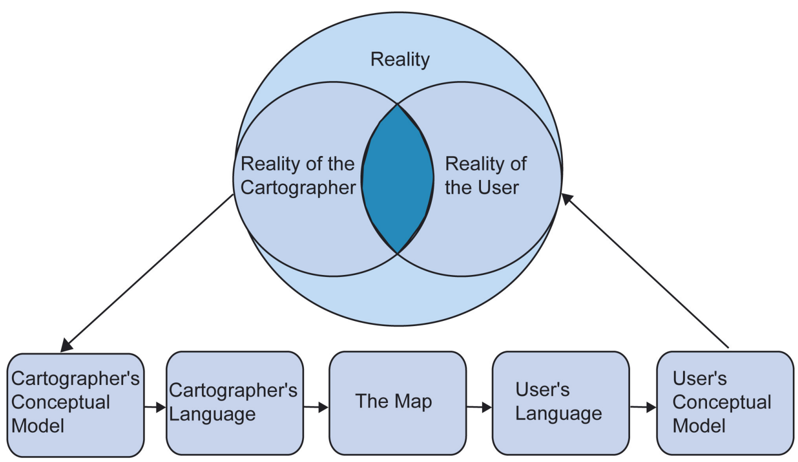

Figure 8. Principles of the map communication model (after Kolacny, 1969).

The theory of the cartographic communication model was developed in the 1960s by Keates (1964), Board (1967) and Kolacny (1969). Kolacny argued that map production and use should be understood as a single process of communicating cartographic information (Figure 8), in which the overall reality includes both the reality presented in the map and the reality of the map user.

This model was later criticised for being only partially cognitive, since it is not necessarily concerned with cognition at all, but with formal theories, such as structural linguistics. However, the communication theory was a strong base for understanding the processes involved in cartographic communication, and several researchers later elaborated on it; e.g.

Morrison (1976) defined the encoding process as the cartographer's cognitive system and the decoding process as the recipient's cognitive system.

3.3 Cognitive research on map design and use

Since maps are representations of the real world, cartographers have been aware for a long time of the relevance of understanding the human mind and the contribution of the maps to the intellectual world of human beings. Montello (2002, p. 283), for instance, states: "the recognition that map design is about the design of human cognition might be termed intuitive map psychology" and continues that in realising this, cartographers of the 20th century began to understand that intuitions about map cognition could be developed more systematically by applying sciences and theories related psychology.

According to Montello (2002), cognitive cartography can be divided into three aspects: 1) map-design research, which aims to understand maps, mapping, and map use in order to improve them, 2) map-psychology research, which has as its goal the understanding of human perception and cognition, and 3) map-education research, which focuses on improving education on maps and how to use them.

Montello (2002) states that some of the earliest empirical map-design research concerned the psychophysics of graduated circles (where a circle stands for a value of quantity at a mapped location), which were studied together with other proportional-area symbols by several researchers over three decades (1950s-1970s) after Robinson (1952) introduced his ideas on the role of maps. The influence of cartographic design on map comprehension has also been studied using other individual map symbols. For instance, Ekman et al. (1961) executed a psychophysical study of cartographic symbols, while Olson (1975) discussed the improvements to cartographic communication, and Brewer et al. (1997) evaluated colour schemes for choropleth maps.

According to Montello (2002), during the late 1970s and 1980s, psychophysical approaches were criticised for focusing too much on low-level map tasks (e.g. for only considering isolated symbols), instead of high-level tasks such as reasoning and inference making, which required more overall consideration of their relation to maps (e.g. Gilmartin, 1981). In a review of cartographic design experiments, Petchenik (1983) therefore called for design-research in which the users tested would be shown real examples of maps under evaluation, rather than the maps made for testing purposes, which isolate the variable to be studied. The psychophysical approaches also neglected individual differences between map users and their different ways of looking and thinking about maps.

Since the 1980s, a number of studies have examined the differences in the spatial abilities of individuals, for example, the differences in map-use skills between the genders have been studied from many perspectives (e.g. Gilmartin and Patton, 1984; Self et al., 1992; Montello et al., 1999). A study considering individual differences in map reading spatial abilities using perceptual and memory processes was reported by Lloyd and Bunch (2005). Another study by Lobben (2004) researched people's habits in navigation map reading, and examined the tasks, strategies and cognitive processes involved. In a survey of map reading abilities, Streeter and Vitello (1986), showed that people with low spatial ability prefer landmarks and verbal directions, while those with high spatial ability prefer spatial representations of the route. There are also indications of cross-cultural variations in conceptualising geographic space in navigation tasks (Mark et al., 1999).

Recording speech together with accuracy in searching for particular targets or answering particular questions were also applied to map perception studies. According to Montello (2002), these included studies on the perception of a variety of symbol and map designs, including region areas in conformal projects, dot area symbols, greytone scales, type fonts and lettering. Cognitive topics recently considered by cartographers have also included the use of colours in maps (Brewer et al., 1997), visual search processes used in map graphics (Lloyd, 1997) and learning processes used for maps and graphics (Lloyd, 1994).

Chen et al. (2003) took a slightly different view on usability by studying the *pleasure* associated with using maps for navigation. In their study they used three different map visualisations of the same area, and test users had to find their way using the maps for the given tasks. They concluded that when considering the usability of maps, the evaluation should concentrate on the map's legibility, identity, learnability, efficiency and memorability.

Map reading behaviour has also been studied from the perspective of the user's eye movements. Preliminary studies were undertaken by Jenks (1973) who recorded the scan paths of users studying a dot map. This was followed by several other studies; see citations in Steinke (1987). The habit of searching for the meaning of symbols from the legend has been studied recently, for instance, by Brodersen et al. (2002), who applied results of tracking the eye-movements of users when they searched for methods to evaluate map reading, map design, and map usability. According to them, users had longer fixations during more cognitive processing, and the longer these fixations were, the higher the level of complexity of the map. Map legends have been evaluated in some studies; Kumar (2004) got test users to compare different legend types for choropleth maps.

3.4 GIS user interfaces

The previous paragraph described usability-related research mainly for paper maps. Computer-based systems for producing digital maps have highlighted other design issues, such as multidimensional approaches, interaction and animation. When considering computer-based screen maps, the usability of Geographical Information Systems (GIS) is also a relevant issue that needs to be analysed. GIS can be defined, for instance, as a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough, 1986). It was originally highly specialised professionals, who were often also responsible for collecting, analysing and visualising the data and developing the necessary operations, who used GIS at the end of 80s. However, GIS has changed over the last three decades: from command line interfaces to Web-based – and recently virtual environment and handheld applications. GIS applications are now used by a larger number of people who are often less experienced or not involved in processing the spatial data beforehand. An important issue related to GIS in terms of usability is the fact that users may be divided into two groups: GIS professionals and/or cartographers on the one hand, and casual users who do not have the same level of experience and expertise on the other.

Although the development of GIS has taken place over three decades, research into GIS user interfaces and the application of HCI were not recognised as important topics until less than two decades ago (Gould, 1989; Mark, 1989; Mark and Frank, 1992). At the outset research concentrated on studying how people perceive space and how the GIS users could be modelled. Kuhn and Egenhofer (1991) reported on a special workshop on 'Visual Interfaces to Geometry', where the goal was to regard interaction with geometry-processing systems as communication with geometric models. In this dialogue a user and the system are both partners in terms of 'internal representations' or the models of a task.

Lanter and Essinger (1991) studied user-centred GUI designs for GIS and stated that traditional UI designs were more focused on how to represent software functionality in the system interface than on how to fulfil user expectations. This often resulted in arbitrary design decisions that made it difficult to use the system. In order to help users adapt to poorly designed system interfaces, more system documentation, training, and end-user support was needed. In addition, Traynor and Williams (1995) analysed different design aspects that made GIS difficult for non-GIS specialists to use, and pointed out that navigation through most of the GIS interfaces was difficult for users, because the interfaces were designed to support the system architecture rather than support user tasks. Lanter and Essinger (1991) suggested that making use of graphic and symbolic clues could help make GIS easier to use.

In addition, Lindholm and Sarjakoski (1992) stated that because GIS technology is becoming available to an increasing number of non-experts, applications designed for ordinary people, such us computer atlases, must have a very clear and simple user interface. They also stated that the design of user interfaces for GIS applications lacked a firm theoretical foundation, and thus presented an approach to building such a theory which involved information theory and user modelling. They listed three variables for describing users: 1) the information the user wants, 2) the information the user already has, and 3) the user's ability to infer deeper information from a given piece of surface information (user queries). Furthermore, Lindholm and Sarjakoski (1994) also pointed out the importance of design by stating that if a user needs to spend time and mental resources figuring out how the screen map is used, less attention will be spent on performing the task.

Interface functionality in a more specific way was presented by Egenhofer and Richards (1993), who tested a prototype virtual light table, on which users were able to drag map overlays and then view the composite image. Speech and natural gestures as interfaces for large screen maps have also been proposed (Sharma et al., 1999), as well as tactile maps for people with disabilities (e.g. Golledge, 1991). Research has also been done to minimise interpretation problems for those with colour vision impairment (Olson and Brewer, 1997).

Oviatt (1996), on the other hand, studied human performance with interactive map system interfaces, which supported spoken, pen-based and multimodal input on interactive maps. One of the findings was that the majority of users preferred interacting with maps multimodally, which emphasised that the need for designing multimodal systems that are easy to use, transparent, flexible and efficient. Multimodal pen-voice input also gives users sufficient flexibility to optimise their own accuracy, efficiency and cognitive load (Oviatt, 1997). Andrienko et al. (2002) stated that interactive techniques and tools can support information exploration and knowledge construction only if users are able to utilise these instruments properly. They assessed the usability of different interactive tools in an exploratory analysis of geographically referenced data implemented in a particular geovisualisation package, specifically from the perspective of tool learnability, memorability, and user satisfaction. The methods employed in the study included the use of profile questionnaire and also involved users performing test tasks and responding to control questions.

In addition to interface functionality, design aesthetics have also been considered in various studies. Richards and Egenhofer (1995) compared two visualisations of a user interface based on a map-overlay metaphor for GIS with the aim of examining whether this approach would be useful for non-GIS experts from the perspective of applications ease of use. In their study, a slightly modified cognitive walkthrough method was used for the most common tasks. The emphasis was on 1) finding out the amount of previous knowledge necessary to handle the visualisation, 2) basic steps needed in order to perform the tasks, and 3) the potential errors users might make when using the system.

At the beginning of the 90s studies on GIS users were mainly based on postal and telephone; for instance, Davies and Medyckyj-Sott (1994) studied GIS usability from a user perspective with a postal survey. The user responses were measured using the Likert-scale and the authors gave recommendations based on their findings and general user interface design principles. Attempts to understand and improve human interaction with GIS was also studied by observing users in their real work context, for example, Davies and Medyckyj-Scott (1996) arranged a workplace observation study, which involved structured interviews, checklists and video recordings of users working with GIS. Other usability methods have been employed; Elvins and Jain (1998) designed a user interface for traditional GIS functions and tested their approach by using Norman’s (1988) heuristics, usability testing and cognitive walkthrough methods.

Bernardo and Hipolito (2000) reported that several user complaints and low access numbers to a specific digital geographic information system (SNIG) motivated them to incorporate a usability approach into the design process. The approach started with focus groups with the aim of finding out the user requirements for the service. Based on the results and a usability evaluation together with web design guidelines, a new site was implemented. As new interfaces were implemented to the service later on, a usability test was also arranged with test users, and the results of the tests were again used as a guide for new implementations. Fuhrmann and MacEachren (2001) applied usability engineering methods (focus groups and questionnaires) to designing interfaces that support movement within geovirtual environments (GeoVEs). Hornbaek et al. (2002) presented an empirical analysis of zoomable interfaces (which were maps) to show how the overview influences the way users navigate information spaces. The experiment consisted of two phases: using one map with an overview interface and using another map without an overview interface. Key dependent variables included: accuracy of the questions answered, task completion time, preference, and navigation activities.

3.5 Screen maps

In addition to UI of GIS applications, studies on the usability of screen maps have also been performed. The importance of gaining knowledge of target users and use contexts in map design was emphasised by Sainio (1992). Beverley (1997) studied the benefit of a dynamic display of spatial data-reliability from the user's point of view with a test using map data for decision-making that included both novices and experts. Harrower et al. (1997) evaluated the design elements and communication quality of Internet maps for tourism and travel in a user survey with two different user groups: professional geographers and non-geographers. Studies have also been done on map animation and interactive tools (e.g. MacEachren et al., 1998) and on the usability of zoomable maps with and without an overview map (Hornbaek et al., 2002).

Arleth (1999) studied the problems of screen map design and listed a few of them; e.g. the map area was too small and both the legend and instructions too dominating on the screen. According to the study, the design process would be more manageable, if it is separated into two phases concerning 1) the map interior (the map elements, symbolisation etc.) and 2) the map exterior (the tools and functions for using the map). The research also discussed the different roles that the cartographers and programmers have in the design process, and emphasised that cartographers should improve their knowledge of usability engineering.

Leitner and Buttenfield (2000) investigated the effect of embedding attribute certainty information in map displays for spatial decision support systems by having test users perform specific tasks test maps. Harrower et al. (2000) studied the development and assessment of a geovisualisation tool designed to support learning about global weather. The study used a focus group method and structured user testing to find out how novice users understood and used the system. A more specific study, which included iterative design with improved map prototypes and testing was described by Ahonen-Rainio and Kraak (2005). The maps in the study were used to visualise geospatial metadata, which users analysed in terms of their suitability to achieve the required objectives. Users had to select the most suitable dataset from among several alternatives, where users determined the suitability of a dataset within a use scenario. It was observed that the visualisation of metadata supported users in selecting dataset, though it was also stated that differences between user strategies for different representations could be investigated further.

Improving usability was also the aim of Agrawala and Stolte (2001) who studied cartographic generalisation techniques designed specifically for route maps. Their research was based on how route maps are used and on an analysis of the generalisations commonly found in hand-drawn route maps. One of the most recent studies evaluated climate forecast maps using an empirical study with test users (Ishikawa et al., 2005). The test results showed that in many cases qualified and motivated test users failed to interpret the maps in a way that the map designer intended. The authors suggested improvements to the design, but also that users should receive training. Jahn and Frank (2004) proposed an additional aspect for usability attributes: information quality (IQ). IQ aims to describe the importance of the data needed by the user and enables data quality to be adapted in an optimal way to meet user needs.

Recent technological developments have provided a vast amount of tools and techniques of interest to geographic visualisation, especially from the point of view of interface and interaction design. As a result of this development, research has started to emerge relating to augmented reality (AR), virtual reality (VR) and mixed reality (MR) within the field of cartographic/geographic visualisation. Hedley (2001) pointed out the importance of understanding these technologies and how they relate to people, in order to maximise the potential of these new technologies within spatial visualisation. In the study a prototype system of an AR visualisation interface was tested with users to identify interface and visualisation features that would be relevant for a new interface setting. Fuhrmann and MacEachren (2001) compared the usability of two geovirtual environments and stated that user-domain-specific designed interaction metaphors support virtual navigation on desktop geovirtual environments. Another research topic has been collaborative work and how this can be supported in the field of geovisualisation (e.g. Rauschert et al., 2002; MacEachren et al., 2005).

3.6 Maps on mobile devices

The convergence of mobile devices, network computing and wireless telecommunications with spatial technologies enable a new form of location-based services (LBS). LBS applications can, for example, deliver geospatial data from GI servers across the Internet to mobile devices according to the location of the user - or to a specific requested location. Reichenbacher (2001, p. 2515) defined the conceptual framework for 'mobile cartography':

> *"Mobile cartography deals with theories and technologies of dynamic cartographic visualisation of spatial data and its interactive use on portable devices anywhere and anytime under special consideration of the actual context and user characteristics."*

There are already a couple of commercial applications for maps on mobile devices that display the maps on a personal digital assistant (PDA) screen or a cell phone screen. Most of the applications are for car navigation purposes, but products for off-road navigation for cyclists or walkers also exists. Most of the services to date provide maps in raster format, but vector formats are also emerging mainly because of the higher quality of visualisation and potential for interaction (Sarjakoski and Nivala, 2005).

Most of the research concerning maps on mobile devices has been carried out on different navigation systems which provide the user wit *route information*. As was the case with commercial applications, this research also was focused first on car navigation systems (citations in Burnett, 2000). Marcus (2000) stated that there are at least three different ways of visualising route information: 1) map displays showing the route superimposed on a map of the area, 2) arrow pictograms giving graphic information on the direction of the next turn with added textual information (e.g. distance to it), and 3) text providing information on upcoming turns in textual format. In contrast, Kray et al. (2003) reviewed different ways of presenting route instructions on mobile devices using a field evaluation method followed by an interview. They divided the different representation forms into: textual and spoken instructions, 2D route sketches, 2D maps, pseudo-realistic instructions (including 3D models) and a combination of these.

Chincholle et al. (2002) evaluated the usability of a mobile navigation and location-based service, and stated that downloading traditional miniaturised maps did not contribute much to meeting the needs of mobile users, whereas route directions were thought to be more valuable. The test results also emphasised the fact that the maps could not really be used for detailed navigation, and that they mainly provided users with only a mental model of the route. The authors also commented that route directions should be given as a table of route directions as a default setting, instead of given a map view of the route, because the 'cluttered' map functionality did not provide the user with adequate information. However, it must be noted that the tests were performed in a usability laboratory, not in a real-life navigation situation. In addition, it was not discussed whether the map design and level of detail had been appropriate for the map scale, and therefore whether different results would have been obtained had these been altered.

Many researchers have compared traditional 2D maps (either paper maps or on a mobile device) with more advanced visualisation techniques (mainly 3D visualisation). Rakkolainen and Vainio (2001) studied the usability of a 3D city model for a PDA using two methods: a laboratory test with a PC and a field test in a city with a prototype version. The results indicated that users preferred the combined mobile system rather than the map or photo-realistic model alone. They also found that users were more likely to recognise their own position and landmarks using the photo-realistic model than the 2D map. Laakso (2002) described the usability evaluation process of a 3D map prototype in a mobile device. According to the results, the 2D paper maps were faster to use in orientation and navigation, perhaps because people are used to them, but 3D maps were more fun to use. People were also able to recognise real life objects from the 3D map without any additional help, which was seen as an advantage compared with the 2D paper maps.

Devices for map applications range from PDAs to mobile cell phones and even wearable computers. For instance, Clarke (2001) described a wearable mapping system and pointed out the critical part played by user interface designs in new, ubiquitous applications, because if map creation and use are synonymous, many traditional cartographic designs will fail. Kolbe (2004) described a system, which provided augmented videos and panoramas to support intuitive orientation.

Research has also been carried out on indoor mobile guides for exhibition/museum visitors, for instance, Schmidt-Belz and Hermann (2004) studied information content and representation simplicity on small screens. However, studies on maps for indoor navigation systems have generally only been a minor concern. Broadbent and Marti (1997) discussed usability issues related to location aware mobile interactive guides, HIPS, which have been designed to allow tourists visiting a city or museum to navigate both the physical space and related information space at the same time. The system was based on audio messages.

As existing commercial LBS applications providing route directions mainly construct their directions based on geometry, orientation and street names, the relevance of *landmarks* has been studied by several researchers, mainly due to the fact that current positioning methods are inadequate for narrow urban streets where people need accurate information on their location. To improve the usability of route instructions, landmarks inspired by human communication of routes could be used (e.g. Denis et al., 1999; Weissensteiner and Winter, 2004; Paay and Kjeldskov, 2005). In order to help the user in different navigation tasks, landmarks have to be distinctive and they must have unique properties, so that they can 'stand out' from nearby symbols on the map. May et al. (2003) studied information requirements for pedestrian navigation aids by asking users to give navigation instructions for a specific route either based on their own memory or during a walkthrough of the route. The results emphasised the use of landmarks as the primary means of providing directions for pedestrians. Hampe and Elias (2004) studied the integration of landmarks with topographic data on a mobile map. They focused on the idea of taking into consideration a user context, their navigation requirements, and situations, to determine the best way to present navigation information, i.e. which landmarks are relevant, and which presentation modality meets the needs of the attention and interaction limitations of the user.

Kjeldskov et al. (2005) stated in their study that their motivation was to evaluate which methods are suitable for evaluating mobile guides and which methods should be selected and why, and who should carry out the evaluations (experts or users). They used four different usability methods and techniques when evaluating the usability of a mobile guide: field-evaluation, laboratory evaluation, heuristic walkthrough and rapid reflection (an applied ethnography method). The results established general guidelines for choosing the appropriate approach. However, the usability of the maps in mobile guides and the user interaction with the map design were not studied or discussed.

While existing studies mainly focus on tourist and route maps, to date only a few studies have been published on usability evaluations of topographic maps on mobile devices (Nivala et al., 2003). Some cartographic research, however, is being undertaken on mobile guides that have factored usability issues into the product development, e.g. WebPark (Edwardes et al. 2003) and LOL@ (Pospischil et al. 2002). Heidmann et al. (2003) studied design principles relating to the interaction of users with map visualisations on small screens in their location-aware guide project called SAiMotion. During the project they applied a UCD approach to validate the design principles using empirical methods involving user participation and user testing. User requirements were established through a focus group method, on the basis of which two usage scenarios were devised. Two iterative rounds of design and laboratory testing with users were conducted, which produced the map design guidelines for the mobile systems. The results included comments on both cartographic issues, and the map's zooming and sliding functionality.

3.7 Cartography and iterative UCD

Broadbent and Marti (1997) stated that when designing a multimedia system, special attention must be paid to the entire context of use, the users and their intended tasks. They undertook a project in which a user-centred design was realised by involving users in all stages of the design and development and iteratively testing the system on site with the potential users. Elvins and Jain (1998) proposed a solution for fulfilling GIS user interface requirements by following a structured, iterative user-centred design approach. Four main usability goals were established and Norman's heuristics was used in the design, finally the design was evaluated with usability tests and cognitive walkthrough methods.

Lähteinen (2002) evaluated the applicability of different user-centred methods in GIS design from an organisational point of view and concluded that GISs are often not user-friendly, since they frequently malfunction, are difficult to use and the system operation does not support task performance. Nielsen (2004) suggested a conceptual level of 3D geovisualisation for describing a user-centred approach that includes four categories: representation, rendering, interface and interaction.

Haklay and Topon (2003) called for a user-centred design approach to Public Participation GIS (PPGIS) projects in order to guarantee that the projects are accessible and easy to use. The reason for this is that it is a field of research, which focuses on the use of GIS by non-experts and occasional users who usually have a diverse range of computer literacy, worldviews, cultural backgrounds and knowledge. Ahonen-Rainio (2005) applied an iterative UCD approach when trying to understand users' actions, needs and preferences for visualisation of geospatial metadata. Furthermore, MacEachren et al. (2005) used a human-centred approach in their study of a collaborative geoinformation interface using speech and hand gestures as a natural input. They stated that the development of more natural interfaces for computer systems has been part of HCI research for a while, and that this approach should also be incorporated into GIS applications in order to improve their usability.

3.8 Observations and further analysis based on literature review

According to the literature review, cartography has a long history of perceptual-cognitive research in to the use of maps and several usability evaluations and a remarkable amount of user testing has been used in cartographic research. However, usability studies seem only to deal with one specific problem under investigation. Systematic usability engineering throughout the lifecycle of map applications (including user requirements, design and iterative evaluation) seems to be rare.

From the literature review it was also noticed that usability studies concentrated either on evaluating GUIs (of GIS applications or mobile guides) or evaluating different types of map visualisations. It was observed that the studies in general did not include both studies related to map visualisation, and studies related to the GUI of map applications. This may be to do with the fact that current map applications were evaluated by two different groups of researchers: 1) cartographers and GIS specialists or 2) HCI engineers (especially in the case of mobile maps) and their results have also been reported in different conferences and journals. The overall usability of map applications was therefore not completely investigated, or at least not reported in academic research papers.

Several researchers have noticed the lack of thorough usability engineering in map application design. MacEachren and Kraak (2001) stated that there is a lack of established paradigms for conducting cognitive or usability studies with highly interactive visual environments. Consequently, one of the crosscutting challenges is the need to develop a human-centred approach to geovisualisation. Fairbairn et al. (2001) also emphasised the need to advance ways of transforming information about the world into models suited to digital and cartographic representations that will lead to effective visualisation. Cognitive issues associated with personalised and flexible possibilities for map use should be studied with an expanded range of map forms in relation to such models.

Despite the fact that the trend appears to suggest that an increasing number of usability evaluation methods are being used, Fuhrmann et al. (2005), for instance, still stated that usability inspection methods are not widely used for geovisualisation at present. One reason for this may be that the required knowledge for integrating usability issues into product development does not exist in the cartographic research community. Bringing the UCD concept into such a specific research area as geoinformatics raises many questions. When usability methods are incorporated into applied sciences, some adaptation to the methods may be necessary. Slocum et al. (2001) also stated that due to the novelty of geovisualisation and the difficulty of defining the nature of users and their tasks, applying usability engineering might be problematic. Therefore, in many situations an outside usability engineer should be brought into the context. In addition, Meng (2004) noticed that map usability tests have so far only concentrated on testing the effectiveness and efficiency of the map's use, whereas the map may still not fulfil those requirements demanded of it by the user, because the hedonistic aspects of the user may not have been considered. Meng concluded that in fact, there is currently not enough understanding about user requirements.

In addition, present developments in hardware and software have led to new innovative methods for visualising geospatial data and there is a change occurring from view-only to highly interactive map applications. However, Slocum et al (2001) pointed out that these novel methods will be of little use if they are not developed within a theoretical cognitive framework and iteratively tested using usability engineering principles. The insufficient number of usability attributes in research is becoming especially critical now that new technical environments are available for geovisualisation applications. Traditional design methods may be insufficient and may not take into account the possibilities and limitations of new environments. For example, Koua and Kraak (2004) concluded that the map use studies that have been carried out for long time in the field of cartography are not necessarily fully applicable in new interactive visualisations that may have new representational spaces and user interfaces. They proposed a usability framework for designing and evaluating exploratory geovisualisation environments that combines visual and computational methods with knowledge discovery.

Slocum et al. (2001) listed six areas in geovisualisation, in which cognitive and usability issues should be considered: 1) geospatial virtual environments, 2) dynamic representations (including animated and interactive maps), 3) metamorphs and schemata in UI design, 4) individual and group differences, 5) collaborative geovisualisation, and 6) evaluating the effectiveness of geovisualisation methods. They also argued that traditional cognitive theory for static two-dimensional maps may not be applicable to interactive 3D and other dynamic representations. In addition, Cartwright et al. (2001) stated that the technological changes involving both cartography and computer graphics have made modern cartographic representation different: a wide range of maps can be made faster and less expensively, and interaction with visual displays in almost real-time is now possible. This results in a change of emphasis from static to dynamic map use and furthermore to new requirements for design and interfaces. The authors emphasise that the main challenge is to find out, in what ways geospatial interfaces should be different from other interfaces, how geovisualisation interfaces should be adapted or created for new and emerging devices, what the most appropriate interaction methods for different users and applications are, and how users with different expertise interact with interface tools.

Furthermore, Slocum et al. (2001) pointed out that the focus of geovisualisation on facilitating work related to ill-structured problems may make it difficult to apply standard usability engineering principles. Fuhrmann et al. (2005) pointed out that it is sometimes difficult to make out the difference between usable and useful when applying HCI methods, because in geovisualisation the data exploration and knowledge discovery tasks are not straight-forward enough to say what the goal is and how well it is achieved. They emphasise the need to assess additional, and mostly qualitative, information, as well as discussing the concept of geovisualisation theory that should have more formal guidelines in the design process to make geovisualisation useful and usable. The design function would be more valid across different applications and culturally different user groups if there was such a theory in place. This theory could be constructed from different disciplines, such as perceptual science, cognitive science or HCI science. However, the role of geovisualisation researchers would be to extend and refine it in ways that would make it specific to geovisualisation (Fuhrmann et al., 2005).

4 SYNERGY MODEL FOR UCD AND MOBILE CARTOGRAPHY

The literature review on map-related usability studies revealed that there has been an extensive amount of research related to the use of maps in cartography, although systematic usability engineering throughout the lifecycle of map applications seem to be rare. It was observed that in general, studies either included aspects concerning map visualisation or GUIs of map applications – but not both. Thus, the overall usability of map applications was not completely investigated.

The aim of this chapter is to provide a synergy model for a user-centred design approach and map application design, especially for mobile cartography, based on the literature review presented in the previous chapter. The hypothesis is that UCD has a fundamental role in designing maps for new technical environments such as handheld computing with wireless communications and positioning features that involve totally new ways of interacting. The mobile map application design should also take into account the characteristics of mobile users and the use situation. The synergy model proposes that these aspects can be successfully approached using an iterative UCD approach. The model also emphasises that by applying usability engineering methods to the design of the map application, a deeper understanding of the real user requirements can be gained. The following paragraphs give a proposal on what a UCD approach may mean for mobile map design and the practical steps and methods that may be used in mobile map development.

4.1 Characteristics of mobile cartography

The number of mobile device users is increasing rapidly: Gartner estimates there will be 2.6 billion mobile phones in use by the end of 2009 (Gartner, 2005). Recently, a lot of effort has gone into the development of mobile devices and applications. This also provides a great chance to provide users of mobile devices with map applications, as maps will act as a relevant communication channel for future mobile services. For example, during the testing of a mobile tourism service (Schmidt-Belz and Poslad, 2003), user trial results showed that 66% of the users ranked maps to be a very important feature of mobile tourism support.

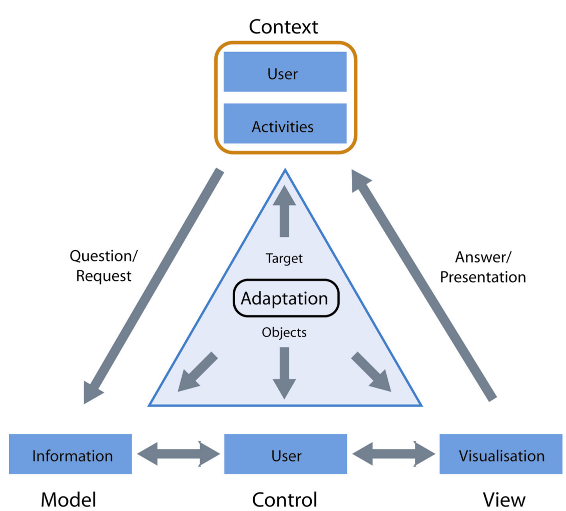

Figure 9. Conceptual framework of mobile cartography (after Reichenbacher, 2004).

According to Reichenbacher (2001; 2004), the framework for mobile cartography consists of mobile users and their activities, information and information visualisation in mobile cartography, and the technology and user interfaces (Figure 9). The researcher also emphasised the requirement for adaptive visualisation of geographic information on mobile devices according to the context of use. These are relevant aspects with regards to the usability of mobile map applications and thus are discussed in detail in the following paragraphs.

4.1.1 Mobile users and their activities

As was highlighted by the literature review, the characteristics of mobile maps, and especially the context in which they are used differ significantly from traditional paper maps – and also from PC screen maps. The users of mobile cartography are more likely to be tourists in on-demand situations, where maps can be accessed quickly and while on the move. The 'out-of-the-box' concept is an important issue to take into account for these kind of situations: demand is sudden and the user does not have time to search and use the map (application) for a long time.

The large number of users also increases the diversity of use situations, which may radically differ compared with traditional usage contexts. Shneiderman (1998) discussed differences among users: physical abilities, cognitive and perceptual abilities and personality differences. Although many of the variants listed are not relevant for mobile map application design, one example of relevant user information is, on the other hand, knowledge on how users become familiar with the map symbols and how able they were using mobile device and the map on it (Nivala and Sarjakoski, 2003).

The different types of users of mobile guides have also been considered in some studies; Goodman et al. (2004) studied the use of landmarks to help older people navigate, and evaluated the design using field trials. They compared traditional paper maps with the landmark-based navigation aid, and concluded that landmarks can be used effectively to support navigation with a handheld device. Anand et al. (2004) discussed the map generalisation process in order to provide different groups of users with appropriate maps for mobile GIS applications. Brown and Laurier (2005) used an ethnographic study to find out how tourists use maps.

Other relevant aspects to consider in design is what users intend to do with the application and for what kind of activity they need it (shortest route to the cinema, hiking route with nice view-points etc.). The type of map that a professional orienteer might require would probably contain abundant detailed topographic information, whereas a family with four children may only need information on the main tracks and campsites in the area. It would be useless to show all the information on the same map; thus the map design should be adapted to each particular situation and purpose of use (Nivala and Sarjakoski, 2003).

4.1.2 Information and visualisation

The information content presented on a map and its visualisation has to be suitable for its intended use and fulfil user requirements. In general, it could be said that mobile navigation guides not only provide maps, but also relevant information for tourists, such as the location of restaurants and shops, public offices, tourist sites, and other points of interest (PoI). Some navigation guides also give information on routes and wayfinding (e.g. Chincholle et al., 2002). A few examples of research systems where the presentation of the user location and its surrounding area is mainly based on maps, include Cyberguide (Abowd et al., 1997), GUIDE (Cheverst et al., 2000), Deep Map (Malaka and Zipf, 2000), and Lol@ (Pospischil et al., 2002). In addition to 2D maps, multimedia information such as texts, photos, and video images are also added on top of the map.

Nissen et al. (2003) studied the characteristics of small display cartography. The basic design restriction is the relatively poor resolution of small displays, which places new demands on cartographic visualisation. They listed the main requirements as follows: few details, pictogram-like symbols, a font-type with no ornamentation, easy-to-read texts, texts which easily refer to objects and presentation of information on PoIs.

4.1.3 Technology and user interface

From a technological point of view, the main difference with maps on mobile devices are that they can be dynamic and flexible and may include different types of multimedia possibilities. In addition, new interface technologies provide users with a vast amount of different interaction techniques and possibilities (compared with traditional and more static maps). New ways of engaging and involving the user, combined with the location information of the user, increase interest in researching the potential of adaptive maps.

According to Kaasinen (2002), as the variety of mobile devices increases users expect to be able to use the same types of services on various devices. However, it would require a great amount of work and time together with space in databases to plan and store different maps suitable for various systems (including for different sizes and screen resolutions, device buttons, input methods and processing power and memory capabilities). One possible solution could be to use the same databases continuously, in which case the application would need to understand the hardware and software limits of the system. Another issue is to be aware of the application's context of use (Nivala and Sarjakoski, 2003).

4.1.4 Context and adaptation

One of the major applications for future mobile information technology may be to enhance user activities by providing contextually adopted information through mobile devices. In general, it could be said that considering the user as the relevant start point for developing mobile map applications seems to be predominant. Discussion on how to use information on the location of the user (i.e. the mobile device) on map applications in more intelligent ways has been ongoing for several years. The context awareness of applications has been in interest in more wide-ranging studies, as other LBS applications can adapt their content or visualisation to fit the user. Cheverst et al. (2000) studied how context awareness can be utilised in a tourist information system, although the actual maps played a minor role in their study. Baus et al. (2002) described a system that determines the location of the user and adapts the presentation of route directions according to the characteristics of the user's mobile device, as well as according to the cognitive resources expected of the user. Reichenbacher (2001) defined the challenges for adaptive map rendering: level of detail (LoD), access speed, rendering speed and interaction. Raubal and Rinner (2004) also emphasised the need to create LBSs that take into account individual user preferences, time constraints and possible subtasks of the user.

Furthermore, Reichenbacher (2003; 2004) studied the process of adaptive and dynamic generation of map visualisations for mobile users and identified the most relevant theories for communicating spatial information in mobile environments: 1) activity theory (activity of the user, user goals, operations, social factors), 2) context theory (situated action, activity context, physical and social context, context awareness), 3) human-computer interaction (interactivity, adaptation, usability, cognitive approaches), and 4) adaptation (adaptability, adaptivity, adaptation methods). However, Gartner (2004) states that today adaptation to the 'user' means being limited to user profiles selected in advance from a list or entered manually by users themselves, although adaptating the visualisation of the current situation may also be performed automatically, for instance, according to the speed of the user (TomTom® navigation software, 2005).

4.2 Usability aspects of mobile cartography

Different users in varying use situations combined with new technology emphasise the need for user-centred approaches and methods in cartography. The definitions of usability were given earlier (ISO 9126-1, 2000; ISO 9241, 1997). The proposed UCD synergy model for mobile cartography is based on these definitions as well as the characteristics of mobile cartography listed in the previous paragraphs. The four main aspects to consider are:

1) users and their activities
2) information and information visualisation
3) technology and user interfaces
4) context and adaptation

Applications must be carefully designed to meet the diverse needs of users, their activities and use situations. Reichenbacher (2004) stated that developing useful and usable geovisualisation solutions for mobile contexts needs to consider the following aspects: 1) the technical limitations (small displays and low resolutions etc.), 2) inadequate geovisualisation by using maps not designed for screens on mobile devices, and 3) the mobility of the user places varying demands on geovisualisation that have not been studied before. Traditionally used methods and design approaches in cartography may not be able to take into account the new use context of mobile map applications.

4.3 Iterative design for mobile cartography

By using an iterative UCD approach and at the same time taking into account the characteristics of maps, it should prove possible to design products with better quality of use and which are more competitive.

4.3.1 Planning a mobile cartography project

Development projects for mobile cartographic applications using a UCD approach start with planning the project, when a decision must be taken on what kind of information is needed with regard to the usability of the product (information about the usability of an existing cartographic product, ideas for developing a new application or information for comparing products already on the market).

The factors affecting the project planning process are strongly related to the amount of resources: money, time, people. In addition, it is preferable to decide during the early stages of the project how the usability evaluation will be carried out:

- by whom (usability experts, cartographers, GIS specialists or users)
- how (usability tests, questionnaires, focus groups etc.)
- when (at which stage of the project)

4.3.2 Specifying context of use

The use situation of the mobile map may vary greatly (outdoors/indoors, PDA/PC, navigation in forest areas/tourist navigation in urban areas). In addition, the physical, social and cultural environment can also be relevant: e.g. workplace, temperature, work practices, organisational structure etc. The context of use should be studied beforehand to compile realistic user requirements, and also during the process to ensure that the design is suitable for the use context.

4.3.3 Specifying requirements

The UCD process starts by identifying all the primary and secondary users and classifying them in a meaningful way according to the project's objectives. The preliminary requirements for the system can be decided by identifying the user requirements for these groups and the real context of use. This is an important stage of the study, since the first prototypes will be based on these results.

Differences between map users may include, for instance, physical abilities, cognitive and perceptual abilities and personality differences. In some situations it may also be necessary to define the specific characteristics of different types of user, for example, users with different levels of experience. In addition to user characteristics, usability components include the intended objectives, i.e. goals, and tasks of the users. The outcome of the interaction is the result of the product being used in a specific context of use.

Methods for collecting such information include surveys, interviews, contextual inquiries, the observations of users, user participation in a context of use analysis, focus groups, brainstorming etc. Questionnaires are often used since they are relatively easy and inexpensive to compile and analyse. This was done, for instance, in the PARAMOUNT

(2002), LoVEUS (2005) and WebPark (Edwardes et al., 2003) projects. Less common methods have also been used: in the PALIO project the user requirements study was based on a combination of brainstorming and emphatic modelling (PALIO, 2005).

The preliminary usability goals can be created from the user requirements, against which future designs can be evaluated and tested. The acquired information can be structured by compiling use scenarios, i.e. use cases, which specify how users perform their tasks in specified contexts (Kulak and Guiney, 2000). User scenarios should include information about which activities should be performed by the user and which activities should be performed by the computer. After compiling the scenarios, they can be validated according to their relevance and importance. Usability goals can be established from the results.

4.3.4 Producing design solutions

After the user requirements and usability goals for the system have been identified, the next stage is to make the first design implementations. At this point it is important for the design to meet user needs in specific tasks. Sometimes the preliminary design ideas can be very rudimentary (even paper prototypes that 'look real', but which do not have real functionality behind them). The purpose is to improve the design step by step in an iterative UCD cycle. By visualising the design ideas at an early stage in the process, evaluations can be presented to users quickly and cheaply. Feedback can be gathered from users, and implementing changes at the early stage of the design may reduce the design costs.

4.3.5 Evaluating designs

After the design phase, and often concurring with it, an iterative UCD cycle approach allows for continued evaluation and testing of the prototypes, to find out whether the design fulfils the user requirements and usability goals established earlier in the project. The motivation behind the continued testing and evaluation is also to find out whether there are usability problems in the design that may negatively affect the actual use of the system. Valuable information and feedback for further developing the UI can be gained from the testing. Usability measures can be used as evaluation criteria, i.e. the application should be easy to learn, efficient to use, easy to remember, contain few errors, and be subjectively pleasing.

Usability evaluation of mobile maps can be performed in many ways, either by the project developers, or by bringing the users into contact with the product (Bornträger et al. 2003; Heidmann et al., 2003; Melchior, 2003; Schmidt-Belz and Poslad, 2003). Involving users is often more time and money consuming than employing usability experts, but it also provides real-usage information, which is sometimes difficult for the developers of a system to perceive. Choosing the appropriate method may also depend on the project's financial and time resources, as well as what needs to be evaluated. These may differ for the various systems and the stage of the current design. It was observed earlier that in general, usability evaluations carried out on map application designs did not include evaluations on both key aspects: map visualisation and the GUI of map applications. However, the overall usability of a product is dependent on both of these aspects, therefore they should both be incorporated into the UCD approach for maps on mobile devices.

Usability problems ascertained during the evaluation can be used immediately to improve the UI and maps. In other instances the findings can be used to redefine the user requirements established earlier. If no usability problems are discovered, then there is no need for another iterative round. Nevertheless, if the user requirements are not fulfilled, the design, implementation, and evaluation continues until the objectives are reached.

4.4 Heuristics

Heuristics are a quick and inexpensive way to evaluate the user-friendliness of applications. Since, for example, Nielsen's heuristics (1993) are designed for general purposes, they are preliminary defined in the following from the perspective of map applications (Nivala et al., 2005):

Simple and natural dialogue: Every additional feature on a screen makes the use of any application more complicated for the user, by increasing the number of things a user has to learn, or can misunderstand, or has to search through when looking for a specific item. Therefore, one of the main usability goals in map application design should be to provide the user with as simple a UI as possible. For instance, the tools for zooming and panning should be self-evident for the user, both from their appearance as well as functioning.

Speak the user's language: To make the UI intuitive for the user, the terminology should correspond to the user's natural language. The main focus is to distinguish between terms used by system developers (e.g. GIS specialists or cartographers) and terms used by end users. In addition to the verbal language used in the interface, this also includes other interface elements; e.g. the graphical design of the icons. Furthermore, the user's experience of the application can be made more pleasant by having a map with an intuitive UI. Intuitivity makes it easier for the user to figure out how to proceed with the application, which is especially important when the user starts to use the application for the first time. The interface should match the user's task in as natural a way as possible. Since different map applications may have different types of users, the interface may sometimes even be adapted to suit different user groups. If an application is being designed for sailing purposes, the appropriate expert terminology for that context should be used, whereas for tourist city guides totally different, more general, terms are needed.

Minimise the user's memory load: The UI should be designed so that it is immediately 'ready for use' by each user group, which is especially important, for instance, when designing map applications for tourist purposes. Users should not have to remember what kind of settings or parameters have to be given in order to achieve certain maps, the functions should be supported by the application instead. Designers should avoid long and complicated command sets that the user would have to remember in order to get something done with the map application. Attention should be paid to the design to create easily recognisable and intuitive symbols and buttons.

Consistency, feedback and clearly marked exits: The map application should have logical function buttons that are consistent in the whole interface. For example, the exit button for the application should always be in the same place, and the zoom in and out function should always work with the same logic. Users should also know what they did, what they are doing at the time, and what they will have to do in the future when using the application. This is very important, e.g., when loading large map files that take long time to be shown on the screen. Users should know that ‘something’ is happening, in order to prevent frustrations and the idea that the application is not working properly. Application buttons should also be designed in such way that the user knows what is currently selected. The user should always how to quit or proceed with the application.

Shortcuts: If the map application is to be used by both novice users and experienced map users, the different demands of both groups should be supported. Novices should be offered a help function and wizards, whereas experienced users should be provided with shortcuts to make the application quicker and easier to use, for example, shortcuts getting a default map, changing the map parameters and selecting different tools for using the application.

Preventing errors, good error messages, help and documentation: The best scenario would be to totally prevent making any mistakes with the application. This is a difficult and often too optimistic approach, and therefore good error messages should at least be implemented. It is not informative to say: “Error code 123423”, but more specific error messages can help the user in a much more gentle way. The ‘help’ function is obviously always an important part of the UI and map application.

In the following chapter, the initial UCD model for mobile cartography is tested in a real mobile map application development project. The objective was to use usability engineering methods and, at the same time, take into account the characteristics of the maps.

5 CASE STUDY: UCD IN THE GIMODIG PROJECT

This chapter describes how the user-centred design synergy model for mobile cartography was implemented in the development of a mobile map application. The research was conducted as part of the GiMoDig project (Geospatial info-mobility service by real-time data-integration and generalisation) (GiMoDig, 2005; Sarjakoski et al., 2002) during 2002-2005. The Department of Geoinformatics and Cartography at the Finnish Geodetic Institute acted as a coordinator for the project. The other participants were the University of Hannover, the Federal Agency for Cartography and Geodesy (Germany), the National Survey and Cadastre (Denmark), the National Land Survey of Sweden and the National Land Survey of Finland.

The project was funded by the European Union's Information Society Technologies (IST) programme, which strongly emphasised the concept of user-centredness (IST, 2005). Therefore, a user-friendly interface and UCD approach formed a significant part of the GiMoDig project (Sarjakoski et al., 2004b). The main goal of the project was to deliver maps in real-time to mobile users. The project resulted in an Extensible Mark-up Language (XML) prototype for a seamless, cross-border mobile map service based on open system architecture (Lehto and Sarjakoski, 2005). Topographic data from national mapping agencies (NMA) was used to provide a vector-formatted, high quality, scalable vector graphics (SVG) map displayed on a mobile device.

One of the main concerns in the GiMoDig project was the need to consider usability issues during the product design. At the start of the project, the project developers lacked experience of how to perform and utilise modern usability testing methods. Although NMAs have a tradition of carrying out studies on user requirements, these studies have mainly been carried out with questionnaires oriented towards developing paper maps and geographic datasets. The project benefited from information gained from the VNET5 project workshop, and by using the material offered here for different tasks relating to user-centred product development (VNET5, 2005). In addition, the first usability evaluations were conducted in cooperation with the KEN project, Key Usability and Ethical Issues, which was one of the horizontal support projects in the Finnish Personal Navigation research and development programme (NAVI programme, 2003; KEN project, 2005).

This chapter describes the implementation of an iterative UCD approach in the GiMoDig project. The study begins with a definition of the project's objectives perspective, and is followed by the research into the potential user groups of the service and investigation of the context of use for mobile map applications. The results were used to establish the user requirements and preliminary usability goals. The study continues by describing how these goals were taken into account when designing the GiMoDig project's GUIs and maps, and how the implemented design was evaluated at different stages of the project from a usability perspective. Finally, the experience gained during the implementation of the UCD approach in the mobile map development process is discussed.

5.1 Project objectives

From a scientific point of view, new innovations relating to real-time generalisation and/or adaptive maps were considered important for the project results. The most critical constraints of the project were the emerging standards (e.g. XML) for transferring vector formatted spatial data over the Internet and mobile devices with small displays. The core objects of the project were (Sarjakoski et al., 2002):

- The development of methods and practices for generalising graphic representations of geospatial data in real-time making them suitable to be displayed in varying scales on small mobile devices with different display resolutions.
- Investigating the problems associated with data contained in national primary geospatial databases, often mutually heterogeneous in thematic definitions, and developing means for the real-time harmonisation of data.
- The analysis of mobile use cases to adapt real-time generalisation and harmonisation of geospatial data to the requirements of users in varying usage situations.
- The development of methods for the real-time transformation of spatial data from different national geo-databases to a common, EUREF-based coordinate system.
- Investigating and developing methods for transferring vector-formatted spatial data to a mobile user using emerging standards, such as XML, and testing the applicability of the standards for web-based spatial services in an international pilot project involving national primary geodatasets.
- The development and implementation of a prototype system that can be used as a test-bed for the methods developed.

From the above list, it can be concluded that the main goals of the GiMoDig project were more infrastructure oriented than end-user application oriented. On the other hand, during the project special emphasis was placed on providing appropriately generalised map data to the user on mobile terminals with limited display capabilities. Therefore, one of the most critical requirements was the need for a working prototype which could be implemented only after the other, scientific, objectives had been fulfilled. This created one of the main challenges for incorporating a UCD approach into the map application research project, since both aspects had different kinds of requirements for the service (Sarjakoski and Sarjakoski, 2005). The emphasis of this study was on evaluating the service from the end-user's point of view. The success of implementation of the other project objectives were discussed in a separate validation process for technology users at the end of the project.

5.2 GiMoDig system architecture

A prototype system for a seamless, cross-border mobile map service based on open system architecture was developed in the project (Lehto, 2003) (Figure 10). The request for a map is received from a *client application*. This request goes through the different service layers of the GiMoDig mobile map service. The data comes from geo-databases contained in the NMAs of participating countries through a *Topographic Data Service Layer*, in which common interfaces are based on XML-coded data delivery and Open Geospatial Consortium (OGC) specifications.

The Data Integration Service Layer is implemented on top of the data services, and it manages coordinate transformations within a common reference frame, and other data integration procedures, such as schema transformations (Lehto and Sarjakoski, 2005). The next layer, the *Data Processing Layer*, manages various data processing and analysis tasks, such as map generalisation or dynamic map labelling. The fourth layer in the system architecture is the *Portal Service*, which processes the service requests coming from the client and forwards the requested Data Processing Layer below, transforming the resulting piece of geospatial data into a visual representation, according to the capabilities of the client platform in question.

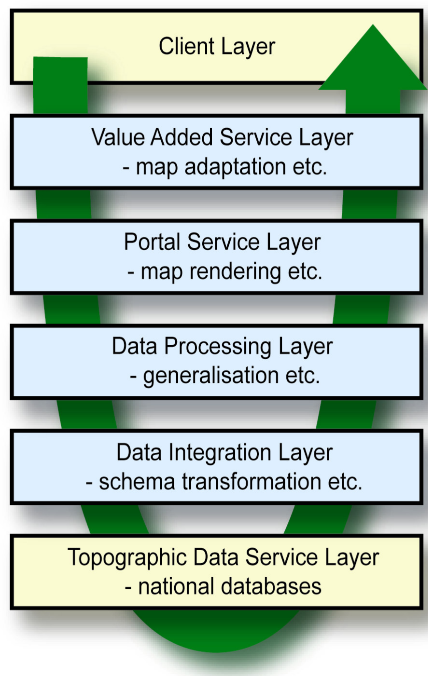

Figure 10. The schematic system architecture of the GiMoDig mobile map service (GiMoDig, 2005).

The mobile map service communicates with the symbol library through the *Value Added Service Layer* (VASL), which controls the creation of the map to be delivered to the client applications, taking into account the parameters relating to the adaptive map display (Sarjakoski and Sarjakoski, 2005). VASL also determines the content of the PoI data to be overlaid on top of the topographic data, and the generalisation and style of the topographic data. Finally, the map is delivered to the user's client application.

5.3 User groups

The GiMoDig project started with a study of user requirements (Jakobsson, 2002) and a market analysis of mobile map services (Pekkinen and Rainio, 2002). The results showed that that potential users of the GiMoDig service could be divided into two main user groups:

a) End-users
b) Technology users

End-users are the potential users of a service. The user requirement study further divided this group into professional users and consumers (Jakobsson, 2002) (Table 1). Jakobsson also classified the different goals which end-users might have in their use of LBSs: locating their current position, being located, locating other people, locating objects, obtaining guidance, obtaining information and obtaining help. *Technology users* are organisations that provide value-added services for LBSs based on data services like GiMoDig. These include, for example, yellow page services, as well as tourism and leisure activity organisations.

Table 1. User groups relevant to the GiMoDig project (after Jakobsson, 2002).

<table>
<tr><td rowspan="4">End-users</td><td rowspan="3">Professional users</td><td>Employers, employees</td><td>• Taxi companies, taxi drivers
• Forest companies, log drivers
• Surveyors
• Electrical companies, electrician
• Pilots</td></tr>
<tr><td>Authorities</td><td>• Emergency centres
• Police, fire brigade and ambulance drivers
• Agricultural administration
• European Commission</td></tr>
<tr><td>Business users</td><td>• Farmers
• Business travellers
• Real estate agents</td></tr>
<tr><td>Private users, Consumers</td><td colspan="2">• General public in a role of citizens
• Property owners i.e. forest owners, buyers of property
• Parents, children
• Tourists in a foreign city, in country side
• Sport audience
• Drivers, cyclists
• People finding friends
• People locating businesses
• People in an emergency
• People with hobbies related to nature (fishermen, hikers, bird watchers, hunters)</td></tr>
<tr><td>Technology users</td><td>Value-added service providers</td><td colspan="2">• National Mapping Agencies
• Electronic yellow-page services
• Tourism and other leisure activity organisations
• Network operators
• Other Location Based Services</td></tr>
</table>

The potential usage areas for the GiMoDig service were: information services, safety, emergency, restrictions for use or movement, guidance or navigation, logistics and military services. 12 different use scenarios, in which a user could benefit from using the service, were compiled using the information on user groups, goals and usage areas.

5.3.1 Critical success factors for different user groups

The preliminary critical success factor expectation of the GiMoDig project was that it would result in a user-friendly prototype, which would meet the needs of the *end-users* (Sarjakoski et al., 2004b). The aim was to provide users with up-to-date geographic information and adaptive maps based on the functionality of real-time generalisation.

The most important issue with the GiMoDig service from *the technology users'* point of view was that they should actually be able to exploit the GiMoDig results and use them to provide their own datasets above the topographic datasets for users with mobile devices.

The most critical issues in the project development were the integration of spatial data from different databases, and the interoperability of datasets and system components. These goals were consistent with the research objectives of the project.

5.3.2 Two divisions of the evaluation

Since both of the main user groups (end-users and technology users) had distinctively different tasks and user requirements, the usability evaluation in the GiMoDig project also followed the same division in the validation procedure (Sarjakoski et al., 2004b). In other words, usability evaluations and validation assessments for the two main user groups were discussed separately during the study in the following way:

a) End-users: evaluation of the usability of the GUI and the maps provided by the GiMoDig service.
b) Technology users: examination of the validity of integrating data from other datasets from the dataset providers' point of view.

The study started by exploring the real context of use for end-users. The user requirements were established after analysing the contexts of use and different user groups, which then formed the basis of the usability goals for the GiMoDig project. The next step was the design implementations, which were evaluated on several occasions during the project.

The validation by technology users started with a creation of user groups and by ascertaining the specific requirements of technology users through contacts built up during the project. The process continued by establishing usability criteria from the technology users' point of view and finally, at the end of the project, the results were validated with feedback received from the user groups.

5.4 Context of use (Papers I and II)

In general, context of use studies aim to increase the understanding of the users of a system. Context of use studies involve going to the place/situation where the user performs the tasks relating to the product, and observing user behaviour and discussing the tasks and the user's reasoning for acting in a particular way.

5.4.1 Field test for studying the real use context (Paper I)

One of the methods of establishing requirement specifications for a product is to actually meet the users and observe their behaviour in real-life situations in the field or in a laboratory. Field evaluations are not normally used at the early stages of product development, mainly due to technical and practical problems in organising the evaluation. However, if the usage environment is an essential element in performing typical tasks with the system, field evaluations should be organised as early as possible in the design process. This was the case in this study, since the environment fundamentally affects the use of maps. The map is strongly related to use situations in which users try to find their way in an unfamiliar environment. This is why it was assumed that field evaluations would give rich feedback on the context of use. In addition, mobile usage – using while moving – could be studied more naturally in a real environment (Nivala et al., 2003).

The context of the use was therefore studied by arranging a field test in a national park following the storyline of one of the use scenarios: *A Hiker in a National Park*. The purpose of the test was to obtain basic information on user requirements relating to the use context, to find out the degree of usability of existing topographic maps on mobile devices, and to identify design principles for adaptive maps to be provided by the GiMoDig map service. In addition, the project developers had to gain experience in arranging field tests and decide whether such tests were adequate with respect to maps developed for mobile devices. The evaluation was conducted in cooperation with the KEN project (KEN, 2005).

The questions studied in the field test were:

- What topographic datasets do users use to resolve predefined tasks, and under what conditions?
- Is the user able to resolve the tasks using the material given?
- Are the maps deficient in any way?
- Are the symbols and feature types easily understood?
- Can the user recognise the map symbols?
- What features are needed to resolve the tasks?

At that stage of the project, the prototypes had yet to be created. Therefore, it was decided that existing maps with existing hardware and software should be tested. However, the aim was not to test the software or hardware, but to use them as a means of accessing the mobile maps. The following paragraphs only give a short summary of the field tests – detailed descriptions are given in Nivala et al. (2003).

Test method

The field test was devised using three usability methods: *thinking aloud, observation* and *interviews*. The predefined tasks that the users were asked to perform were based on the use scenario, which formed the background to the test:

> *A hiker goes on a camping trip to Nuuksio National Park. The hiker uses topographic maps on a mobile device (PDA) that are provided by a map service. Specific maps with different scales allow hikers to find the nearest campsites, determine their position, navigate to other locations and obtain information on restricted areas etc.*

Test procedure

Test users were transported to Nuuksio National Park in Espoo, southern Finland. They were informed about the 'Nuuksio scenario' and were asked to complete predefined orienteering tasks using topographic maps on a PDA. Hikers were asked to look for a suitable campsite from the map, describe the mental image of their chosen site from the information based on the map view, and finally to navigate to the selected campsite using the maps on the PDA. Two observers monitored the users during the test and interviewed them in the field. The tests were recorded on minidisk and partly on videotape.

Test material and equipment

The PDA used during the field tests was a Compaq Pocket PC with Genimap Navigator LT software. The mobile maps used for the test were derived from the Topographic Database (TDB) of the National Land Survey of Finland (at a scale of 1:10 000) (Figure 1). Some improvements were made to the information content, e.g. symbols of campsites and routes were added to the maps.

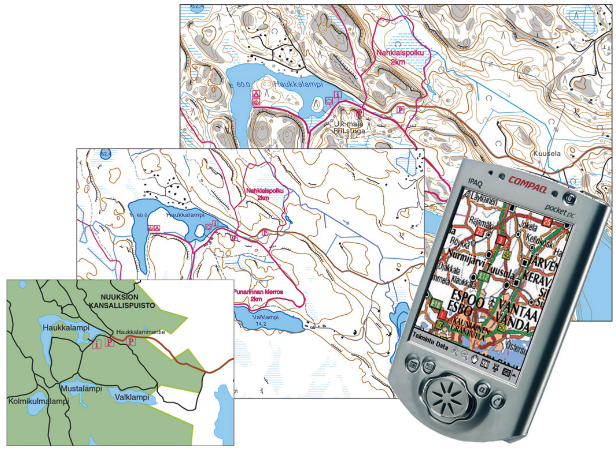

Figure 11. PDA, navigation software and maps used in the Nuuksio field tests (Nivala et al., 2003).

Test users

The user group in the study was small, since the aim was only to look for qualitative results. One pilot-test user was included in the user group to make sure that the test set-up worked as planned, along with six actual test persons. The test users were selected to represent average users of map services. The participants included both genders and their ages ranged from 24 to 60. The group contained both novice and expert map users.

5.5 User requirements (Papers I and II)

The results of the field evaluation highlighted the fact that the cartographic presentation and symbols on current topographic maps were not well suited for mobile small-display devices. The field evaluation identified several problems concerning the usability of maps in mobile devices. These included problems with:

- technical equipment and navigation software
- cartographic presentation

The results also showed that the separate topographic datasets were not sufficient from the users' point of view. The users obviously needed other information to be presented over the topographic map data, and there was therefore a clear need for *data integration* from separate databases.

During the tests it was also observed that users need meaningful map entities that are adapted according to the *context of use*. Every map user had specific user requirements, so adapting the map presentation and content according to the usage context would greatly improve the usability of mobile topographic maps.

All of the above aspects were considered relevant for defining the user requirements. The following paragraphs give a more detail description of the usability problems and observations concerning the functionality of the navigation software, cartographic presentation, database integration and context-aware adaptive maps.

5.5.1 Technical aspects (Paper I)

The focus of the tests was not on the hardware or software, but on the mobile maps and usability testing itself. However, the users raised several problems and usability issues concerning the technical aspects during the test. Detailed results are provided by Nivala et al. (2003); however, a short summary is also given here.

The PDA that was used had some problems; for example, users noted that in some cases the most important functions could not be executed with one hand. Users also worried about how long the batteries would last, especially during winter. They also thought that the PDA might not be the best technical equipment for field use, since it was sensitive to dirt, not waterproof and not designed for heavy handling. The screen also reflected light, which made it difficult for users to see the map in bright sunlight.

Many problems arose when using the software for showing map data on the PDA display. One of the most severe problems was the application's slowness in some situations. In such situations no indication was given of how long the processes would take. The user was also unable to see which tool was active while using the map service. Many mistakes occurred, for example, when users thought the scrolling tool was active, when they were in fact actually controlling the zooming tool. Another problem from the point of view of the users was that when the GPS was connected, it was not possible to scroll up or down the map, since the map was always presented in such a way that the current location was displayed in the centre of the screen.

5.5.2 Cartographic presentation (Paper I)

During the tests it was observed that the current cartographic presentation was not well suited to mobile small-display devices (Table 2). Users found it difficult to understand some of the map symbols, most of which were either unfamiliar or not clearly and distinctively different from other symbols. Furthermore, the fact that mobile map services are used outdoors, and in this instance in bright sunlight, made it more difficult for users to recognise the different colours. Light colours were also difficult to recognise, e.g. yellow and light grey. Detailed results are given in Nivala et al. (2003).

Map symbols and how they are placed, together with other cartographic presentation clearly needed redesigning for small displays. This meant that symbol colours needed to be more distinct from each other compared with paper maps. The maps would have to be tested in as many light and weather conditions as possible before making the final decision on colours and the symbols used.

5.5.3 Integration of databases (Paper I)

The original idea to integrate different databases in the GiMoDig project only covered integrating different topographic databases on the border area of participating countries. However, one of the central outcomes of the field test was that separate topographic datasets are not enough from the users' point of view: users need meaningful map entities that can be adapted according to their context of use. The main benefit of mobile map services was considered to be the combined additional information from different databases, presented over topographic map data. Table 3 lists the different requirements for additional databases, which were observed during the user tests.

Table 2. Examples of map symbols that users had problems with during the tests (Nivala et el., 2003).

Symbol	Meaning of the symbol	Feature type	Colour	Users' comments
	Deciduous tree	Point symbol	Black	Believed to be a small contour line.
	Coniferous tree			Tree symbols should be more illustrative or displayed as a coloured area.
	Boulder	Point symbol	Black	Symbol unknown to all the users, not descriptive enough.
	Precipice	Line	Black	Symbol unknown to some users.
	Outcrop	Area	Light grey	Symbol unknown, not seen very well in bright sunlight.
	Contour lines	Line	Brown	Indistinct from the path symbols. Should be more descriptive: several users suggested shadowing of the slopes.
	Weir	Point symbol	Black	The symbol for the weir was unknown to all of the users. Suggestions for more picturesque symbols for the human-made structures (e.g. houses, bridges) were made.
	Residential building			
	Outbuilding			

Table 3. Additional information requirements described by users during the tests (Nivala et al., 2003).

Type of the information	Examples of the information content
Datasets of Park and Forrest Service	• Location of camping and campfire sites, toilets, firewood, information points • Limits of fishing licenses, availability of drinking water, swimming spots, places 'with a view' • Detailed information about hiking trails (how long and how demanding, suitability for cyclists or families with the small children, topographic differences etc.)
Datasets of meteorological information	• Weather forecasts, warning about potential forest fire hazard in the area
Datasets of environmental information	• Information about the terrain and the vegetation • Areas containing endangered species, wildlife conservation areas (e.g. birds nesting places)
Datasets of geological formations	• Information about the soil (where to camp) and the bedrock (special bedrock formations e.g. the 'Giant's Kettle')
Datasets of commercial services in the area	• Rentable cabins, cafes, places to rent sports equipment (kayaks, tents etc.)

5.5.4 Context related requirements (Paper II)

Mobile map use context situations are not a simple matter. First of all, the context changes every time the user moves, or the area surrounding the user changes in various ways, even if the user is not moving. It was observed in the tests that users need meaningful map entities that are adapted according to context of use. Adaptating the presentation and content according to the usage context could greatly improve the usability of mobile topographic maps. In general, current maps for mobile devices do not provide users with these features. Once location context has been developed as an integral part of mobile devices, new kinds of map services will be needed, along with different maps for different purposes. Maps will need to be available in different scales and will have to provide comprehensive information in various formats for various types of devices.

Because context was found to be critical for a user-friendly map application, more research was done on context categorisation. The literature research on computer science showed ongoing research into defining ‘context’. The available information was gathered and integrated with the results of the GiMoDig project’s field tests (Figure 12). A detailed description of the different contexts relevant to mobile map usage is given in Nivala and Sarjakoski (2003).

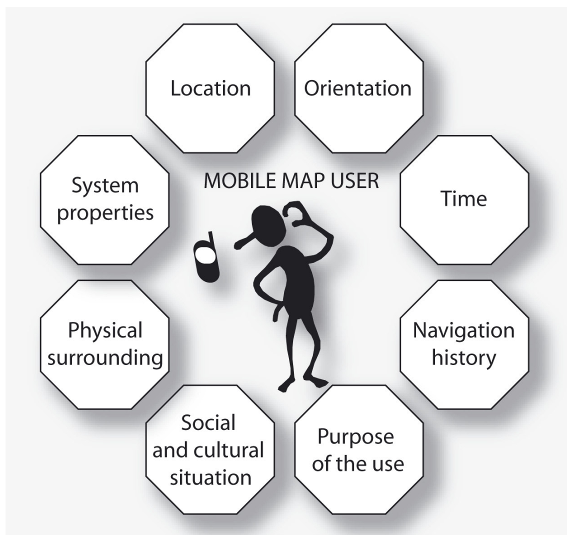

Figure 12. The surrounding context of a mobile map user is composed of different elements (Nivala and Sarjakoski, 2003).

5.6 Usability goals (Paper IV)

As was previously discussed, the field evaluation identified several problems relating to the usability of maps on mobile devices. These included problems with the functionality of software and the cartographic presentation. It was also observed that users had special needs requiring the integration of different datasets and for more intelligent, context-aware maps.

Usability evaluation criteria were established on the basis of the field tests and the end-user requirements identified during the study and the first prototypes were built according to these criteria (Sarjakoski et al., 2004a). The usability goals were divided into four main subjects, each of which included more specific requirements:

a) **Easy-to-use user interface:** Users had problems with the commercial navigation software during the tests; therefore, this study included making the UI easy to use as one of its goals. This was concluded using two different adjectives: simple and intuitive UI. The main focus was to differentiate between the terms used by system developers and the terms used by end-users in the actual context of use.

b) **Cartographic presentation suitable for mobile devices:** Users experienced a number of problems with current map symbols during the field tests. The goal was therefore to create a cartographic design suitable for two different environments: maps designed for a portable laptop PC and maps designed for a PDA. Special emphasis was placed on the intuitivity of PoI symbols, with the aim being to make them so intuitive that users would be able to understand them without a legend.

c) **Integration of different datasets:** Because separate topographic datasets were not sufficient from the point of view of the users, one of the project's goals was the integration of additional information from different databases. This included integrating value-added services data presented over topographic map data. One of the most important goals with integrating different datasets was to ensure compatibility between diverse datasets: how to present them seamlessly and in a way that users like them to be presented.

d) **Context-aware maps:** During the tests it was observed that users need meaningful map entities that can be adapted according to the context of use. The ability to adapt map presentation and content according to the usage context would greatly improve the usability of topographic maps for mobile devices. The implementations needed to fulfil this requirement were also studied as one of the project's main goals.

5.7 Design (Paper III)

The characteristics of small display cartography were studied in the GiMoDig project (Nissen at al., 2003). The basic design restriction is the relatively poor resolution of small displays, which sets new challenges for cartography. Nissen et al. listed the main design requirements and on the basis of which and in conjunction with an analysis of user requirements (Jakobsson, 2002), a cartographic design was created for delivering maps using the GiMoDig map service prototype.

5.7.1 Adaptation based on personalisation

In order to fulfil the user requirements, an effort was made to implement a service that was able to deliver context-aware maps for different users in different usage situations. One way of adapting maps to fit the usage situation is to personalise mobile map services. The implementation of a personalised system is described by Sarjakoski et al. (2004a), Sarjakoski and Nivala (2005), Hämäläinen (2005) and Sarjakoski and Sarjakoski (2006). By changing some of the personalisation parameters, the GiMoDig service can deliver different maps of the same area for different users. Maps are delivered to users' devices in real-time, according to the parameters selected by the user:

1. choice of use case (user's current activity mode)
2. identity (user's language, age group)
3. time (time of the year/day)

The choice of the use case refers to the situation in which the map is going to be used. The user can choose between a set of use cases: *outdoors, cycling, emergency and expert use*. If the user is going hiking, the person may, for example, choose the outdoors option, or if a person is cycling in a strange city, the option that delivers a map especially designed for cyclists may be chosen.

A group of points of interest (PoI) was also created in the project on the basis of user requirements from field tests, in which users commented that topographic data was not sufficient and that they also needed additional information on different PoIs in the area to be displayed on the map.

Personalising the service according to the identity of the user comprises two different sections: a choice of language and choice of age group. The choice of language is reflected in the language of the user interface. The choice of age group changes the layout of the requested map, because different age groups are provided with different PoI symbols, therefore satisfying special user needs appropriate to that particular age group.

To make maps even more comprehensible for particular usage situations, users can also define the time of year by selecting a season, which brings up a photorealistic presentation style of map. This is done so that the map correlates to the user's situation and therefore helps the user find a link between the map and their current surroundings. Topographic map data received from the map service is displayed in vector format in SVG, and the PoI symbols are shown on top of the topographic data. Additionally, a background raster image, 'snow' for winter maps and 'grass' for summer maps, is added locally on the PDA. Night map cartography was also included in the final prototype.

5.7.2 GiMoDig map examples

In order to illustrate how the system responds to personalisation of user properties and the context of map use, four different maps are presented in Figure 13. The use case here is called 'outdoors'. Age group and the season vary in the maps.

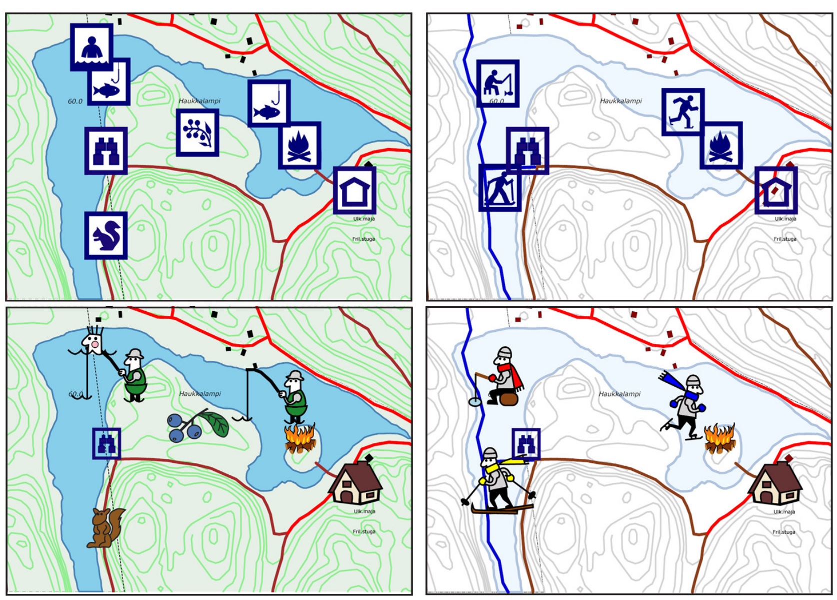

Figure 13. GiMoDig maps for different seasons and age groups (Nivala and Sarjakoski, 2005).

The maps on the left are summer maps for age groups 46 and above (upper) and 11-17 (lower). The maps on the right are winter maps for the age groups 18-45 (upper) and 11-17 (lower). The most obvious difference between the maps is the totally different symbols. The maps on the left and on the right also differ in information content: different kinds of PoIs are relevant for the user during winter and summer (for instance: swimming places in summer and skiing tracks in winter). There is another difference between the top two maps: elderly people (46-) are provided with pictograms with a white background to improve the contrast of the symbol. The map on the right has transparent symbols instead, to prevent as much of the information as possible from being hidden, which is critical with small screens.

The maps also differ in information visualisation: the same PoIs have different symbols for expert map users/adults and for teenagers. Traditional map symbols may not be so familiar to young people; therefore more illustrative symbols were designed for them that more accurately reflect how they perceive the world. However, it must be kept in mind that the question of which symbol set should be used is a subjective matter in many cases (Nivala and Sarjakoski, 2005).

5.8 Usability evaluations (Paper IV)

To evaluate the GiMoDig service from the end-users' point of view, the evaluation started immediately after the first prototype became available. The usability evaluations in the GiMoDig project were carried out using four different methods: 1) heuristic evaluations, 2) expert evaluations, 3) usability tests, and 4) intuitivity tests (Table 4). A short description of the methods used is given below, more detailed results are given in Nivala et al., 2005.

Table 4. The usability goals together with the methods used for evaluation.

Usability goal	Evaluation method	Quality Dimension
Easy-to-use UI	Heuristic evaluation of the PDA GUI	Simplicity and intuitivity of the UI
	Expert evaluation of the web GUI by Consortium members	Simplicity of the personalisation Simplicity of opening a map application Intuitivity of the personalisation Intuitivity of the UI
	Usability test of the web GUI in a laboratory	
Suitable cartographic presentation	Expert evaluation of the cartographic design	Design suitable for PC
		Design suitable for PDA
	Intuitivity test	Intuitivity of the PoI symbols
Integration of different data sets	Expert evaluation by Consortium members	Functionality of the integration from the users' perspective
Context-aware maps	Expert evaluation by Consortium members	The acceptance of the context-aware maps from the users' perspective

5.8.1 Heuristic evaluations of the GUI

As the aim of the project was to develop an easy-to-use UI, the first evaluations were carried out during the early development and design stages of the prototype to discover any potential problems with the GUI. The preliminary results were needed quickly, which was also one criterion for choosing this method. In heuristic evaluation, the usability of the UI is studied using simple heuristics, i.e. guidelines, and it is a quick and inexpensive method to use. The heuristics used in this study were compiled by Nielsen (1993), see more details in paragraph 4.4, 'Heuristics'.

A usability expert carried out the heuristic evaluations for the GiMoDig project. The evaluator went through all the menus in the UI and evaluated each step against the heuristics. Some of the problems found were related to the fact that the evaluation was done on a prototype still under development, so not all of its properties were complete. Table 5 below lists a few examples of the problems found. The first column describes the problem and the second column lists the heuristics that the problem violated. In the third column the problems are classified according to their seriousness in terms of being able to use the application (on a scale of 1-4, where: 1 = only a cosmetic problem, 2 = makes it a little difficult to use, 3 = considerable difficulties with the function, 4 = unable to use). In the last column, the possible improvement is proposed.

Table 5. A few examples of the usability problems found during heuristic evaluations of the GUI (Sarjakoski et al., 2004b).

Description of the problem	Which heuristic does it violate?	Seriousness of the problem? (1-4)	Improvement proposal
Possibility of returning to the start page is missing from some views.	4,6	3	All the views should have an icon for going back to the start page, and always in the same place on the UI.
Tools do not have any indication of being 'active' when selected.	1,2,4	3	Active tool could be enhanced with a different colour.
There is no quick way to receive a default map.	7,9	2	Shortcut should be added.
When loading a map, there is no indication that the application is processing something.	5	1	User should be informed that the process is still going on, e.g. with the text 'Loading the data'.

The heuristic evaluation highlighted problems with the GUI that needed to be improved to develop a more user-friendly application. A usability evaluator reviewed these problems together with UI designers and programmers. At the same time, discussions were held on possible improvements to the problems, on the basis of which changes were implemented to the UI, for example, to the navigation buttons, page hierarchy, to the visual look and to make the functionality more logical. Heuristic evaluations were repeated several times during the project, and improvements were made at each stage on the basis of the results.

5.8.2 Expert evaluations of the GUI

Heuristic evaluations were carried out at the early stage of the project, but as the design became more sophisticated, experts working in the area of cartography or geoinformatics were required to evaluate the GUI. Experts went through the GiMoDig user interface and, at the same time, performed predefined tasks as instructed on a questionnaire. A total of 13 persons filled out the test questionnaire.

The main aims of the evaluation were to find out whether users managed to access different types of maps through the service and if the visual design of the GUI and the maps were met with approval, and what users thought about the parameters and preferences used and the different types of maps they could access. Research was also carried out on user recognition of the different GUI buttons, i.e. how intuitive they were.

The questionnaire results were analysed and grouped under different divisions. As with the heuristic evaluations, it was observed that many of the problems were mainly due to the prototype and the research nature of the application. However, a number of critical bugs were also discovered in the GUI, and these needed to be fixed.

5.8.3 Usability tests for the GUI

A usability testing method was implemented in the evaluation of the GiMoDig GUI to obtain more detailed information on the actual use of the map application. The tests were arranged so that users conducted certain tasks using the GUI following instructions given by a moderator. Users were also encouraged to think aloud during the test tasks. The PC screen that was being used by the user and their comments were recorded on video.

At the start of the evaluation, a total of five participants were going to be used, however, it was observed during the first tests that the same problems occurred repeatedly in the results from two test users. The test results also overlapped with results obtained from expert evaluations of the GUI. Therefore, the tests were stopped after only 2 test users had talen part and the problems discovered were analysed. The result of the tests was a list of usability problems encountered by users during the test situation, and a list of positive and negative comments relating to the design.

5.8.4 Intuitivity test for map symbols

A set of PoIs relevant for each use case was also included in the project following recommendations from earlier studies and on the basis of the results from the user requirements study. One of the main aims of the usability evaluation was to ascertain the validity of the symbols created, i.e. do users understand what the symbols mean? Are the symbols intuitive, so users can understand them without explanations, or do users need a legend to understand what the symbols mean? Are symbols internationally understandable or are there some symbols that only have meaning e.g. for Finnish people. The aesthetic qualities of the symbols were not considered a measurable property. Therefore, the aim was only to record qualitative comments stated by the users about the symbols.

To measure the usability of these cartographic PoI symbols, a special intuitivity test was arranged (Sarjakoski et a., 2004b; Nivala and Sarjakoski, 2005). For example, Bewley et al. (1983) tested the intuitivity of some symbols by showing them to users and asking them to describe "what they think it is". In an intuitivity test, it is not necessary to use symbols and terms that will be used in the final UI; paper pictures can be used as well.

The test was carried out by sending a test form to several users by email. Users were asked to look at each of the PoI symbols (a total of 46 symbols) one by one and write down beside the symbol what they thought it signified. Users were also asked to write down any other comments about each symbol. 22 users responded to the intuitivity test, of which 12 were females and 10 males. The respondents' ages varied from 13 to 47, and they were also different nationalities (17 Finnish, 2 Chinese, 2 German and 1 Indian). Quantitative data on how many users recognised the symbols was gathered together with qualitative data from user comments. Detailed results are provided by Nivala and Sarjakoski (2005).

From the tests results, it could be stated that most of the PoI symbols were easily recognised. However, there were some exceptions to this; some symbols obviously needed to be redesigned. One interesting finding was that all the adults recognised the symbol for a 'view sight', but none of the four teenagers participating in this study were able to. Adapting map symbols for different user age groups may therefore be a relevant issue to be studied further.

As most of the PoI symbols were designed by the GiMoDig partners in Finland and Denmark, it was also interesting to find out which of the symbols were nationality related. An analysis was conducted on the correct answers of participants from different nationalities. The results support the idea of adapting map symbols for different users; more details in Nivala and Sarjakoski (2005).

5.8.5 Expert evaluation of the cartographic design

The cartographic design of the GiMoDig prototype was evaluated several times during the project: either by project members or by other cartographic experts. The expert cartographic evaluation was aimed at analysing different kinds of GiMoDig map designs and gathering information on map usability to improve the design. A specific form was created for this purpose: for each map, the evaluator had to consider each cartographic object according to its 1) area fill colour, 2) line or outline colour, and 3) contrast compared to other map symbols. The overall layout of the maps was also considered on the basis of the following questions: Is the map harmonic? Are the symbol colours harmonic? Are the symbol colours associative? Are the symbols self-evident? Is the map easily understandable without a legend? What is the overall legibility of the map?

Since the GiMoDig maps were provided for two different media (a PDA and a portable laptop PC), the cartographic design was designed separately for both environments. Therefore, the maps were also evaluated in two separate environments; maps designed for use on a PC and maps designed for a PDA. When evaluating the PDA maps, the evaluators went outdoors to test the application in a real use context under different light conditions, whereas the maps for laptops were evaluated indoors.

The results of these evaluations showed that the overall layout and style of the maps was successful, and were considered simple enough for a good overview. However, several critical comments concerning the map's design were also received. The problems identified were taken into account in the design and improvements were made accordingly (Sarjakoski et al., 2004b).

5.8.6 Summary of the usability evaluation results

Detailed results of the final usability evaluations of the GUI and maps in the GiMoDig project are listed in the project's internal report, Report on usability and validity (Sarjakoski et al., 2004b). A short conclusion is given below on how the usability goals established in the earlier phase were achieved at the end of the project (Nivala et al., 2005).

Simple and intuitive UI

It is evident that the prototype GUI for the GiMoDig project exceeded the preliminary goals and quality strategies set out for the project. The visual layout of the GUI was considered clear and fresh, and some of the new ideas contained in the application were considered interesting. However, it was noted during the GUI evaluations that the prototype is only suitable for demonstrating how maps can be delivered in real-time – improvements would still need to be made if it was going to be used by real end users.

A number of critical bugs were discovered in the GUI, which needed to be fixed at the outset. It was observed, for instance, that some of the buttons did not function at the same time, which was critical from the users' perspectives. It was also observed that many of the problems experienced by test users were a result of using a prototype application. For example, the users missed some functions that they were used to having in other map applications. There were also problems with some GUI symbols, which were not immediately 'intuitive'. However, users commented that after using the tools once, it was easy and clear to use thereafter. Therefore, the intuitivity of the visual layout was not regarded as a critical problem. Furthermore, the 'level of detail' feature in the GiMoDig project was a new concept, which was surprising to most of the users when zooming between different maps. If the application were to be developed further, these results would have to be taken into account and better solutions would have to be created.

Suitable cartographic presentation

Several new ideas for map design for mobile usage situations have been implemented during the project life span (Sarjakoski and Sarjakoski, 2004) and a lot of research has also been done on the cartographic design. A map specification tool was developed with the aid of which the map design could easily be changed to suit the different uses of the map data (maps for PDAs, PCs, children, adults etc.) (Sarjakoski and Sarjakoski, 2005; Sarjakoski and Sarjakoski, 2006). Therefore, individual problems observed with current maps provide a good basis for creating maps in the future, but they are not a threat to the overall usability of the maps.

However, during the evaluations it was observed that not all users welcomed new ideas on cartography. This was clear especially when asking for opinions on the 'seasonal map' designs. The feedback was divided into two opposite opinions: some liked the idea and some thought it was insignificant and not useful at all. This was considered to be more a question of getting used to something: if a user expects to get a traditional map, the different visualisation may be irritating. But the changes in visualisation for maps on small displays, are almost a necessity compared with traditional maps. Therefore, new experiments are considered relevant at this stage.

Another interesting topic was the intuitivity of the map symbols used. During the evaluations, it was discovered that users had problems with several PoI symbols, which had been specially designed for mobile map usage situations. Because most of the symbols were designed by Finnish cartographers, it was also interesting to note that not only did the most evident symbols cause problems for foreigners, but also symbols that were thought not to be influenced by national differences. The subject of national differences becomes significant when dealing with mobile map services mainly targeted for tourist purposes (the situation at the moment), particularly in terms of the acceptance and use experience of the map service from the users' point of view. Therefore, research into intuitivity should be followed by research on small-display cartography, especially regarding maps for people from different countries.

Integration of different datasets

One of the usability goals was the integration of different datasets and the compatibility of diverse datasets. There were two approaches to this: the first approach involved the integration of different datasets in the border area (Illert and Afflerbach, 2004). As this mainly related to the issue of harmonising topographic data, it was not treated in this part of the validation. The other aspect of integrating datasets was based on the results from the Nuuksio field tests, i.e. integrating different datasets over topographic data. PoI database was created for this purpose that included PoIs for different GiMoDig use cases (Sarjakoski and Sarjakoski, 2005).

The evaluation results showed that the main idea was working, and the icon placement algorithm (described in Harrie et al., 2004) improved the visual look of the map, where the PoI symbols were placed over topographic data. In addition, the integration of datasets can also be seen as an area for future research, to automatically restrict or select PoI targets and show only the relevant symbols for users with small displays on mobile devices.

Context-aware maps

Context-aware maps was another topic to come out of the user requirements for mobile maps. Since automatic sensing of the context was currently not realistic, the context awareness of the map application was achieved with a simple active personalisation: users gave the context parameters. There was also an option for users not to give any preferences, in which case they were provided with default parameters and a default map.

The implementations aiming to provide context-aware maps were evaluated to find out whether they were suitable for mobile use situations. Setting user preferences was not attempted by all the users. Users also had questions about what functions the preferences would affect and whether they would lose some interesting information by selecting, for example, their own age group instead of the age group for children. Defining user groups according to age was not seen as the most natural way of updating context parameters, and some users suggested that the configuration could be linked to different uses and styles rather than different age groups.

The question of 'seasonal maps' is also related to the same question. Some users commented that they liked the different seasonal maps. At first some users considered it strange that the colours of the contour lines changed, however, it did make them feel as though they were in that season. Users also liked the idea of including different symbols relating to the possible activities of that particular season. However, it was also observed that even though some users favoured context-aware maps, some almost disliked them.

Context-aware maps form an interesting area for future research, although some context features cannot yet be implemented with today's technology. Furthermore, evaluating context-aware maps should also involve outdoor testing with end-users in real-use situations. This kind of testing would provide relevant information on real-use situations of maps targeted at different users in different situations. Thus far, the concept of adapting maps was a feature designed specifically for the GiMoDig project. However, adapting maps automatically to suit different contexts in varying geographical locations and for more varying purposes will be a challenging task for future cartographic research to solve.

5.9 Validation with technology users (Paper IV)

The user requirements for technology users (paragraph 5.3, 'User Groups') were gathered by arranging meetings with the organisations which provide value-added services for LBSs, and also at various scientific conferences (Sarjakoski et al., 2004b). The most important feature of the GiMoDig service from the technology users' point of view was being able to exploit the project results and using the service for providing their own datasets above topographic datasets for users with mobile devices. The GiMoDig service quality goals were established on the basis of the contacts made with potential user groups and discussions held with them. Establishing the quality goals also took into account the restrictions of the project and scientific goals necessary to fulfil the project objectives:

- Functionality of service layers in the prototype environment.
- Conforming to the Web Feature Service (WFS) interface for value-added service providers.
- Conforming to the Web Map Service (WMS) interface.
- Conforming to the Presentation Service interface.
- Effectiveness of the real-time coordinate transformation process.
- Quality of real-time data generalisation.
- Quality of real-time data integration.
- Availability of the service.

Achieving the quality goals was a requirement of the service from the technology users' point of view. Failure to achieve any one of these criteria might have resulted in being incompatible with the services offered by a user group. The validity and functionality of the project objectives were examined at the end of the project.

5.9.1 Focus group method

The validation was carried out by using a focus group method, which has been described, for example, by Nielsen (1993). Several issues need to be considered before arranging a focus group: 1) the list of issues to be discussed, and 2) the goals to be achieved from the information gathered. After the data has been analysed a report is written summarising the sentiments of the focus group.

A total of 5 user group meetings were arranged. Because the participants consisted of private companies with private marketing interests, a small exception compared to normal focus group meeting was made: only one company at a time (1-x persons) attended each meeting. The following aspects were considered for each topic during the discussion: usefulness, usability, functionality, necessity, implementation possibilities, need for development, rationality, and feasibility.

5.9.2 Results of the validation

The goal of the GiMoDig project was to create a prototype geospatial info-mobility service utilising existing, large-scale topographic databases maintained by the NMAs. The integration prototype implemented was advanced and complex and included features and capabilities that went beyond the goals of the original research plan. These included features such as context-sensitive adaptive maps, real-time integration of PoI data and icon placement. The members included in the focus groups represented parties that currently run and implement operational systems. Consequently, the technology gap between the achievements of the project and the practical reality of current systems was wide. There was also a large diversity in the opinions received from the different members in the focus groups. Therefore, it was not possible to draw definite conclusions from the results.

In general, the approach and technology used in the GiMoDig prototype received positive feedback. The usage of standards was supported and the distributed service architecture was accepted. The use of vector-formatted data was considered important on the server side, whereas on the client side the use of raster-formatted data was considered necessary for the solutions in the near future, because of the capacity limitations of mobile devices. In the longer term, applications should use vector data because of its greater flexibility and potential for more advanced services (Sarjakoski et al., 2004b).

The use of multi-resolution databases was considered to be a necessity. The need to use real-time generalisation was questioned to some extent. On the other hand, real-time icon placement and integration of value-added data were greatly appreciated. The use of context-aware map adaptation was such a new approach that it created mixed opinions. However, its great potential was understood, but on condition that the overall design was implemented with care and the level of complexity was minimised from the end user's point of view. In addition, it could be concluded that the project was seen as a forerunner for demonstrating the potential and limitations of implementing Pan-European Schema specifications for large-scale topographic data, and also implementing the schema transformations as part of query/response processing.

In conclusion, the validation process highlighted the importance of the reliability of the underlying data service. It is likely that in some cases the provision of this kind of service is beyond the capacities and business models of the NMAs and rather more suitable for external service providers. In order for these service databases to be updated by NMAs, a mechanism must be available to transmit the updates in incremental fashion. This highlights the further need for research and development on incremental schema and resolution transformation combined with appropriate web feature services (Sarjakoski et al., 2004b).

6 CONCLUSIONS

The aim of this thesis was to study how a user-centred design approach could be included in the development of a mobile map service. Due to the multidisciplinary nature of this work, the study started with two literature reviews, which summarised the basics of usability and user-centred design approaches, and usability research that has been carried out on maps.

The literature review revealed that map application projects are currently carried out in two separate research fields: by cartographers and by software application developers. Therefore, there is a need for multidisciplinary approaches that combine knowledge of both cartographic design and usability engineering, because both disciplines lack information on research into both respective fields. One way of approaching this goal is to emphasise the need for implementing usability engineering methods among map designers, too. Although, the concept of a UCD approach is slowly being incorporated into map design, knowledge on how to execute UCD methods is still almost non-existent. Application developers, on the other hand, do know about UCD methods, but usually have a lack of knowledge about cartographic design principles. Consequently, there is a need for interdisciplinary research when designing mobile map applications.

Furthermore, understanding emerging technologies and new application areas bring new challenges to cartographers. The hypothesis following the literature review proposed that by using a user-centred approach, these challenges could be met in an effective way. Therefore, a proposal was presented for a synergy model combining a UCD approach with usability research in cartography based on the findings gathered from the literature review. The aim of the model was to provide preliminary guidelines on how to implement a UCD approach and usability methods in practice in developing a mobile map application.

The connection between these two research disciplines and the validity of the synergy model was tested using a case study: UCD in the GiMoDig project, where the aim was to develop a mobile map service using a user-centred design approach. During the project an iterative design cycle was followed and different usability methods were implemented. The design at each phase of the project was based on carefully defining the different user groups and their tasks and goals in a particular situation where the mobile map would be used.

6.1 Experience gained

One of the central findings was the realisation of the relevance of user-friendly map applications based on true, meaningful user requirements. The importance of the UCD is significant in this context, because an iterative design cycle starts by ascertaining the user requirements. This is especially important when designing new technology applications, since the user requirements may not be the same as for the traditional application environments. Only by understanding the users and their real context of use can realistic applications for new technological environments be created.

The diverse and innovative aspects gained from the design process during the case study strongly supported how appropriate a UCD approach for developing mobile map services was. During the study, in keeping with the hypothesis, it was observed that cartographic systems are specific in a way that the usability of the system is composed of different elements. The design of a map application should take usability issues into account in two different areas: the usability of the cartographic design and the GUI together with the device. In addition, the users and the context of use, which should also be taken into account during the design stage, affect these areas (Figure 14). These aspects are discussed in more detail in the following paragraphs.

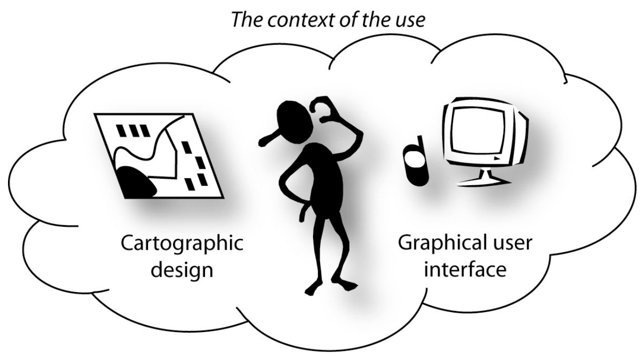

Figure 14. The usability of a map application is composed of different aspects (Nivala et al., 2005).

6.1.1 Users and their characteristics

First, the users of an application may be diverse along with their user characteristics. Each user or different user group may have specific user requirements: children/elderly or handicapped people, tourists/GIS specialists etc. The question of cultural differences, including languages, is an issue to be taken into account when designing internationally used map applications, for example.

6.1.2 GUI and the device

The second aspect to be considered is the graphical user interface and the device on which the map is used, and which also have to fulfil the needs of the user (PDA/PC, browsers, implementation techniques etc.). If the UI evaluation has to be done quickly, and/or at the early stage of the design, the most suitable method to achieve this may be by using the heuristic principles. But if the design is more sophisticated, or even nearly 'finished', involving users in the evaluation process is necessary and usability tests, for instance, should be arranged.

6.1.3 Cartographic design

Thirdly, there is the map, which has to be user friendly and usable in its context. Cartographic design is the key issue when developing mobile map applications. The choice of colours or symbols, map content, and level of detail should be wholly reconsidered compared with previous applications. Both the disadvantages of a mobile device (small screen, robustness, batteries running low) and the advantages (dynamic, interactive, adaptable, location aware) bring new aspects to the design process, not to mention the need for more advanced visualisation, such as 3D, virtual reality, and animation, which were not discussed in this study. Psychology and cognitive sciences (users' memory, knowledge, decisions etc.) are also relevant aspects to be considered with the map application design. Not only should the map be readable, but it should also be intuitive, exciting, aesthetically pleasing and perhaps even fun. The design could also be personalised to meet the different needs of different map users and map use situations.

According to the experience gained, the best way to evaluate cartographic design is by using cartographic experts. They posses the knowledge on the possibilities and restrictions of visualisation, as well as additional knowledge on the spatial cognition ability of map users. The possession of such knowledge gives experts a realistic insight into the design. When carrying out an expert cartographic evaluation, the context of use should also be taken into account: e.g. maps on mobile devices have to be evaluated outside in varying light conditions. Although, involving users is necessary when looking into answers for questions such as pleasantness or the intuitivity of the map design, it also is worth bearing in mind that asking users about the pleasantness is always a subjective matter and the results gained are not valid, unless a statistically sufficient number of users were involved with the evaluation. In addition, if users are involved in the map evaluation, it must be borne in mind that in many instances using a map is strongly related to getting used to something: if the user expects to get a traditional map, the different visualisation may be an irritating factor. Because the nature of maps in mobile devices is still quite a new topic, there remains a lot of research to be done in the future.

6.1.4 Context of the use

Mobile maps may be used in a variety of situations. However, good design is based on a good knowledge of the potential users of the mobile map service and the situations in which maps may be used. The mobile use context should be studied beforehand to compile realistic user requirements, and also during the process to ensure that the design is suitable for the use context. On the basis of the experience gained in the project, arranging field tests proved to be the most suitable method for ensuring the suitability of the design. The method is more applicable when evaluating mobile maps as opposed to paper maps, because more factors can affect the use of mobile maps, and some features are difficult to recognise in a laboratory environment. Arranging field evaluations can take time and effort, but it was the only way to truly evaluate the usability of maps for mobile outdoor situations and varying contexts. However, one aspect that was observed during the tests was the fragility of each test situation; i.e. participants were easily influenced. For example, if the test supervisor asked why a person chose a specific option, the user started to doubt the decision and cancelled it. This should be kept in mind when asking user opinions.

6.1.5 UCD approach

As was expected, adopting a UCD approach strongly supported the relevancy of understanding mobile map users and context of use, which is critical with today’s mobile map design. It would appear that one of the crucial elements in today’s map design is to meet real users right at the beginning of the project. Only by understanding the real needs of potential users and their use context can realistic commercial map applications be created. Understanding the context becomes especially critical with mobile map applications, because they can be used in various situations and for various purposes. New technological possibilities and restrictions create the potential for new design approaches, and therefore the UCD approach can be used as a method to incorporate material and increase designers' knowledge on user requirements and thus support innovativeness. Although the need for involving real users in the design process was considered important, expert evaluations (such as market studies etc.) can also be used for gaining information from secondary sources.

The iterative evaluation and the different methods used in the research also highlighted critical information on the usability problems in the map application. Choosing suitable usability evaluation methods and the appropriate way to perform these varies depending on the type of design and the stage of the design process. During the project usability evaluation methods and a UCD approach were successfully implemented in the map application project. The case study illustrates which evaluation methods were appropriate and at what stage of the project. The proposed synergy model and experience gained during the research can also be used as a preliminary guideline when designing map applications. However, the methods still need to be further developed and adapted to suit the multidisciplinary nature of mobile map application projects.

On the other hand, it may be that the ability to incorporate usability issues in product development does not exist in the cartography research community. Hence, it is emphasised here that there is a need for increasing awareness of human computer engineering knowledge among cartographers and GIS specialists.

Finally, it must also be noted that when a UCD project is completed and the final product is on the market, the usability of the system needs to be monitored after its release, to make sure it continues to meet user needs. This information can be used to establish requirements for new versions.

6.2 Discussion

There are several limitations to this research. Although the model described here gives a preliminary idea of how usability engineering can be applied in practice in developing map services, it must be noted that the UCD approach was tested here in only one project. Although the project lasted for three years, it was still only one project.

Second, the study presented here was a research and development project, so it is therefore also necessary to find out if, and how, a UCD approach can be applied in the commercial world with real map application providers. The author has already started to define the needs of map application developers in product development. The results of these studies have not been published yet, but the preliminary ideas can already be seen: The need for a UCD approach has become a central issue, especially now, when applications are provided to users in a mobile device or in different contexts. The provider who can design the most usable map application may win the battle for market dominance. Therefore, most companies would like to implement a UCD approach, but the problem seems to be a lack of resources, and the lack of knowledge on how to implement this approach that has its origins in computer science. As the techniques involved in map design are converging with techniques applied in computer programming, there is a specific need to adapt usability methods for business developers, and at the same time to understand the multidisciplinary world of cartographers.

Not all the methods used in traditional usability engineering are either suitable or useful for map applications. Therefore, the usability methods need to be further developed to suit the multidisciplinary nature of mobile map application projects. Established map use research is still applicable to some extent; however, it should be developed to suit the purposes of today's interactive, dynamic and location-aware map applications. This research addresses the underlying principles and methodologies for providing a basis for further developing application-specific guidelines and techniques. The challenge in this specific research is its multidisciplinary nature. Therefore, research into how to apply UCD methods, heuristics and usability testing methods in map design and developing map applications should be continued.

Cartographic design is the key issue in the development of map applications, but the choice of colours, symbols, content, and level of detail should be wholly reconsidered for new technical environments to guarantee usability. The disadvantages and advantages of mobile devices bring new aspects to the design process, in addition to which there are the more advanced visualisations such as 3D, virtual reality and animation. Thus, the increased variety of potential applications which can be offered to users is another issue that should be further researched. Psychology and cognitive sciences are also relevant aspects to be considered with the map application design. Additionally, more information about the diversity of users and usage situations will be needed in providing users with so-called adaptive maps. It can be concluded that a lot of new research will be needed to provide users with suitable map designs and symbols for different situations.

6.3 Future work

In general, the benefits of applying a UCD approach are widely accepted and the methods are advanced. It could be stated that usability evaluations of maps and a UCD approach are relevant to the overall usability of map applications, and as the UCD approach is still quite new in the cartographic research community, the research aspects are also scientifically important. A number of researchers have emphasised the need to include usability engineering principles in geovisualisation processes. Despite this, almost no research has so far been carried out on consolidating knowledge from both disciplines.

However, The LBS conference in Vienna 2004 was among the first cartographic conferences to include a session on 'Usability'. During this year's International Cartographic Conference of the ICA (International Cartographic Association), a working group on usability issues was established with the name "Use and User Issues". The aim of the working group is to gather and share information on usability issues relating to map applications and map users.

The Department of Geoinformatics and Cartography at the Finnish Geodetic Institute has included user-centred design in geoinformatics as one of its central research topics. The usability group of the department was formed in connection with the GiMoDig project. This thesis ends with a vision of the main research tasks that should be executed in the future concerning usability and user-centred design in map applications. The following four tasks are based on, but go further than the results of this thesis:

1. To 'build a bridge' between HCI engineers and cartographers

Cartography has a long history of cognitive research into map use and there have been several usability evaluations and a remarkable amount of user testing in cartographic research. However, usability seems only to deal with one specific problem under investigation. Systematic usability engineering throughout the lifecycle of map applications seems to be an exception. At the same time, application developers (software programmers) do employ UCD methods, but they usually have a lack of knowledge about cartographic design principles. The goal of this study is to merge knowledge of cartographic research with usability methods and 'bring together' the cartographic and usability engineering research areas. The tasks to be executed require knowledge on research methods, techniques, and other relevant issues from both disciplines. Grounding in experimental techniques and methods is a relevant part of this research to familiarise researchers with the research environment so a thorough understanding of the specific needs of both disciplines is required. As a result, more understanding of multidisciplinary research will be gained.

2. To adapt HCI methods to better suit the needs of map application developers

The aim of this task is to find out, whether there really is a need for a UCD approach in the market and why/why not? How do the companies providing current map applications ensure that the applications meet user needs? Only by understanding the business needs can the research produce valid and exploitable results.

Not all the methods used in traditional usability engineering are either suitable or useful for map applications. Therefore, research into how to apply UCD methods in map design and for developing map applications should be carried out. Usability engineering methods should be further developed and adapted to suit the multidisciplinary nature of map application projects. A more systematic comparison of which methods should be used and in which situation should also be carried out. When developing map applications, questions need to be asked on which kind of evaluations are user tests needed for and for which kind of evaluations are heuristics most suitable for? Choosing suitable methods and an appropriate way in which evaluations are to be performed varies depending on the type of the design and the stage of the design process. Sets of guidelines should be created that can be used when designing a map application.

3. Research into usability issues concerning maps on screen

One of the fundamental questions to be solved and defined is the relationship between usability and map applications: what is a user-friendly map application and what are the elements and measures that define it? What is the conceptual structure for these elements, and where is usability situated in the hierarchy of map creation? In addition to cartographic design, the usability of mobile map applications is also composed (at least) of a diverse range of users and user characteristics that may vary a lot. Each user or different user group may have their own specific user requirements. When designing cartographic representation, the context of use should also be taken into account (e.g. maps on mobile devices have to be evaluated outside, in varying light conditions). Furthermore, it is not only the map that should be readable and intuitive, but the GUI should be so too and the device should also be logical and easy to use.

The aim of this task would is to compile a usability definition for map applications and to observe the different components and conceptual hierarchies in map applications. Arranging usability evaluations for commercial map applications in co-operation with both usability engineers and cartographers should be the approach to this question. Creating this knowledge would allow the research to merge knowledge on cartography and usability in real situations, and give recommendations and definitions on usability aspects for map applications.

4. To give guidelines for implementing a UCD approach with map application design

The UCD approach seems to support the relevancy of understanding map users and the context of use, which is critical in today's map design. Nevertheless, there are no specific guidelines on how to apply a UCD approach in such specific products as cartographic products. The objective of this task would be to ascertain the specific needs for designing cartographic products and adapt a UCD model so that it could easily be implemented in the cartographic application design process. The task aims to evaluate and validate models and concepts designed in earlier tasks by testing the approaches with real business cases. The guidelines will be created in an attempt to provide help in including a UCD approach for designing specific map applications.

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PAPERS I - IV

PAPER IV