FACULTY OF ENGINEERING, UNIVERSITY OF PORTO

FEUP

A Novel Visualisation Paradigm for Three-Dimensional Map-Based Mobile Services

Mário Tiago Pereira Vasconcelos Freitas

Dissertation

Master in Informatics and Computing Engineering

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(Ph.D. and Professor at the Faculty of Engineering, University of Porto)

2008, July

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31st July, 2008

This work is entirely dedicated to my mother.

Abstract

After several years where 3D maps were only possible to visualise with the powerful desktop computers, the Location-Based Mobile Services (LBMS) technology has finally reached a maturity level that enables the development of 3D map-based Graphical User Interfaces.

Nowadays, there is already a vast range of commercial LBMS products available to the masses, mainly in the form of Personal Navigation Assistants (PNAs) and mobile phones featuring GPS functionality and mobile 3D maps. Motivated by commercial interests, many of these products promise to offer the "best visualisation experience ever", in search for a differentiating factor from the competition. Given the complete disparity of ideas and a visible disorientation in the Mobile Industry, it becomes of uttermost importance to study the visualisation aspects that are concerned with user performance and experience in the exploration of urban environments using 3D maps.

In this work, a generic conceptual framework is proposed, whose main purpose is to unify and to objectively evaluate all the relevant visualisation elements (*feature vectors*) that influence user performance and experience. With this conceptual framework in mind, an online questionnaire was developed and administered to 149 test subjects, in order to measure the real impact of the most important visualisation features. The results clearly demonstrated that, just by displaying buildings with a 3D appearance, subjects were able to match more accurately the real environment with the one presented on a mobile map. Moreover, users were able to perform the tasks entrusted to them faster, if they were provided imagery with a superior level of realism (e.g., Photo-realism).

This work proposes a visualisation paradigm of 3D maps for urban environments, by specifying the high-level requirements for generic LBMS, which maximise user performance and experience. The possible conflicts that may arise between these requirements are discussed, and several solutions and alternatives are suggested.

To evaluate the applicability of the proposed visualisation paradigm, an automotive navigation system prototype was developed, using the current mobile technology.

Resumo

Após vários anos em que os mapas 3D apenas poderiam ser visualizados com recurso aos poderosos computadores pessoais, a tecnologia de Serviços Móveis Baseados na Localização (LBMS – *Location-Based Mobile Services*) atingiu finalmente um nível de maturidade tecnológica que possibilita o desenvolvimento de Interfaces Gráficas de Utilizador baseadas em mapas 3D.

Hoje em dia, existe já uma vasta gama de produtos comerciais, disponível ao grande público, fornecendo serviços baseados na localização, principalmente sob a forma de Assistentes Pessoais de Navegação (PNAs – *Personal Navigation Assistants*) e de telemóveis com funcionalidade GPS e mapas 3D móveis. Motivados por interesses comerciais, muitos destes produtos prometem proporcionar "a melhor experiência de visualização jamais vista", na procura de um factor que os diferencie da concorrência. Dada a completa disparidade de ideias e uma visível desorientação na Indústria Móvel, torna-se importantíssimo avaliar os aspectos de visualização que estão relacionados com o desempenho e a experiência de utilizador na exploração de ambientes urbanos usando mapas 3D.

Nesta dissertação, é proposta uma *framework* conceptual genérica cujos principais objectivos são o de unificar e de avaliar todos os elementos de visualização relevantes (*vectores de características*) que influenciam o desempenho e a experiência de utilizador. Tendo esta *framework* conceptual em mente, elaborou-se um questionário *online* que foi administrado a 149 participantes com o objectivo de medir o verdadeiro impacto das características de visualização mais importantes. Os resultados demonstraram claramente que, apenas por representar edifícios com uma aparência 3D, os participantes foram capazes de associar o ambiente real com o que era apresentado no mapa móvel. Além disso, os utilizadores conseguiram desempenhar, mais rapidamente, as tarefas que lhes eram confiadas, se lhes fossem fornecidas imagens com um nível superior de realismo (por exemplo, Foto-realismo).

Esta dissertação propõe um paradigma de visualização de mapas 3D para a exploração de ambientes urbanos, através da especificação de requisitos de alto nível para serviços móveis genéricos baseados na localização que maximizem o desempenho e a experiência de utilizador. Foram discutidos os possíveis conflitos que advenham da interacção entre estes requisitos, tendo sido sugerido várias soluções e alternativas.

Para avaliar a aplicabilidade do paradigma de visualização proposto, foi desenvolvido um protótipo de sistema de navegação automóvel, usando a tecnologia móvel actual.

Acknowledgements

In the opening part of this thesis, I would like to express my sincerest gratitude to all those who somehow helped me complete this work. Without any specific order, I will dedicate this space to all of them.

I would like to express my thanks to my supervisor Professor António Fernando Vasconcelos Cunha Castro Coelho who, despite all the difficulties and the considerable amount of work ahead of me, always supported and encouraged me during all this process, providing vital suggestions for the completion of this work.

To the present course Director of the *Master in Informatics and Computing Engineering* and my Professor António Augusto de Sousa for all his suggestions regarding the preparation of the questionnaire in this thesis. I have furthermore to thank him for considering me eligible and suggesting me for the position opened at *NDrive Navigation Systems, SA* where I am currently an internee.

To all the Computer Science and Informatics students and professors from the Faculty of Engineering of the University of Porto, and from the Department of Engineering of the University of Trás-os-Montes and Alto Douro, Portugal; and my co-workers at *NDrive Navigation Systems, SA* who answered the questionnaire, thank you very much!

To *NDrive Navigation Systems, SA* chief executive officers Eduardo Carqueja and João Neto, and to *NDrive* product development team leader Eurico Inocêncio for all their encouragement and support during the negotiation and mediation with *BLOM*'s subsidiary in Spain (*Opera Wireless*).

Thanks to Paco Varela from *BLOM* for providing me important data required to build the 3D prototype presented in this thesis.

And at last, but not least, I want to express my gratitude to my family and Kaori who were always by my side, supporting me during all the difficult times. Thank you very much!

Mário Tiago Pereira Vasconcelos Freitas

古人の跡を求めず、
古人の求めたるの所を求めよ。

“Seek not the footsteps of men of old.
Seek the place they sought.” (tr.)

Matsuo Bashou

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List of Acronyms

API .... Application Programming Interface
AR .... Augmented Reality
CSS .... Cascading Style Sheet
DEM .... Digital Elevation Model
GIS .... Geographic Information System
GPS .... Global Positioning System
GPU .... Graphics Processing Unit
HLOD .... Hierarchical Levels Of Detail
HMD .... Head-Mount Display
HUD .... Head-Up Display
HVS .... Human Visual System
INSTAR .... Information and Navigation System Through Augmented Reality
IP .... Internet Protocol
LBMS .... Location-Based Mobile Service
LOD .... Level Of Detail
PDA .... Personal Digital Assistant
PND .... Personal Navigation Device
POI .... Point Of Interest
PVS .... Potentially Visible Set
SRTM .... Shuttle Radar Topography Mission
TMC .... Traffic Message Channel
VDM .... Visual Discrimination Metric
VDP .... Visible Differences Predictor
VRML .... Virtual Reality Modeling Language
XHTML .... Extensible Hypertext Markup Language

LIST OF ACRONYMS

Chapter 1

Introduction

Since many thousands of years ago, humanity started using one of the most useful creations: maps. Maps could be found carved into stone steles; painted in cave walls; or drawn in paper or cloth. Maps were first used to study the stars in the sky, rather than the Earth's surface, but during all this evolution process, they needed them, in order to explore their way through the world; to be able to express it visually instead of words and to communicate with other people.

Today, maps can be easily found in a variety of forms (e.g., road maps, railroad network maps, nautical maps, bicycling maps, city guide maps, etc.) and in great number of sources (e.g., public walls, encyclopaedias, Atlas, the Internet, mobile services, etc.). The one of most interest to this study are the kind of maps that take into account the user's current position: mobile maps.

Despite the progresses of Computer Science, mainly in the Computer Graphics field, and the technological improvements in desktop computer hardware, *Mobile Technology* has been traditionally regarded as very resource-limited, because it could never pick up this fast-growing technological pace, until just recently.

1.1 Context and Scope

1.1.1 Problem

The LBMS technology, namely in the form of GPS[1]-based navigation systems, has just recently reached a state of technological maturity, enabling the development of 3D map-based graphical interfaces. Nowadays, there is a wide offer of LBMS[2] solutions for the

[1]Global Positioning System
[2]Location-Based Mobile Service

masses, especially in the form of automotive navigation systems. Mainly commercial driven, these solutions usually propose the “best visualisation experience ever”.

By looking at the variety of visualisation paradigms being proposed, one can clearly notice a great disparity of ideas and a complete disorientation in the *Mobile Industry*. Because of these reasons, a more objective and clear definition on what visual elements or properties effectively contribute to the users’ performance – when they are dealing with mobile maps – is required.

1.1.2 Enterprise Context

This dissertation work has been developed in cooperation with *NDrive Navigation Systems, SA*, a Portuguese brand of automotive navigation systems established in the same city as the Faculty’s (Oporto, Portugal), that opened a position for a candidate with knowledge of 3D Computer Graphics.

Approximately half of the time (10 weeks) was spent at the company, divided into commercial development of the main company’s product entitled *NDrive*, but also dedicated to the development of the prototype that is presented as part of this dissertation work. Nevertheless, the experience acquired, during the commercial development of *NDrive*, proved to be very useful in the following ways:

- It helped me familiarising with the *Mobile Industry*, LBMS and automotive navigation systems in particular;
- Having developed support for full-textured 3D landmarks in *NDrive*, I was able to use and include graphical material (e.g., screenshots) as part of the dissertation, mainly for the questionnaire’s exercises;
- Becoming more aware of the technological barriers that exist in current mobile devices, in order to successfully develop a 3D prototype.

Product

NDrive Navigation Systems, SA develops a product with the same name entitled *NDrive*, in separate or included in PDA[3]s, PND[4]s, and mobile telephones.

This company works with in cooperation with the mother company named *InfoPortugal, SA*. *InfoPortugal, SA* is responsible for the production and survey of geographic contents, POI[5]s, maps and guide-books, which makes up the main contents for *NDrive* navigation systems.

[3] Personal Digital Assistant
[4] Personal Navigation Device
[5] Point Of Interest

NDrive was created in 2005 as “yet another” navigation system, but soon achieved world fame and success, especially after becoming the first navigation system in the world to include Orthophotomaps rather than standard coloured vector maps.

Nowadays, *NDrive* is a full-featured software product, including but not limited to *Orthophotomap*s and full-textured 3D landmarks of most European countries and the Americas, and an enormous amount of *POI*s and other contents.

1.2 Motivation and Objectives

Provided the complete disorientation that can be observed in the *Mobile Industry*, and the nonexistence of an objective state-of-the-art generalising theory capable of unifying and evaluating all the visualisation elements and properties, the main motivation of this work is to study all these features and the possibility of adjusting them appropriately, in order to maximise the usability of the navigation experience with mobile maps.

The main purpose of this dissertation is to define a new visualisation paradigm of 3D maps for mobile devices, maximising location-based mobile services’ usability, in accordance with the following specific objectives:

1. Elicit and assess the state-of-the-art contributions regarding visualisation paradigms of 3D maps, with particular interest on mobile services and devices;
2. Develop a methodology for evaluating the different issues that improve the user experience and performance;
3. Define a new visualisation paradigm of 3D maps for urban environments;
4. Develop a *LMBS* prototype for real-time navigation according to the defined visualisation paradigm.

1.3 Dissertation Outline

This dissertation is divided into 7 chapters and includes 2 appendices.

This first chapter focuses on the definition of the context, scope and main objectives of this dissertation work.

The evaluation of the state of the art is given in both Chapters 2 and 3 of this dissertation. Chapter 2 focuses on the visual perception of realism and in a general overview of the state-of-the-art contributions on LBMS that provide 3D maps for urban navigation. In Chapter 3, a new conceptual framework is proposed which aims to help specifying, developing and evaluating new and existing visualisation paradigms of 3D maps for LBMS solutions. In the same chapter, the framework is described and illustrated through its application in the state-of-the-art contributions enumerated in Chapter 2.

Having described a novel evaluation framework in the third chapter, Chapter 4 aims to measure the real impact of the most important components of this framework, i.e., by developing an online questionnaire and administering it to test subjects, without incurring the risk of being “too extensive” by focusing on the components for which there are not many scientific indications, given by the state-of-the-art studies, regarding the best approaches to follow.

Taking input from the evaluation of the components that were assessed by the questionnaire described in Chapter 4, Chapter 5 completes the evaluation of the whole framework, based on state-of-the-art studies, experience in practical use and empirical knowledge, aiming to propose the “ideal” visualisation paradigm of 3D maps for *LBMS* solutions. This framework is then discussed as a whole, the interactions of each component of this framework are analysed, and the restrictions and incompatibilities are elicited.

Chapter 6 briefly describes the specification and development of a specific *LBMS* prototype, according to the proposed evaluation framework.

In Chapter 7, the general conclusions are drawn from the entirety of this dissertation work. Some notes and indications for future work are also given.

The two appendices consist of the listing of the online questionnaire’s web pages and its results.

Chapter 2

Visual Perception of Realism and Location-Based Mobile Services

Nowadays, there is a wide variety of free and commercial products featuring three-dimensional map-based mobile services, mainly in the automotive navigation systems industry. On this ground, there is also a vast scientific literature and pilot studies regarding the significance of some visualisation elements in 3D maps. The contributions range from very abstract to reasonably realistic and immersive visualisation experiences. However, there is a common misconception on what is *Image Realism*, how is it visually perceived, and how can it be effectively "measured". This chapter provides an overview of such concepts, and an outline of the state-of-the-art solutions that contribute with the most relevant visualisation paradigms which can be applied to the primary tasks that 3D maps are used for.

2.1 Visual Perception of Realism

Image realism can be easily defined in a subjective way, and – because of that – a more "scientific" explanation on what is realism and how it can be measured is required.

A scientific experiment has been conducted with test subjects to understand what aspects of an image can make it look "photographic" / "real" or "computer-generated" / "not real" [Rademacher et al., 2001; Rademacher, 2002]. Note that this doesn't necessarily imply that a computer-generated image cannot be real. On the contrary, the studies evaluated the impact of altering some of the parameters when producing computer-generated images on the visual perception of "realism". This is to say that it is possible to fine-tune some of those parameters (such as shadow softness, surface smoothness, number of objects, variety of shapes, and number of light sources in [*op.cit.*]) to make computer-generated images look real, i.e., being perceptually indistinguishable from the corresponding photographs.

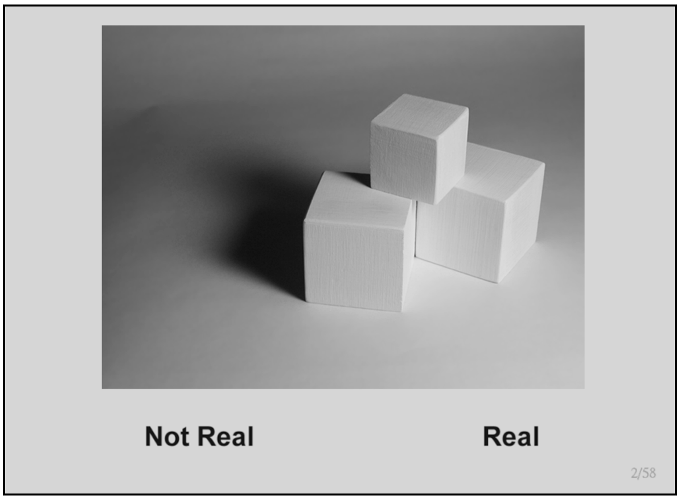


Figure 2.1: One of the screenshots to evaluate shadow softness – adapted from [Rademacher, 2002]

Interestingly, the results of the test showed that subjects were not convinced by the increasing number of light sources and shadows nor the variety or number of shapes. Equally surprising, the results demonstrated that "perfectly sharp" shadows or "perfectly polished" surfaces, yielded the worst scores, i.e., test subjects were not convinced by their "realism".
Another experiment has been carried out with 75 test subjects (grouped from lay persons to experts) to classify 90 images of the virtual landscape of Brunnen / Schwyz (Switzerland) from three different viewpoints in a degree of realism from 1 (very low) to 5 (very high) [Lange and Ch, 2003]. The majority of the images were computer-generated, a few were photographs, and one was the superposition of a photograph foreground with a virtual (computer-generated) background. In the same study different combinations of elements in the image set were distinguished:

Element	Possible Scenarios		
terrain	colour shaded	satellite imagery	satellite and aerial (Orthophotographic) imagery
buildings	not included	colour shaded (Figure 2.2a)	texture mapped – in the foreground scene (Figure 2.2b)
single trees	not included	texture mapped	
forest	not included	texture mapped	

Table 2.1: Matrix of possible test scenarios [Lange and Ch, 2003]

(a) Colour Shading

(b) Texture Mapping

Figure 2.2: Two techniques to depict buildings façades – obtained from [Lange and Ch, 2003]

The results generally demonstrated that the variable that most contributed to the sense of realism was – by far – the high-resolution Orthophotographic imagery. The second most important variable was texture-mapping: if textures were provided, the degree of realism significantly increased. There was, however, a disagreeing opinion about the significance of buildings in the foreground-scene. Specifically, only the group consisting of the local experts reacted negatively due to the absence of buildings in the foreground scene, which were present in the original photographs.

In other works the importance of perception-based image quality metrics is studied [McNamara et al., 2000], such as the ones given by the VDP[1] and the VDM[2]. These two metrics aim to analytically predict the differences between a computer-generated image and the photograph it depicts, taking into account the limitations of the human eye described by the HVS[3] model. The VDP quality metric takes the two images as input and generates a *difference map* that predicts the probability of the human eye finding differences between the two pictures [*op.cit.*], as demonstrated in the following picture:

[1] Visible Differences Predictor

[2] Visual Discrimination Metric

[3] Human Visual System

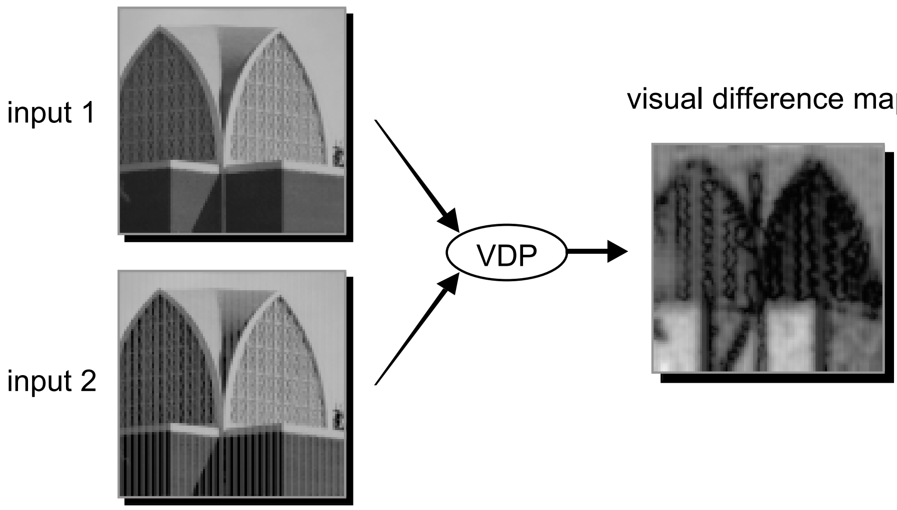


Figure 2.3: *Difference map* in the VDP quality metric – adapted from [Bolin and Meyer, 1999]

A simplification of the VDM quality metric was provided by following a similar approach [Bolin and Meyer, 1999]: instead of finding a *difference map*, a *just noticeable difference map* was proposed which corresponds to a 75% probability of a person detecting a difference between the two images [McNamara et al., 2000].

Because there is some controversy an no agreed-upon standards for measuring realism in computer-generated imagery, a conceptual framework for measuring image realism and evaluating its usefulness was proposed [Ferwerda, 2003]. The framework distinguishes three different varieties of realism:

Physical realism – In order to exist physical realism, the renderer must be able to accurately reproduce the spectral and intensive properties of the light energy as captured from a particular viewpoint in the scene. This is to say that the image must provide the same *visual stimulation* as the scene, exactly as if the viewer was perceiving it directly with his own eyes. Currently, there are no displays that are capable of achieving this, so it is technically impossible to generate *physically realistic* images.

Photo-realism – If an image is to be classified as photorealistic, then it must produce the same *visual response* as the scene. In other words, the goal is to obtain an image that is indistinguishable from a photograph of a scene, taking into account the limitations of the HVS. Technically speaking, the image must be *photo-metrically realistic*, i.e., it must produce the same eye's response to the perceived light energy, as if it was the energy was physically coming from the real scene. The next figure is an example of a photorealistic environment:

Figure 2.4: Example of a photorealistic image – adapted from [Qingfeng, 2007]

Functional realism – In this last standard, the image must provide the same *visual information* as the scene. 'Information' in this case conceptualises visual properties of the objects in a scene, such as shapes, sizes, positions, etc. in a way that allows the users to perform a visual task or to take assumptions consistent with the real scene. Examples of photorealistic images given in [Ferwerda, 2003] are the ones typically produced in flight simulators, i.e., while they are not photorealistic according to any of the previous two concepts on image realism, they are *functionally realistic* in the sense that they provide visual information equivalent to the one that can be observed if the viewer was flying a real airplane. Other examples include technical illustrations, as represented in the following picture:

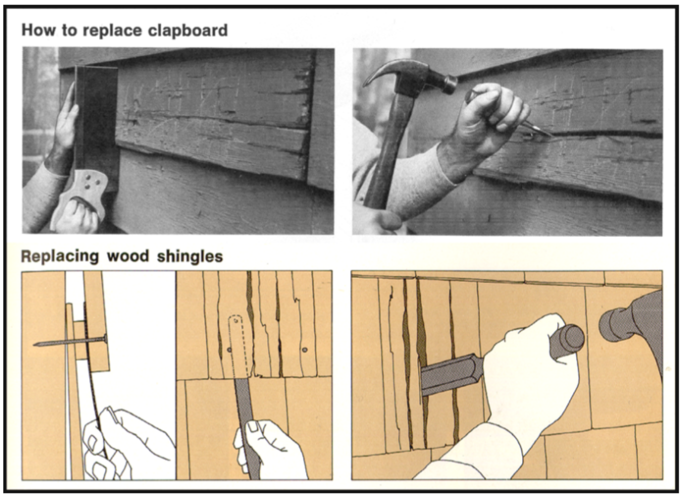


Figure 2.5: Example of a *functionally realistic* image – adapted from [Ferwerda, 2003]

However, this framework does not seem to be enough to encompass the extents to which *realism* can be "augmented". Accounting for such circumstances, the concept of

Virtuality Continuum in the field of *Mixed Reality* was introduced [Milgram and Kishino, 1994]:

Figure 2.6: The *Virtuality Continuum* – adapted from [Milgram and Kishino, 1994]

At the left end, we have the "completely real" *Real Environment*, which is made up of "real" objects: *any objects that have an actual objective existence* [*op.cit.*]. At the right end, we have the "completely computer-simulated" *Virtual Environment*, which is made up of "virtual" objects: *objects that exist in essence or effect, but not formally or actually* [*op.cit.*].

The next figure is provided to help clarifying the difference between *real* and *virtual* objects/images:

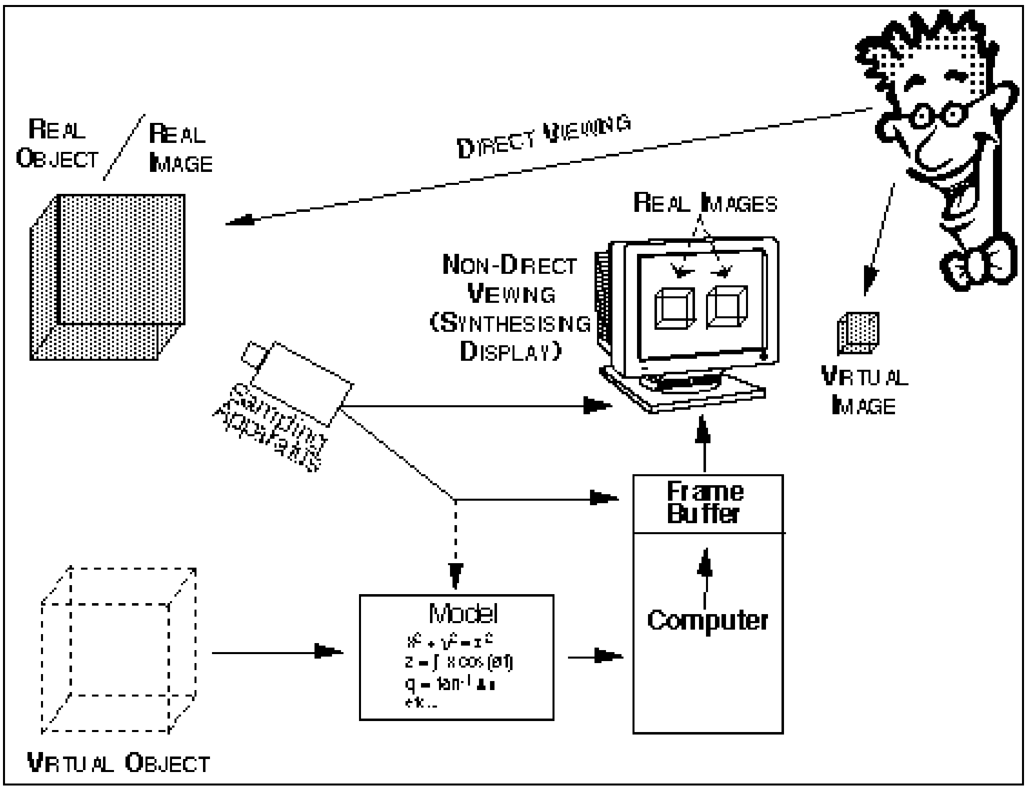


Figure 2.7: Distinguishing *reality* from *virtuality* – adapted from [Milgram and Kishino, 1994]

In-between the two extrema (*Real Environment* and *Virtual Environment*), there is a continuum which defines the concept of *Mixed Reality*: a combination of real world objects and computer-generated imagery. Depending on whether the visualised environment is closer to a real environment or virtual environment, it can be more further subdivided into *Augmented Reality* or *Augmented Virtuality*.

2.2 User tasks

Without a doubt, the underlying basic equation that can help us find the "perfect" balance in map-based mobile services is what could be called of *Mobility Equation*. This equation was first formulated by Leonard and Durrant-Whyte for mobile robot navigation [Borenstein et al., 1996] but can be equally extended to human navigation. The equation is made up of three following questions [Coelho and Freitas, 2007]:

- 'Where am I?'
- 'Where am I going?'
- 'How do I get there?'

These are the most basic questions the users ask themselves when performing any of the previously stated user tasks and from which all other questions are derived, when using maps. Subsequent questions may include 'And now what?' when users ask for additional contextual or situational information, based on the current time and location.

There are studies where the tasks are classified into four different groups of high-level user tasks [Hunolstein and Zipf, 2003] that have a strong relationship with these questions:

Task	**Description**
Locator Tasks	Identification of the user's own position and other objects. Answers 'Where am I?' questions.
Proximity Tasks	Inform the users of nearby facilities. Implied by 'Where am I going?' questions.
Navigation Tasks	The most tangible example is routing from one location to another. Answers 'How do I get there?' questions.
Event Tasks	Time/Location dependent objects, allowing the users to know what is happening and when/where. Answers 'And now what?' questions.

Table 2.2: The primary tasks that 3D maps are used for

2.3 Main Contributions

This section provides an overview of the state-of-the-art visualisation paradigms regarding 3D map-based mobile services. The contributions will range from pilot studies to commercial products, within the scope of road and pedestrian maps.

2.3.1 *TellMaris*

TellMaris project [Nurminen, 2003] was a pilot study to evaluate the impact of three-dimensional maps for tourist information retrieval purposes. *TellMaris* focuses primarily but is not limited to boat tourists travelling in the Baltic Sea Region and it can be divided into three different applications [Laakso, 2002]:

TellMarisPlanner A web-based service to help planning a successful boat trip

TellMarisOnBoard An application to be used in the boat's laptop, providing 3D sea charts, weather forecasts, and other relevant information during the boat trip (see Figure 2.9)

TellMarisGuide A city guide application to be used in the destination city (see Figure 2.8)

TellMarisGuide, the most relevant to this study, was also the first guide using 3D maps as the main communication interface [Bessa, 2007] for tourist information providing a LBMS.

Tests sessions were conducted with ten subjects and one pilot user [Laakso, 2002; Gjesdal et al., 2003], in which they were asked to go from one location to another using either *TellMarisGuide*'s 2D and 3D digital maps or normal 2D paper maps and guidebooks, without the help of a GPS to keep track of the current position but with the starting and target locations annotated on the maps (see Figure 2.8).

The test results demonstrated that people were able to recognize buildings and use them as reference points in navigation tasks [*op.cit.*], although the same couldn't be told for users proficient with two-dimensional paper maps. In general, 75% of them would prefer to use this kind of service rather than 2D paper maps and guidebooks. The same results showed the general navigation strategy was to recognize the 3D buildings – a distinctive feature of the 3D maps – and to follow the 2D map dots.

In the same study, some of the individual users who participated in the tests, said they desired a higher graphical quality in the 3D model, namely more geometric and texture details, but others pointed out that highlighted targets in the 3D model would help them make the right decisions when navigating [*op.cit.*].

Figure 2.8: A test subject navigating with *TellMarisGuide* – adapted from [Laakso, 2002]

Figure 2.9: Screenshots from the *TellMarisOnBoard* application – obtained from [Nurminen, 2003]

2.3.2 *m-LOMA*

A few years later, in the same laboratory where *TellMaris* was created, one of the first full-featured mobile 3D map applications – entitled *m-LOMA* – was built [Nurminen, 2006].

m-LOMA was created for tourism, based on high quality 3D city models and digital photographs from building façades. The application is capable of running on standard GPS-enabled PDAs and mobile phones, without any kind of GPU[4] acceleration hardware, as shown in the following pictures:

Figure 2.10: *m-LOMA* running on PDAs and mobile phones – obtained from [Nurminen, 2006]

Tests were conducted with 8 subjects, and the method used followed the *pointing task paradigm*. This paradigm focuses on spatial cognition tasks and emphasises the problem of mapping the two worlds (virtual and physical), and relies on the following procedures [*op.cit.*]:

- Each subject is brought to a spot in an urban area
- The subject is shown a building in one of the possible spaces: virtual (on the device's screen) or physical (in the real environment)
- The subject is asked to point (with the index finger) to the corresponding building in the other space

The study demonstrated the advantages of the 3D visualisation approach over the 2D's. The general reason for this is that it is more difficult for the users to align themselves with the map's axis when looking at a map with one dimension less than reality's, which requires a higher degree of visual-spatial abstraction. In general, the results demonstrated that people performed, on average, 23% quicker by using a 3D map. The number of restarts with the 3D map was also a bit lower: 12% against 17%.

[4]Graphics Processing Unit

m-LOMA also introduced some interesting ideas such as dynamic streaming of 3D models, textures and other contents avoiding the need for static storage of huge amounts of geospatial data and ensuring this information can be more easily found up-to-date.

2.3.3 *TomTom*

Apart from tourism, there is another industry moving at a very fast pace towards the use of three-dimensional maps for navigation purposes. In the past three years, the automotive navigation systems industry has been influenced by and influencing the way people evaluate maps, with the proposition of different 3D visualisation paradigms that should help users getting more adequate information from 3D maps. The approaches to visualisation paradigms vary from simple implementations to more complex as seen in the video-games industry, on a reduced scale, due to the great limitations of mobile devices.

TomTom – the product of the leading manufacturer of navigation systems in Europe [Wikipedia, 2008] – uses a traditional approach to three-dimensional map interfaces. One could argue that this is not a "pure" 3D map but somewhat of a "2.5D" map. Despite that ambiguity, this study will consider it as a kind of 3D map, since a perspective (e.g. bird's-eye) projection of a two-dimensional vector map is used with perspective foreshortening of road vectors.

When the user is operating the software in routing or demonstration mode, it is possible to follow the arrow shaped manoeuvre indicators that lay on top of the road vectors, and to check several items of information such as the current street name, speed, distance to next manoeuvre, GPS signal power, time to destination, and so on. There is an association between the street names and the corresponding road vectors, as they are oriented accordingly, and nearby POI icons are also displayed. The overall look and feel of the application is depicted in the following figure:

Figure 2.11: Screenshot of *TomTom* – adapted from [TomTom, 2008]

As we will see from the following brief reviews, most of the presented features are, to some extent, generally shared by the leading players' navigation systems in the industry, not only by *TomTom*'s.

2.3.4 *Navigon*

Navigon, another leading solution in the automotive navigation systems industry, has a peculiarly different 3D approach to navigation.

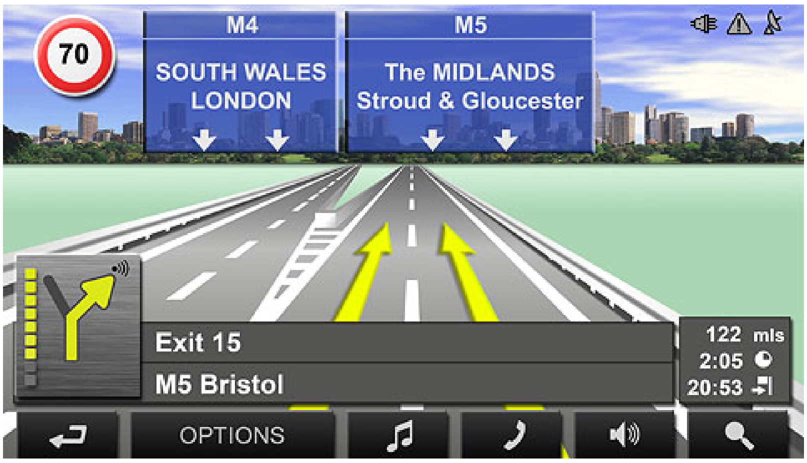


Figure 2.12: Screenshot of *Navigon*'s *Reality View*^{TM} – obtained from [Navigon, 2008]

The most interesting feature is, by far, *Reality View*^{TM} – a technology that provides static [Marketnews, 2008] 3D imagery that present signposts and lanes the driver should follow according to the coloured manoeuvre arrows (see Figure 2.12). This only happens in certain situations, i.e., when a matching is found between the real interchange and the digital map generated from GIS[5] databases. In this case, the closest representative image is displayed, according to the matched pattern.

Apart from the usual POI icons, *Navigon* includes traffic jam warning icons positioned on top of the congested roads, updated automatically through the TMC[6], as shown in the figure below:

[5] Geographic Information System
[6] Traffic Message Channel

Figure 2.13: Traffic jam icons in *Navigon* – adapted from [electronista, 2007]

2.3.5 *NDrive*

NDrive – another major player in the automotive navigation systems industry – has provided two different approaches to three-dimensional mobile maps visualisation:

Orthophotographs in birds-eye view (45 degrees) of entire cities (see Figure 2.14)

Full-textured 3D landmarks using photographs of historic buildings (see Figure 2.15)

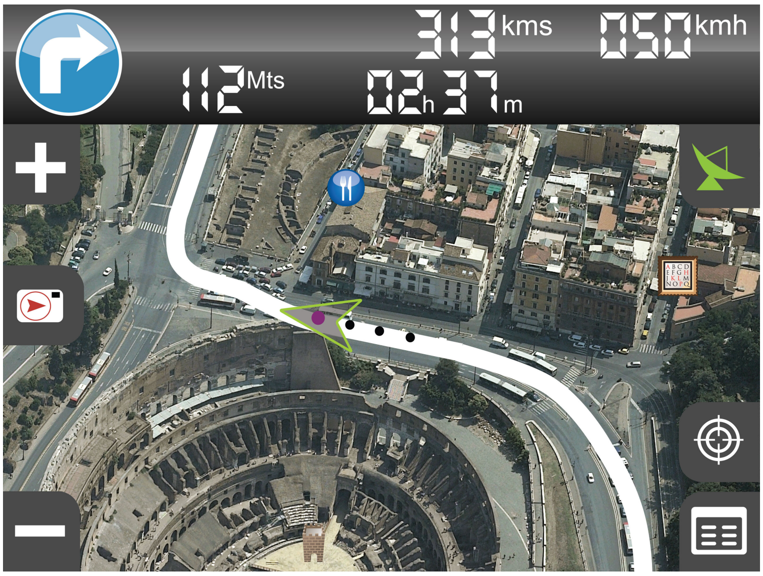
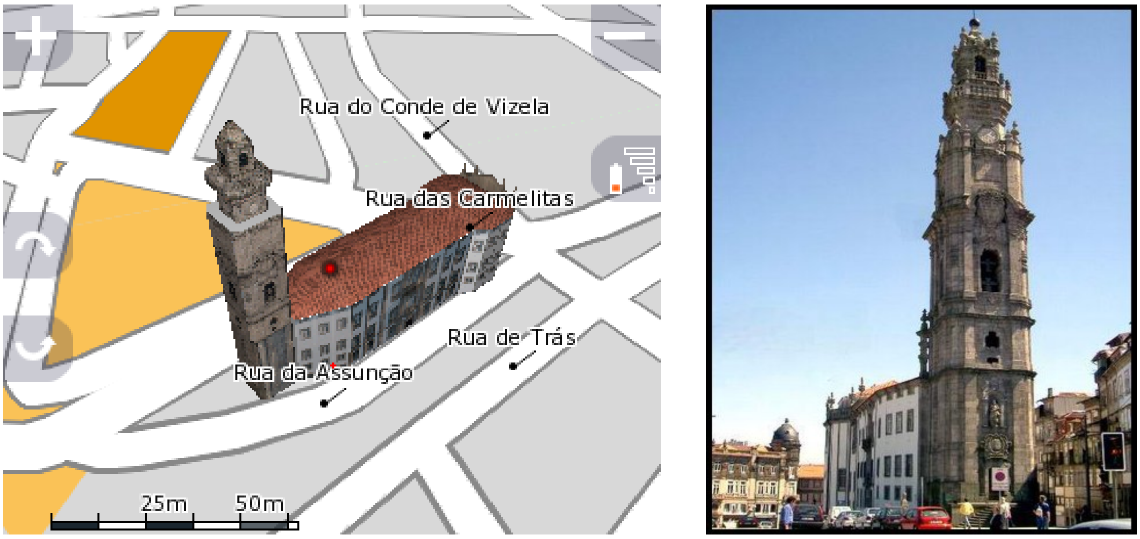


Figure 2.14: Screenshot of *NDrive*'s Oblique Orthophotograph – obtained from [NDrive Navigation Systems, 2007]



(a) A full-textured 3D landmark

(b) Corresponding photograph

Figure 2.15: Screenshot of *NDrive* showing full-textured 3D landmarks (ver. 3)

In the latter approach, the houses and other historically irrelevant buildings were left out. Only road vectors and known landmarks are shown.

2.3.6 *iGO*

Another leading automotive navigation systems industry player with a different approach to three-dimensional visualisation paradigms is *Nav N Go*'s *iGO My Way* which features 3D landmarks and "regular" buildings from entire cities, as seen in the following figure:

Figure 2.16: Screenshot of *iGO My Way 8* – obtained from [Nav N Go, 2007b]

2.3.7 *Google Earth*

Google Earth is a desktop application that represents the Earth as a 3D model. Despite the fact that it is not capable of running on mobile phones, PDAs or PNDs, it is possible to integrate it with a GPS device and use it to navigate.

The first visual impact and the biggest difference from each of the previously mentioned contributions, is that *Google Earth* depicts the world as a globe rather than an atlas, as shown in the following figure:

Figure 2.17: View of the Earth as shown by *Google Earth*

2.3.8 *LAMP3D*

A system for the location-aware presentation of tourist information called *LAMP3D* was also proposed [Burigat and Chittaro, 2005]. This system is capable of synchronising a 3D virtual environment presented in a mobile device with the physical environment through the use of a GPS device. The virtual environment comprises 3D buildings and ground textured with photographic material defined by a VRML[7] model.

LAMP3D provides location-based information to the user when he/she taps an object that is physically in front of him/her as demonstrated in the following figure:

[7] Virtual Reality Modeling Language

Figure 2.18: User tapping an object using *LAMP3D* – adapted from [Burigat and Chittaro, 2005]

The *LAMP3D* system was evaluated – in a practical way - in a square of the city of Udine (Italy). The tests were carried out on a limited group of subjects, but nevertheless some useful indications were elicited. As happened before with *TellMaris* and *m-LOMA*, users demonstrated no significant difficulties in matching the 3D virtual environment with the real environment. The biggest issues and difficulties pointed out by the test subjects were related to the poor precision of the orientation revealed by the application, specially when the user is standing still and looking around. These problems are not technically possible to overcome in an optimum way due to the limitations of the GPS devices which only provide discrete points in space. There is no concept of "direction", although it can be roughly estimated by interpolating consecutive GPS data points. However, while the user is not moving, the mobile application will constantly receive points pertaining to the point in space where he/she is (with imprecision caused by noise), and it will be practically impossible to "guess" the facing orientation. Therefore, [*op.cit.*] refers the importance of additional technology such as electronic compasses to help reducing orientation imprecision problems.

2.3.9 Prototypes on Augmented Reality

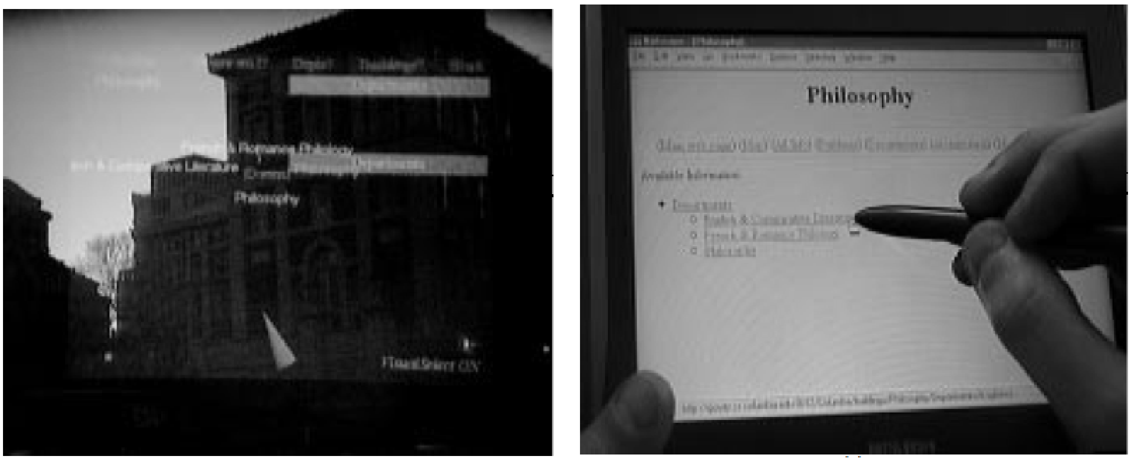
Although the prevailing current of thought to what might be the "best" visualisation paradigm for 3D maps in a LBMS context can be – subjectively – observed in today's automotive navigation systems, there are many studies in a different field of research: the Augmented Reality. In fact, the first references and studies in AR[8] applied to tourism and navigation date back from 1997. [Azuma, 1997] states that a breakthrough in AR through LBMS can make several applications possible such as navigation maps and visualisation. According to [*op.cit.*], this would allow tourists to visit historical sites such as

[8] Augmented Reality

a civil war battlefield, or the Acropolis in Athens, Greece. In the same year, [Feiner et al., 1997] provided an AR-based approach for exploring urban environments in which users could automatically obtain location-based information like the names of the buildings of a university campus, when looking at them via a HMD[9], as shown in Figure 2.19:

Figure 2.19: User with a HMD and a handheld device – adapted from [Feiner et al., 1997]

After getting context and location-aware information – via the HMD – from the buildings the user is facing to (Figure 2.20a), he is able to interact and to get further information from them – via a handheld device (Figure 2.20b).



(a) Getting information

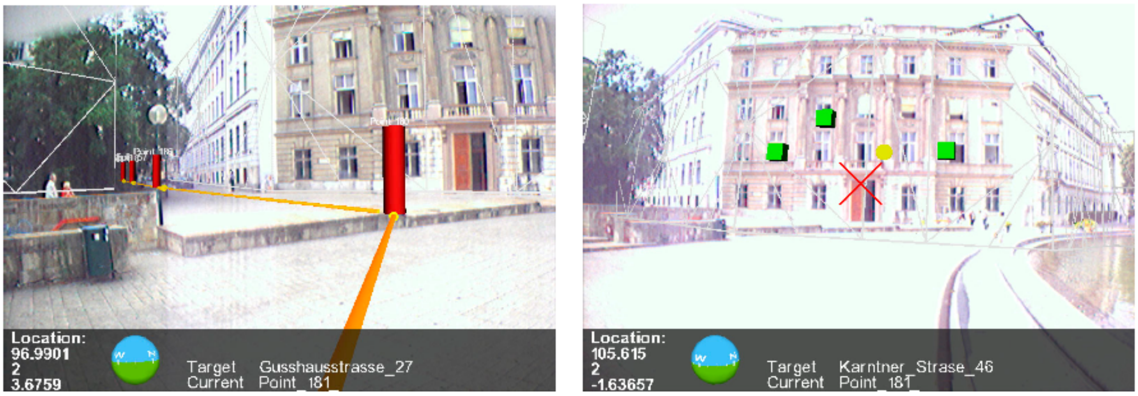
(b) Interacting

Figure 2.20: User getting information from and interacting with a campus information system – adapted from [Feiner et al., 1997]

Other study provided a similar approach but to collaborative navigation and annotation in pedestrian mode [Reitmayr and Schmalstieg, 2003]. Users are able to see the way

[9]Head-Mount Display

points and route (Figure 2.21a), and to set annotation icons (Figure 2.21b):



(a) Displaying the route with way points

(b) Setting annotation icons

Figure 2.21: Screenshots in video see-through mode – adapted from [Reitmayr and Schmalstieg, 2003]

2.3.10 *INSTAR*

In [Narzt et al., 2004] and [Narzt et al., 2006] the benefits of using Augmented Reality were extended to navigation systems. With an application entitled *INSTAR*[10] (see Figure 2.22), they introduced a new visualization paradigm in which, taking into account the driver's perspective, the route would be painted with a translucent colour (ideally) projected directly in the windshield.

Figure 2.22: *INSTAR* in a PND – adapted from [Pomberger, 2002]

INSTAR works by mapping the current position (given by a GPS device) and orientation (using compasses, gyroscopes, etc.) to 2D and 3D maps (DEM[11]s of the terrain).

[10]Information and Navigation System Through Augmented Reality
[11]Digital Elevation Model

Finally, after the mapping is performed, the information from the current route is considered to superimpose the computed the virtual route image over the camera's captured image [$op.cit.$]. The following figure illustrates this process:

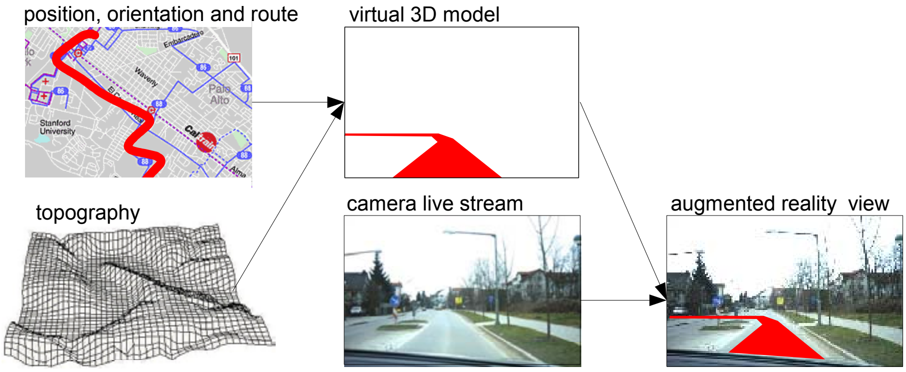


Figure 2.23: *INSTAR*'s process of computing the AR image – adapted from [Pomberger, 2002]

In [Narzt et al., 2006] it is argued this approach avoids the metal abstraction that is required in order to match the user's perspective and the perspective shown in the device. When navigating, the ambiguities that may arise from the counting of exits or hidden junctions (because of other cars or landscape rises) would be eliminated with this paradigm.

2.3.11 *Virtual Cable™*

Likewise, a company with the name of *Making Virtual Solid, LLC* has developed a new technology using Augmented Reality for navigation tasks [Making Virtual Solid, 2007] entitled *Virtual Cable™* (Figure 2.24):

Figure 2.24: *Virtual Cable™* via the in-car HUD display – adapted and modified from [Making Virtual Solid, 2007]

Please notice where the two black arrows that were added to the original figure are pointing to, so it becomes more clear where exactely the "virtual cable" is projected on the screen.

Instead of a HMD, this technology is based on a HUD[12], therefore not obstructing the user's view. With this technology, a virtual cable (hence the name) suspended over the road – representing the route – is projected in the HUD.

One can argue that this technology may provide a high degree of immersion for navigation tasks, but it is important to refer that it is limited to in-car navigation tasks, i.e. by using a HUD, it is not possible to apply *Virtual Cable™* for pedestrian activities, because it must be factory-installed into the car's mirror [*op.cit.*].

2.3.12 *Enkin*

Enkin is aimed to introduce a new handheld navigation concept by combining the use of GPS, orientation sensors, 3D graphics, video capturing and web services via wireless. The user interface implements three modes of operation [Spring and Braun, 2008]:

Map Mode – An aerial mode to help getting a quick overview of the map, as shown in the following figure:

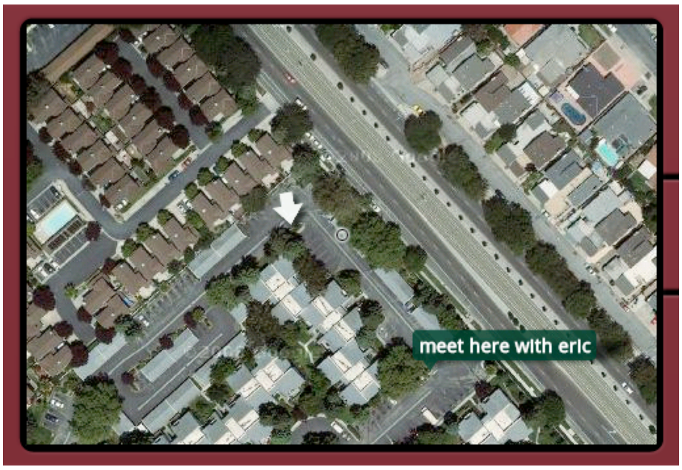


Figure 2.25: *Enkin* in *Map* mode – adapted from [Spring and Braun, 2008]

Landscape Mode – A three-dimensional mode that is very close to *Google Earth*'s 3D view, as shown in the following figure:

[12]Head-Up Display

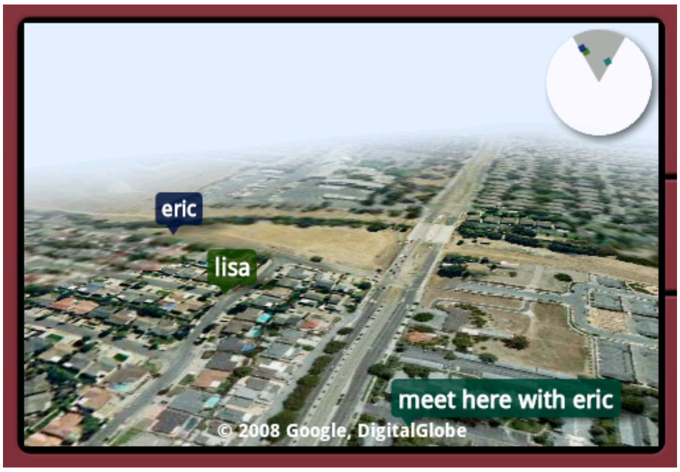


Figure 2.26: *Enkin* in *Landscape* mode – adapted from [Spring and Braun, 2008]

Live Mode – A three-dimensional mode that uses AR to superimpose computer graphics over the live video provided by the device's built-in camera, as shown in the following figure:

Figure 2.27: *Enkin* in *Live* mode – adapted from [Spring and Braun, 2008]

2.4 Summary

In this chapter, a clearer definition on how can image realism be perceived and measured was briefly described, according to the state of the art. At the same time, the basis function for mobility was described through the *Mobility Equation*'s definition, and the classification of primary user tasks, that 3D maps are used for, was performed.

The variety of visualisation paradigms that can be observed in pilot studies, free software applications and commercial products was also described. As we could see, the contributions range from very simple 2.5D maps to completely immersive AR-based solutions, indicative of today's disorientation in the *Mobile Industry*.

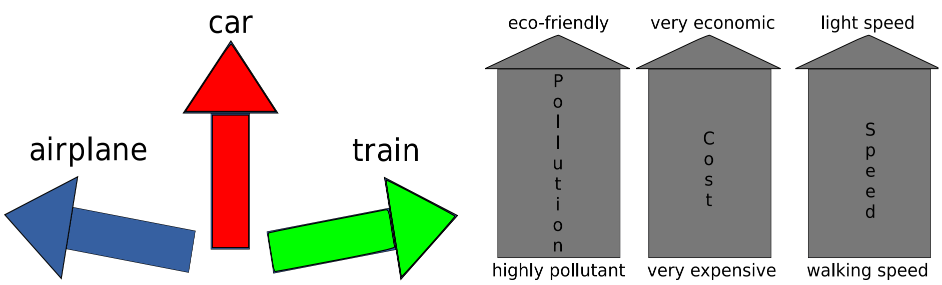
Chapter 3

Evaluation Framework

Having outlined the state-of-the-art studies and contributions on visualisation paradigms for three-dimensional location-based mobile services in the previous chapter, there is still no objective state-of-the-art generalising theory capable of unifying and evaluating all the relevant visualisation elements. In this chapter, a novel generic evaluation framework is proposed which can be used as the main methodology for the specification, development and evaluation of new or existing solutions in the visualisation problem domain for location-based mobile services. The framework will be described in detail and exemplified by applying it to the different visualisation features that make up each state-of-the-art contribution outlined in the previous chapter.

3.1 Feature Vectors

For the sake of simplicity, the metrics that will be used in the evaluation framework will be referred to as "feature vectors". These vectors will include in themselves the mathematical concepts of vector *orientation* and *magnitude*, as exemplified in the following figure:



(a) Orientations (b) Magnitudes

Figure 3.1: An example of a *feature vector* for "Transportation"

Each *feature vector* shall evaluate a single high-level feature, and must be related to one or more of the before-mentioned user tasks. *Feature vectors* should be capable of classifying – in an objective way – the visualisation paradigms by providing a clear, concise and comprehensive grading system with few distinct components.

Orientation will be defined by the idea or concept the paradigm represents, and the *magnitude* will be defined by the degree/level to which the paradigm "amplifies" the vector. As we can see in the example above, *orientations* define the range of concrete possible choices, like the form of transport in a given transportation system (e.g., car, airplane, train, metro, space shuttle, etc.). *Magnitudes* define properties or restrictions that can be observed or manipulated in a given *feature vector*. For instance, if we are classifying means of transportation, several possible magnitudes could be proposed like their cost, speed, pollution levels, and so on.

In certain cases it may happen that a given *orientation* restricts the classification to a certain *magnitude* level. For instance, considering the previous example on transportation, a space shuttle will be restricted – in normal circumstances – to a "highly pollutant", "very expensive", and a very fast form of transportation. In other cases *orientations* may allow a higher degree of freedom in the classification of *magnitudes*, like the colour of a car, a visible property that has no influence in its pollution, cost or speed.

3.2 Overview

The following figure illustrates the framework through *feature vectors* that will be used for evaluations:

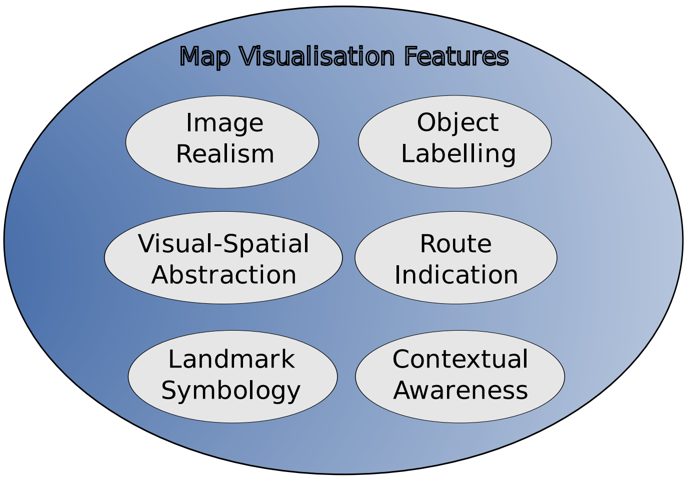


Figure 3.2: Evaluation Framework through *feature vectors*

Some features may overlap or can even be contained within others. Nevertheless, a description of each vector is given, including the connections with other vectors. Along each *feature vector*, the main state-of-the-art contributions will be mentioned and how they significantly contribute to the vector in question.

3.3 Image Realism

Image Realism is the feature vector that is concerned with how real, i.e., free from any idealisations or abstractions, is the image of the map presented to the user.

Taken into account what was previously mentioned on this matter (see Section 2.1), one can conclude that there are a number of ways to assess image realism, and all of them are complementary and valid to some extent. Some frameworks allow us to measure *realism* in terms of *image fidelity* (reproduced environment's image quality) while others focus on *virtuality* (whether the image is a representation of a *real environment* or *virtual environment*). However, when comparing the image on the screen with the real environment, and in order to classify every paradigm in an objective way, the *magnitudes* proposed for this vector should encompass these two dimensions of the problem. For all these reasons, the suggested *magnitudes* will be based on the framework proposed in [Ferwerda, 2003] and the concepts on *virtuality continuum* defined in [Milgram and Kishino, 1994], with a few modifications. Firstly, a "relaxed" version of *physical realism* will be adopted, i.e., it is assumed that current displays are considered perfect in the sense that they can emit the actual energy we want them to reproduce. This is to say that if a video camera is placed on a scene and the recording is played on a conventional display, it is considered a kind of *physical realism*. Secondly, this framework will be incorporated into the *virtuality continuum* as illustrated by the following figure:

Figure 3.3: An illustration of the proposed framework combining the *Virtuality Continuum* spectrum with varieties of image realism

As we can see in the left end, the relaxed version of *Physical Realism* allows us to map this term to the *Real Environment*, i.e., a type of realism in which the environment can be observed directly or indirectly through a synthesising display (see Figure 2.7 on Section 2.1).

On the opposite extremum, there is a complete *Virtual Environment* which can be associated to the concepts of *Photo-Realism* and *Functional Realism*, i.e., the types of realism in which the environment is computer-synthesised while respectively producing the same *visual response* or carrying the same *visual information* as the associated real environment. *Photo-Realism* is located to the left of *Functional Realism*, not because it is considered "less virtual" than *Functional Realism* but because it is closer to the *Physical Realism*, and consequently providing a more "realistic" environment.

As previously observed [Milgram and Kishino, 1994], in the case of a *Mixed Reality* environment, it is not significantly meaningful to count the relative number of objects, nor the proportion of pixels in the display to decide which concept best describes it, i.e., it is not relevant whether we are in the presence of an *Augmented Reality* or an *Augmented Virtuality*, hence the need of a more generalising intermediate concept like *Mixed Realism*. The proposed *magnitudes* will cover the following concepts:

Magnitude	**Description**
Physical Realism	The degree of realism that can be experienced directly or indirectly through a synthesising display.
Mixed Realism	A combination of both physical and virtual objects.
Photo-Realism	The degree of realism pertaining to "life-like" rendering.
Functional Realism	Instructional or task-oriented realism.

Table 3.1: Proposed *magnitudes* for assessing *Image Realism*

Examples of contributions providing a *Mixed Realism* paradigm are given by *Enkin*, the prototypes proposed by [Feiner et al., 1997] and [Reitmayr and Schmalstieg, 2003], *Virtual Cable*^{TM}, and *INSTAR* as demonstrated in the following figure:

Figure 3.4: *INSTAR* as an example of *Mixed Realism* – adapted from [Narzt et al., 2004]

Following the same reasoning, and because one single visualisation paradigm may provide multiple degrees of realism in different groups of elements, the classification will be performed separately for each group. For instance, if buildings are photorealistic and streets are functionally realistic (e.g. depicted by coloured vectors), the visualisation paradigm will not be defined conservatively as being functionally realistic nor completely photorealistic.

Regarding the use of 3D buildings, there are generally three approaches being followed: not to show buildings at all; showing coloured buildings (i.e., no texture mapping involved) or presenting them with simple textures such as façade patterns; and finally to show buildings whose façades are textured with photographic material.

Contributions such as *TomTom* and *Navigon* follow the first approach, i.e., they do not render three-dimensional buildings in the map. *TomTom*, however, simulates 3D buildings in an interesting way: when the user is near an urban area, the polygon vectors are extruded by a few pixels on the screen, creating the feeling on the user of being surrounded by buildings and navigating in an urban landscape, as shown in the next figure:

Figure 3.5: *TomTom* extruding polygons to represent buildings – adapted from [TomTom, 2008]

In *TellMarisOnBoard*, it is possible to observe (see Figure 2.8) that, although buildings are not very geometrically complex (about 0.4 meters of precision [Laakso, 2002; Gjesdal et al., 2003]) and use simple textures or are simply colour shaded, they serve the purpose of matching the virtual with the real environment, to a significant degree. In a similar way, *iGO* is capable of displaying buildings which are not considered landmarks by rendering simplified versions of the real ones – rougly represented as 3D "boxes" and without photographic texture imagery. Instead, generic texture patterns are used repeatedly to paint houses, hotels, and other regular buildings as shown in the following figure:

Figure 3.6: *iGO My Way 8* depicting regular buildings – obtained from [Nav N Go, 2007a]

m-LOMA, *NDrive*, *iGO*, *Google Earth*, and *LAMP3D* are able to display photo textured 3D buildings. In *m-LOMA*, the photographic material does not cover the whole buildings, because the rooftops are not texture mapped at all, i.e., they are just colour shaded (see Figure 3.24). On the other side, *Google Earth* is even capable of doing it for entire cities. While most of the buildings are not textured due to the lack of textures, it is still possible to see a considerable amount of them using photographic material, as demonstrated below:

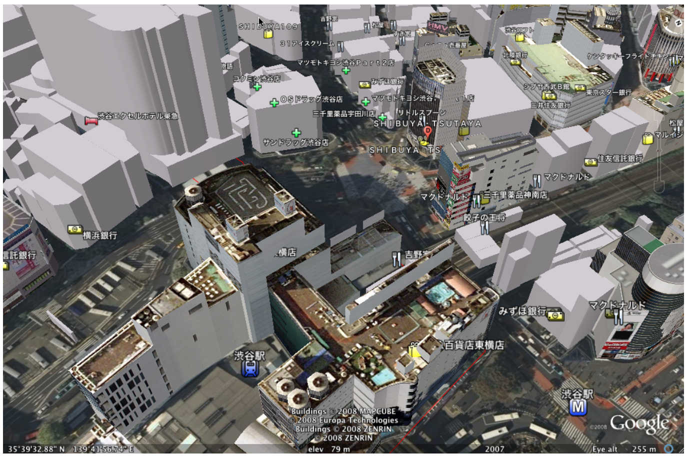


Figure 3.7: *Google Earth* displaying 3D buildings with photographic textures

As we could see, in these past few years there has been a clear movement towards the use of ever more detailed 3D buildings. The growing detail usually comprises photographic material rather than simple textures or colours, as demonstrated in the following comparison chart:

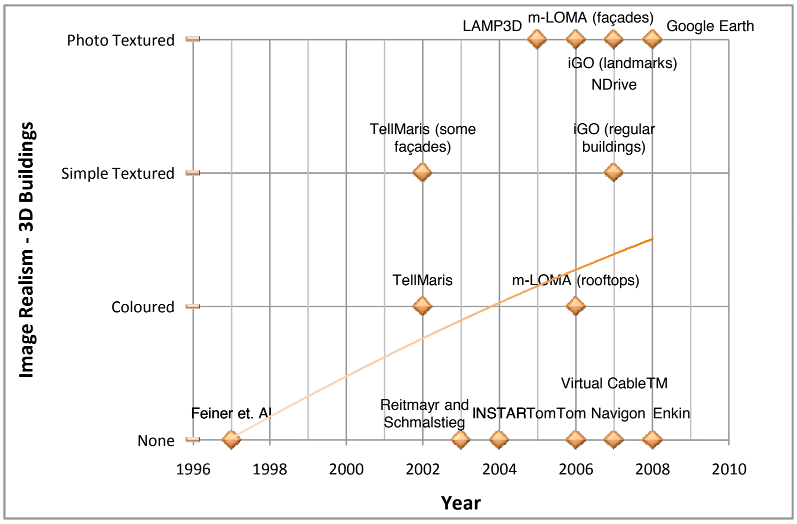


Figure 3.8: Classification of the state-of-the-art contributions in terms of 3D buildings detail, according to the proposed evaluation framework

Speaking of map polygons, all contributions except *NDrive* and *Google Earth* represent the map by colouring road vectors and polygons. To compensate for the lack of visual information, carefully chosen colours are used to fill the polygon vectors. Such colours represent topographical and urban features of the map (e.g., blue is associated to rivers and lakes; green is used for parks and forests; etc.), as shown below:

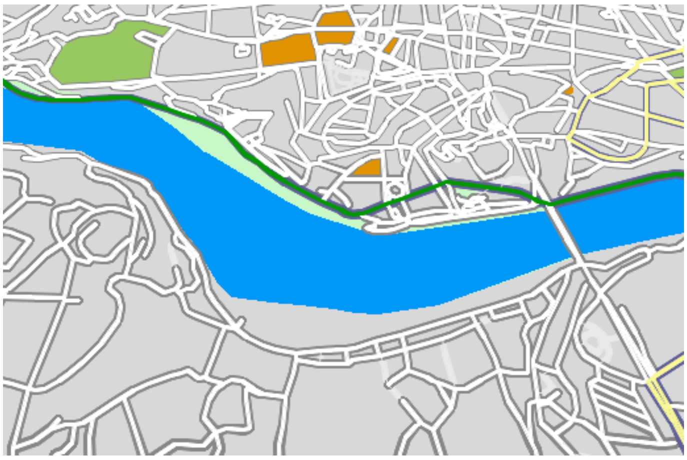


Figure 3.9: An example of a coloured vector map

The other two above-mentioned contributions provide a visually richer paradigm through the use of an Orthophotomap, i.e., instead of using solid colours to fill the polygons, they are filled with raster data from aerial and satellite imagery:

Figure 3.10: *Google Earth* displaying an Orthophotomap

Contrarily to the use of highly detailed 3D buildings, the increasing detail given by the orthophotographic material to represent map polygons and vectors has only been made possible and adopted in these past recent years. The following chart represents the classification of each contribution and shows a clear tendency towards the use of orthophoto rather than coloured maps:

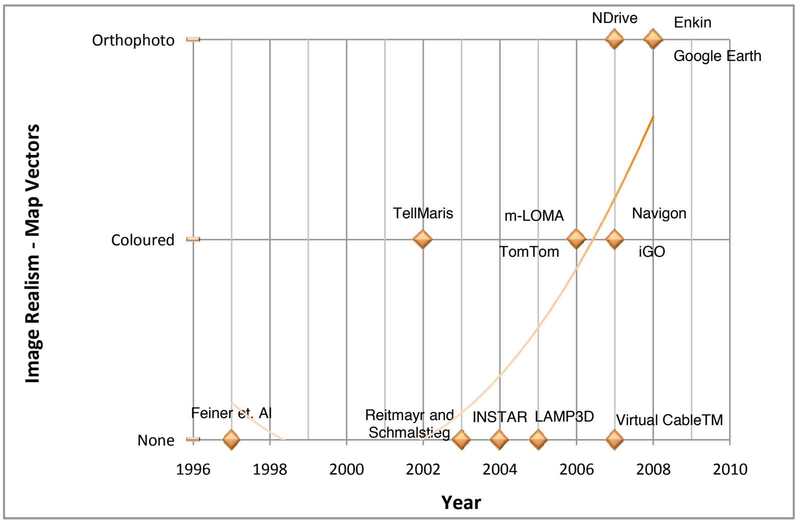


Figure 3.11: Classification of the state-of-the-art contributions in terms of representation of map vectors, according to the proposed evaluation framework

In terms of the Earth's surface model, most contributions use a flat model, thus no surface elevations are represented (i.e., mountains are flat, rivers are at the street level, etc.) as represented in the following example:

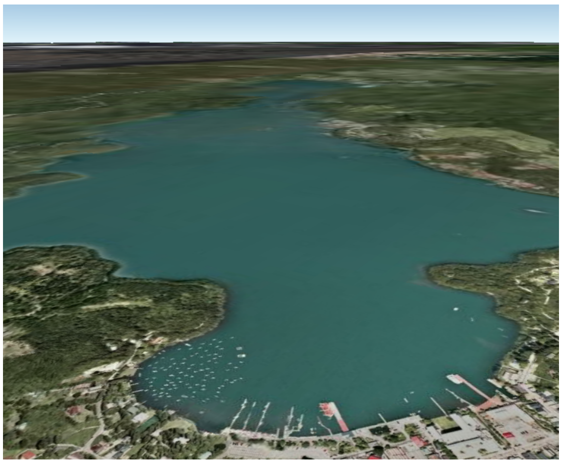


Figure 3.12: An example of a map's surface without elevations

iGO, *INSTAR*, *Enkin*, and *Google Earth* follow a different visualisation paradigm. Instead of a flat model, a DEM obtained from GIS databases is used, as represented below. Although all of them use a three-dimensional terrain model, the achieved level of detail is different from contribution to contribution, depending on the strategy that is used to paint the surface.

In *iGO*, contrarily to the buildings, the terrain model is not textured at all, i.e., a greenish colour with simple shading is applied to the DEM. A light-green colour is used for higher elevations, and a bit darker colour for lower altitudes, as shown in the following figure:

Figure 3.13: *iGO My Way 8* using a terrain model – obtained from [Nav N Go, 2007a]

Google Earth uses a DEM of the entire Earth's surface while overlaying the satellite and aerial imagery from the Orthophotomap onto it. In a similar way, these two features are achieved separately by *NDrive* and *iGO*, but *Google Earth* is capable of integrating them both. In practise, this means that it is possible to see the varying elevation of the Earth's surface – from rivers to mountains – with the photography "pasted" on top of that surface. The final result is similar to the following figure:

Figure 3.14: Terrain model using orthophotography as represented by *Google Earth*

Similarly, *Enkin* incorporates the DEM provided by the SRTM[1], and interoperates with the *Google Maps* API[2] to get the orthophotographs to texture map the terrain.

INSTAR does, in fact, use a three-dimensional terrain model not for the purpose of painting the ground but to accurately indicate the route – in a consistent manner with the reality – as explained in section 2.3.10.

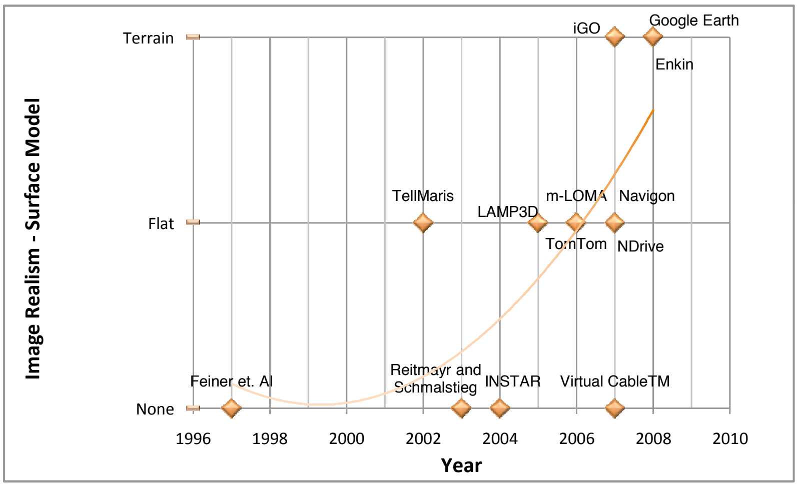


Figure 3.15: Classification of the state-of-the-art contributions in terms of map surface model according to the proposed evaluation framework

As we can see in the previous figure, there have been a few progressions in these past 3 years, towards the use of 3D surface models that represent Earth's surface elevations and other topographic features in way that it more accurately resembles reality.

Regarding additional visualisation elements or effects, one can say that several contributions depict the horizon / sky in different ways. For instance, in *iGO* and several other contributions, it is possible to observe a blue transparency effect where the map meets the limits of the perspective's far plane, simulating a horizon (see Figure 3.13). In *Navigon*, the typical blue transparency visual effect is replaced by a photorealistic image of the city/town the user is going to (see Figure 2.12). Both *TellMarisOnBoard* and *Google Earth* even provide the user the ability to see considerably good looking images of a 3D sky (see Figure 2.9). *Google Earth* takes one step ahead in the provided level of realism by representing and displaying the sun. When this mode is activated, it is possible to view the whole scene as if it was illuminated by the Sun itself, regarding the current time and location. None of the previous contributions take daylight into account. An example is shown in the following figure:

[1] Shuttle Radar Topography Mission
[2] Application Programming Interface

Figure 3.16: Sun as shown by *Google Earth*

As we could see, the *orientations* for this vector represent the visualisation elements that represent the real world visual information, as summarised in the following table:

Orientation	**Description**
3D Buildings	Indicates whether buildings and other 3D objects are shown or not.
Map Vectors	Indicates whether road vectors, polygon vectors, etc. are represented as part of the map.
Surface Model	Indicates whether the map's surface is represented or not.

Table 3.2: Proposed *orientations* for assessing *Image Realism*

Depending on the levels of *Image Realism* that are employed, the major map elements (*3D Buildings*, *Map Vectors*, and *Surface Model*) will be displayed in accordance with them. The following table captures the most important kinds of instances (*orientations* and *magnitudes* combined), according to what can be found in the state of the art:

Instance	**Description**
Coloured or Simple / Photo Textured Buildings	Indicates whether buildings and other 3D objects are just colour shaded; or whether their faces are textured using computer-generated or photographic imagery.
Coloured Map / Orthophotomap	Indicates whether the map is just coloured (with or without shading); or whether it combines aerial and satellite imagery.
Flat / Terrain Model	Indicates whether the map's surface model is just flat; or whether it is equivalent to a DEM.

Table 3.3: Instances of *Image Realism* vectors found in the state-of-the-art contributions

Provided the previous comparisons regarding the use of 3D buildings, representation of map vectors and surface models, one can argue that the clear state-of-the-art tendency is towards the use "realism" rather than "functionalism". With respect to the addition of "special" visual details (e.g., sky and sun modes) that many contributions are trying to propose, it is possible to observe an evident transition to an ever growing photorealistic approach, as shown in the following comparison chart:

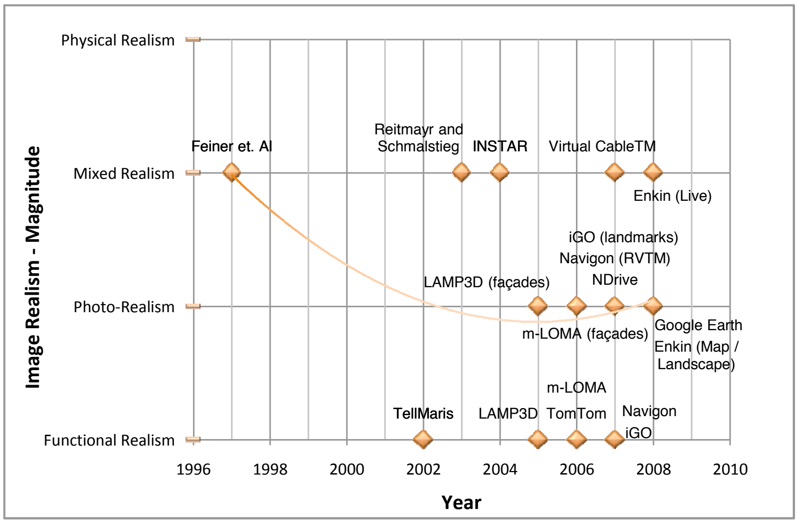


Figure 3.17: Classification of the state-of-the-art contributions in terms of *Image Realism* level according to the proposed evaluation framework

The only exceptions that struggle to take this movement a step higher are the contributions on *Augmented Reality* which rely on live imagery to represent reality in an almost visually imperceptibly genuine way. Of course there is a limitation intrinsic to every contribution that solely depends on AR which makes impossible for such solutions to be used in a wide range of application and tasks like exploring a map or getting an overview. Such tasks naturally require the visualisation paradigms to be applicable in an location-independent way, i.e., they must be capable of representing the 3D map, not only within a 50 meter radius from the current position (as often seen in live imagery captured by built-in cameras), but also away from the current place. For this reason, *Enkin* tries to ameliorate such limitation by bridging the gap between both reality and virtuality, using not only AR but also three-dimensional virtual maps that can be used away from the current location.

3.4 Object Labelling

Object Labelling encompasses the kind of visual techniques and strategies that are followed to label map elements such as rivers, bridges, streets, regions, cities, and so on.

There is an extensive collection of literature on this subject, so the approach that is going to be followed of classifying every paradigm will be unambiguous by means of using conventionally accepted terminology.

Some studies refer the importance of two types of labelling, namely *static labelling* and *dynamic labelling* [Been et al., 2006]. This is important to distinguish since, depending on the case, we might be dealing with dynamic maps, i.e., maps that support continuous zoom (changing the scale) and continuous panning (usually by dragging the map). The same work defines a new framework for both *Dynamic Selection* and *Dynamic Placement*, according to 4 *desiderata* summarised below:

D1 When a label is visible, it should not disappear and then re-appear under monotonic zooming;

D2 When a label is visible, its placement (position and size) should vary continuously under panning or zooming;

D3 Under panning, i.e., within a fixed scale, labels should not appear or disappear, except when they slide in or out of the view area;

D4 Selection and Placement depend solely on the current scale and view area, i.e., they do not depend on past events.

Dynamic labelling is further subdivided into *dynamic selection* and *dynamic placement*. If the map is to support *dynamic selection* then it must be able to decide which labels will be selected for every zoom level. On the other hand, if the map is to support *dynamic placement*, then it must be able to decide the size, position and orientation for a given scale. This must be done in a continuous way, so no popping of labels or other artefacts cause confusion. These two operations can be modelled as a cone, depicted in the following picture:

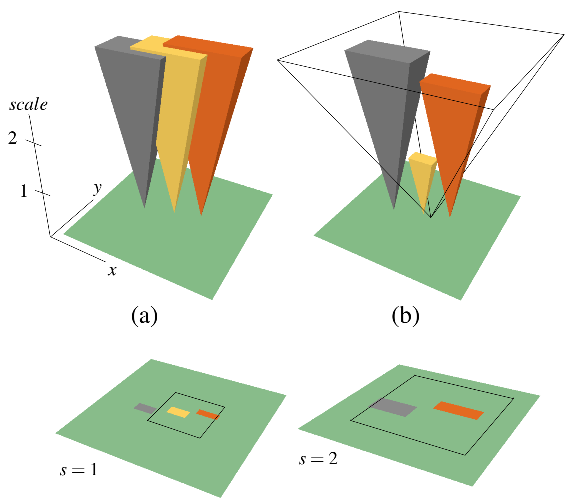


Figure 3.18: A map with (a) / without (b) overlapping problems – adapted from [Been et al., 2006]

A cone's depth can be thought as the range of scales within which the associated label will be visible on screen. The area of the cone's base at a certain scale will define the view area on screen (as shown in outline).

The proposed *magnitudes* for *Object Labelling* will then be a combination of *Static/Dynamic* in terms of *Selection/Placement* of labels, as summarised below:

Magnitude	**Description**
Static Selection	When the selection of labels that should be set visible is performed irrespectively of the current map state (both zoom level and view area definitions).
Static Placement	When the size, position and orientation of visible labels are set irrespectively of the current map state.
Dynamic Selection	When the selection of labels that should be set visible is performed in a continuous way, taking into account the current map state.
Dynamic Placement	When the size, position and orientation of visible labels are set in a continuous way, taking into account the current map state.

Table 3.4: Proposed *magnitudes* for assessing *Object Labelling*

In *TomTom* and several other contributions, the labels that lie in the limits of the screen's view area often pop in or out, which is symptomatic of *static placement*. Nevertheless, the selection of labels that should appear at a given zoom level is performed in a continuous way, thus *dynamic selection* is achieved. As a matter of fact, *dynamic selection* is also a common feature to all contributions that perform labelling.

As opposed to the rest of the contributions, *Google Earth* features both *dynamic selection* and *dynamic placement* of labels, i.e., labels do not suddenly pop in or out near the view's boundaries, and there is a clear definition of the range of scales for which each type of label should appear.

One of the possible approaches when labelling objects is to project the labels oriented towards the current perspective, analogous to a billboard in Computer Graphics. This approach is followed by the all contributions except *Google Earth*. In *Google Earth*, the labels are flattened and laid down on the map's surface, as demonstrated in the following figure:

Figure 3.19: *Google Earth* projects labels laid down on the map's surface

Based on the works of [Wolff, 1999; van Dijk et al., 1999] and the previous discussion on adaptiveness to the current perspective, the proposed *orientations* for this vector are:

Orientation	**Description**
Perspective-Adaptive	When labelling is perspective-adaptive, i.e., when labels are oriented towards the current perspective (see Figure 3.19 for a counterexample).
Point Positioning	Labelling of point symbols or other symbols.
Line Positioning	Labelling of polygonal chains, such as rivers.
Area Positioning	Labelling of areal features such as regions or countries.
General Positioning	Labelling as a combination of the three above-mentioned methods (see Figure 3.20).

Table 3.5: Proposed *orientations* for assessing *Object Labelling*

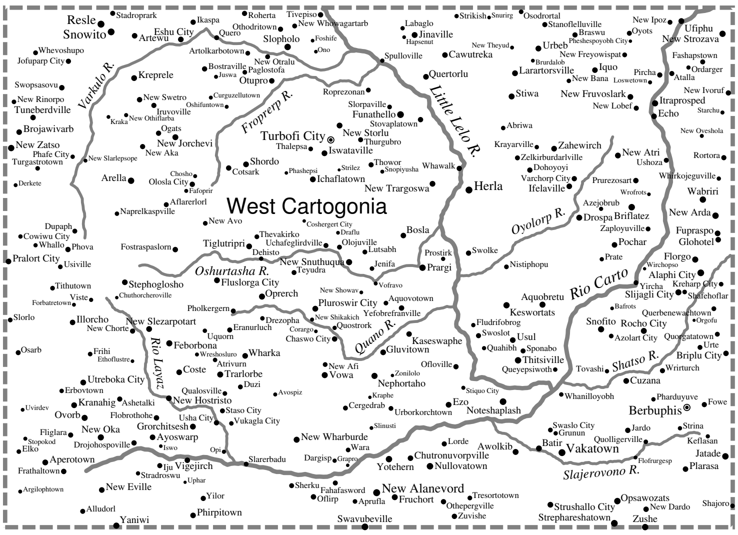


Figure 3.20: An example of *General Positioning* – adapted from [Edmondson et al., 1997]

The classification of contributions in terms of perspective-adaptive labelling clearly shows that most state-of-the-art applications support this feature, but that recent contributions such as *Google Earth* may become one of the leaders of an opposite strategy:

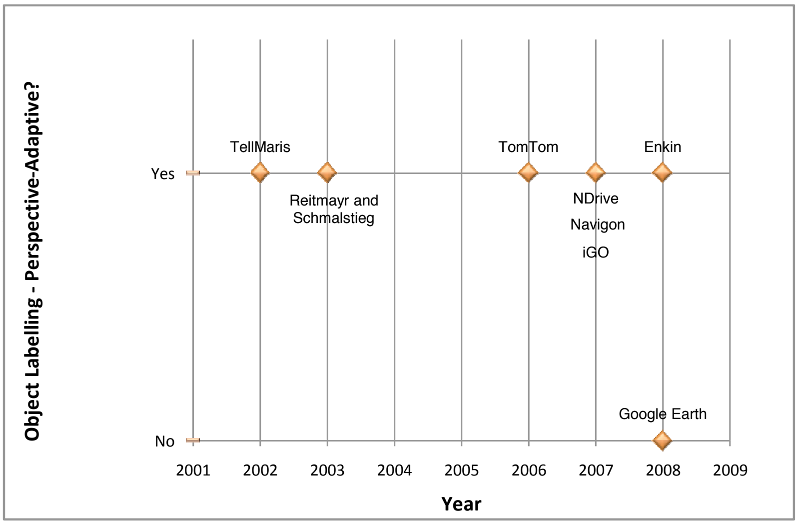


Figure 3.21: Classification of the state-of-the-art contributions in terms of perspective-adaptive *Object Labelling* according to the proposed evaluation framework

All these *orientations* can be observed in the set of the previously mentioned contributions. However, some contributions do not perform labelling at all, or apply different strategies than the above-stated definitions. For instance, in the case of *m-LOMA* it is not possible to say that it supports street labelling in the 3D map, according to the proposed *orientations* for this vector. In fact, after a user "picks" a street in an auxiliary 2D map, the closest-matching address is drawn at the top of the screen of the 3D map [Oulasvirta et al., 2007]. Contrarily, in all contributions where labelling is performed with the exception of *Enkin* and the prototype proposed by [Reitmayr and Schmalstieg, 2003], the *General Positioning* approach is chosen. These other two contributions only provide *Point Positioning*, by allowing the creation of *placemarks* that refer to specific positions in the real world like in *Google Earth* or *Google Maps*. *Enkin* displays such placemarks as balloon-like boxes with a caption projected in the 3D virtual world (see Figures 2.25, 2.26, and 2.27). On the other hand, the prototype proposed by [Reitmayr and Schmalstieg, 2003] is capable of displaying the label associated with each way point that makes up the route (see Figure 2.21a).

In the following comparison chart, it is possible to see that there is a natural tendency with regards to *Object Labelling* strategies towards the application of *General Positioning* algorithms, provided that applications have evolved from simple city guides to general purpose mobile maps:

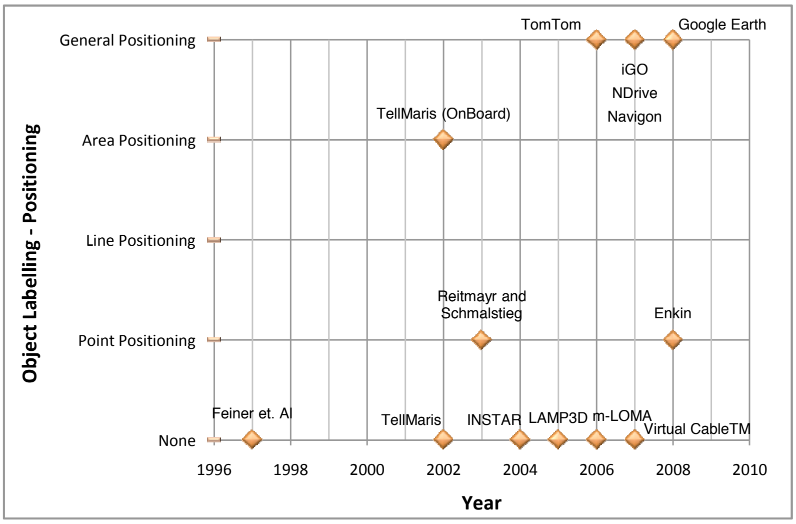


Figure 3.22: Classification of the state-of-the-art contributions in terms of *Object Labelling* positioning according to the proposed evaluation framework

3.5 Visual-Spatial Abstraction

This *feature vector* measures the complexity of mental operations that are required to perform the visual matching of the real environment that can be observed and the one on the screen. This vector and *Image Realism* are highly correlated, in the sense that a higher realism easily allows the user to immediately find a match between the reality and the representation on the screen, but it all depends on how that "translation" to the screen is done. This feature will be specifically focused on the mental viewing/camera transformation that is required in order to have a perfect correspondence between both images: the reality's and the screen's.

In the case of *TellMaris*, three camera modes are supported, namely *walking*, *flying* and *top* views as seen in the following picture:

Figure 3.23: Viewing perspectives supported by *TellMarisGuide* – adapted from [Laakso, 2002]

Similarly in *m-LOMA*, three kinds of views are supported: *street level*, *bird view* and *top-down view*. As demonstrated below, the last two perspectives roughly correspond to *TellMaris*' *flying* and *top view* modes, and are used for getting an overview of the surroundings and planning an itinerary:

Figure 3.24: Viewing perspectives supported by *m-LOMA* – adapted from [Oulasvirta et al., 2007]

The proposed *orientations* for this vector are given, regardless of the elevation angle of the "camera":

Orientation	**Description**
Ground Level	When the altitude of the camera is at the ground level, i.e., it is only possible to observe the current street and eventually it's junctions.
Local-Area Level	When the altitude of the camera is at the "street" level, i.e., it is possible to observe multiple streets that may not even be part of the route.
Wide-Area Level	When the altitude of the camera is at a wide level, i.e., it is possible to observe multiple municipalities and consequently an overview of the route.

Table 3.6: Proposed *orientations* for assessing *Visual-Spatial Abstraction*

Generally speaking, all the chosen contributions support the three previously identified camera levels, with the exception of the ones that are solely based on *Augmented Reality*. The later contributions cannot possibly follow a different *orientation* than *Ground Level*, since the cameras that are used to capture live imagery of the surrounding environment are moving with the users at a very low altitude. Despite being based on *Augmented Reality*, *Enkin* implements the three camera levels in its three modes of operation (see Section 2.3.12 for more details), as shown in the following comparison chart:

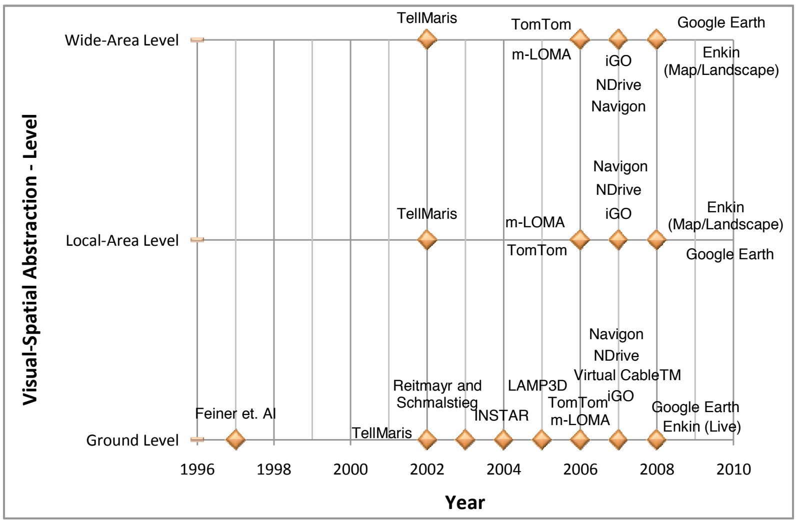


Figure 3.25: Classification of the state-of-the-art contributions in terms of camera altitude levels, according to the proposed evaluation framework

Regarding the adaptiveness of the viewing perspective to the user's current behaviour, there are several possible approaches that can be followed. For instance, *NDrive* and many other navigation systems have a feature called *auto-zoom* which makes the camera altitude adapt continuously to the current speed, i.e., if the user is driving slow, the camera continuously lowers to the street level; if the user is driving fast, it goes up to a wide-area level. Another possibility is adaptiveness to the user's looking direction such as the provided by *Enkin* (see Figures 2.27 and 3.26) and the prototypes proposed by [Feiner et al., 1997] (see Figures 2.19 and 2.20), and [Reitmayr and Schmalstieg, 2003] (see Figure 2.21). In the case of *Enkin*, such adaptiveness is possible with the help of a 3D accelerometer and a digital compass [Spring and Braun, 2008], which is crucial for an accurate matching of both *Live* mode's imagery and the current viewing orientation in the real environment.

Figure 3.26: *Enkin* indicates orientation with an arrow – adapted from [Spring and Braun, 2008]

As seen in the previous figure, *Enkin* displays a circle that acts like a radar showing nearby placemarks and the user's current direction, which may significantly help the user during *Locator* and *Proximity* tasks.

The proposed *magnitudes* that will help define the adaptiveness of the camera to the properties of the user tasks are summarised below:

Magnitude	**Description**
Adaptive Level	When the camera adapts to user's movement, according to some reasoning (like speed).
Adaptive Orientation	When the camera adapts to user's looking direction.

Table 3.7: Proposed *magnitudes* for assessing *Visual-Spatial Abstraction*

As we could see, in these past few years there has been a steady progression towards the use of orientation-adaptive solutions, specially in the field of AR. At the same time, several contributions are already providing support for an adaptive-level behaviour, usually by means of adapting to the user's current movement speed. The overall results are shown in the following comparison chart:

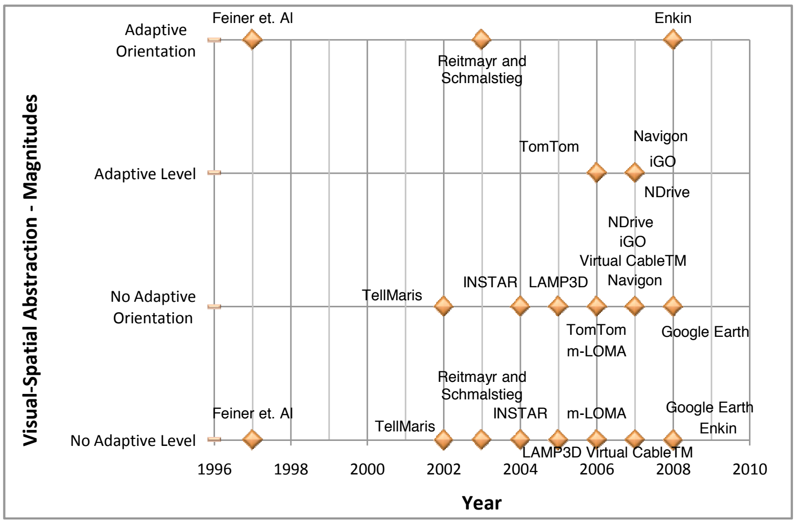


Figure 3.27: Classification of the state-of-the-art contributions in terms of *Visual-Spatial Abstraction* adaptiveness levels, according to the proposed evaluation framework

3.6 Route Indication

This *feature vector* provides a classification of the visual techniques and strategies for showing the itinerary path in the road maps, and the kind of manoeuvre indicators or way points that are presented in the display.

In *TellMaris* the route indicators that are presented on the display depend on the application. Although *TellMarisGuide* displays an *arrow* indicator in front of the user (see Figure 3.23), this is not equivalent to a manoeuvre (i.e., it is not analogous to a “turn left”, “go straight”, etc. instruction). Instead, it represents the linear direction to the target destination, and because of this, some users complained [Laakso, 2002]. On the other hand, *TellMarisOnBoard* – alongside with the prototype proposed by [Reitmayr and Schmalstieg, 2003] (see Figure 2.21a) – use *way points* and *cord* lines to present the route, together with the names of cities, and icons representative of ports in the Baltic Sea region (see Figure 2.9).

Most automotive navigation systems provide a common approach to present the route by covering it with a carpet-like shape. Such paradigm is followed by *INSTAR* which takes the DEM of the terrain into account to display the route with the same elevation as the current street (see Figure 2.22). One can argue that specially in the case of traditional navigation systems, where 2.5D vector maps are rendered, there is not much difference between painting a road vector or the route, i.e., the only parameter that changes is the colour which is used to fill the road vectors that make up the route.

Virtual Cable™ provides a different paradigm by representing the route with *cord* lines suspended over it, and projecting them through a HUD (see Figure 2.24).

Google Earth mixes both *way points* (as placemarks) to indicate major manoeuvre points, and a coloured carpet-like route, as shown below:

Figure 3.28: *Google Earth* displaying manoeuvre indications as placemarks along the route

The possible route indicators, which are the proposed *orientations* for this vector, can be regarded as the approaches that are generally followed by the majority of the contributions:

Orientation	Description
Arrows	When arrow-like shapes are used to denote “go straight”, “turn left”, “turn right”, etc. instructions.
Cords	When cord-like objects are used to indicate the route.
Way Points	When way points are used to indicate the points that make up the route – often used with *Cords*.
Carpet	When a carpet-like shape is used to cover up the streets indicating the route.

Table 3.8: Proposed *orientations* for assessing *Route Indication*

As we can observe from the selected state-of-the-art contributions, in the past years, the range of possibilities to visually indicate the route has not changed much. In the following chart, the classification of each contribution, according to the use of visual indicators to represent the route is shown:

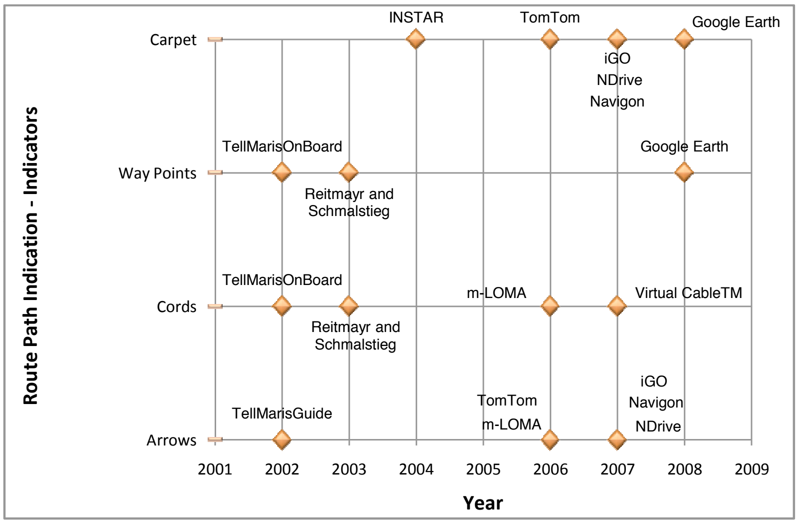


Figure 3.29: Classification of the state-of-the-art contributions in terms of route indicators, according to the proposed evaluation framework

When looking at the comparison chart above, one can argue that there is no clear definition of what visual indicators are the most appropriate to represent the route in a *Navigation Task*, given the sparse distribution of points.

In *m-LOMA* and most automotive navigation systems, the world is augmented with flags (or equivalent) in the start and destination points. This makes it easier for the user to discern the route during *navigation tasks* usually when acquiring a route overview (see Figure 3.24).

The indicators used by each contribution can be used with different “immersion” levels which are considered the proposed *magnitudes* for this vector:

Magnitude	Description
Instructive	When the indicators are merely instructive.
Simulative	When the indicators are used in a somewhat immersive way such that they simulate or resemble real world indicators.

Table 3.9: Proposed *magnitudes* for assessing *Route Indication*

One example of a *simulative* approach is the one provided by *Navigon* which presents real world-like signposts using photorealistic imagery along with more abstract arrow indications (see Figure 2.12). All other contributions follow a more *instructive* approach by generally combining two of the above-mentioned indicators. The following chart givens an overview of the classification of the state-of-the-art contributions, according to these two immersion levels:

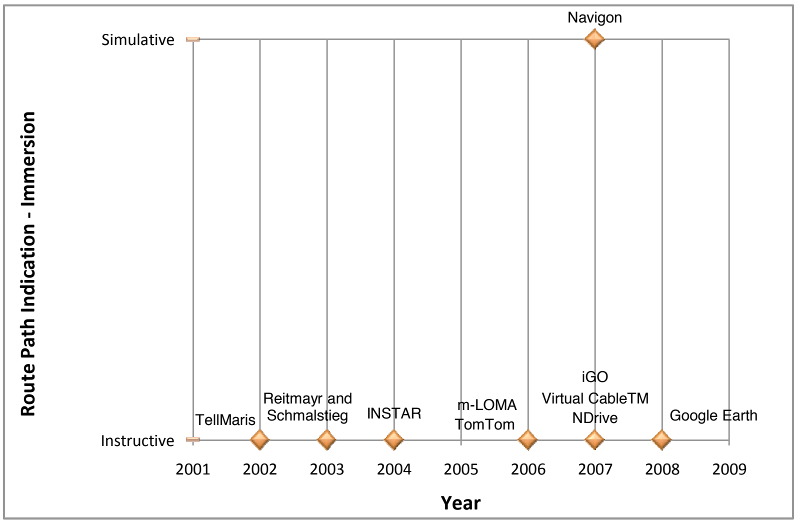


Figure 3.30: Classification of the state-of-the-art contributions in terms of *Route Indication* immersion levels, according to the proposed evaluation framework

As seen in the previous chart, the progression towards the use of simulative indications is not as fast paced as in the previous comparison charts, due to the great disproportion between the number of solutions that follow a simulative approach and the number of solutions that follow an instructive approach.

3.7 Landmark Symbology

Landmark Symbology evaluates the cartographic symbology that is used to portray the world using a pictorial language, represented by "map symbols", often accompanied by a legend in the paper maps. This vector is also related to *Image Realism*, in the way that both should be complementary, i.e., excessive realism may distract the users, but a great lack of symbology may completely blur their sense of orientation.

[Elias et al., 2005] proposed new concepts and design guidelines for the cartographic visualisation of landmarks in mobile maps. The study considers four categories of building landmarks: shops referenced by name; shops referenced by type, buildings referenced by their unique name / function, and finally, by their unique visual properties. Based on these concepts, the *orientations* for this vector will reflect the kind of buildings represented by symbols, as follows:

Orientation	**Description**
Shops (referenced by name)	Well-known shops and restaurants often referenced by their trade name (e.g., KFC, McDonalds, etc.).
Shops (referenced by type)	Shops referenced by their general type of function (e.g., hotel, pharmacy, etc.).
Buildings (with unique name / function)	Buildings referenced by their unique name (e.g., Tokyo Tower, Statue of Liberty, etc.); general function (e.g., library, church, etc.); or a combination of both name and function.
Buildings (with unique visual properties)	Buildings referenced by their unique visual properties, although not considered "historical" landmarks (e.g., "the large yellow house", etc.).

Table 3.10: Proposed *orientations* for assessing *Landmark Symbology*

In order to convey the information in the best possible format, a range of abstraction levels for designing landmarks is required, as proposed in [*op.cit*.]:

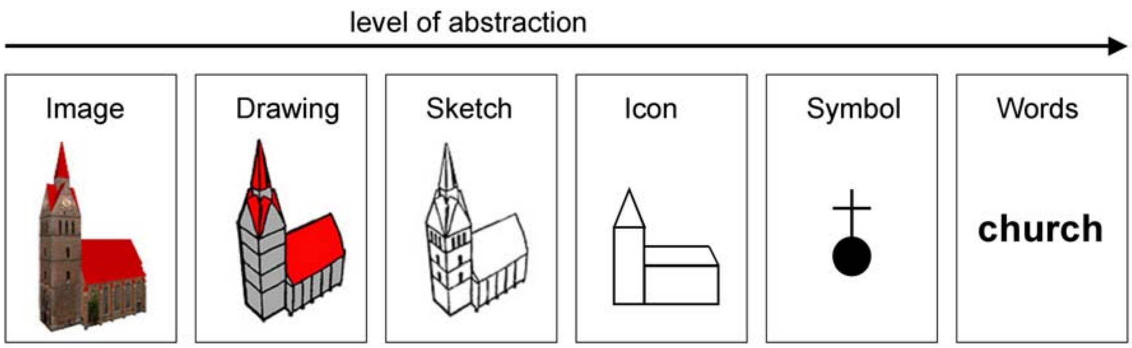


Figure 3.31: Levels of abstraction for landmark design – adapted from [Elias et al., 2005]

According to the proposed range, the most abstract representation of a landmark (i.e., a textual description) is always possible to overlay onto a more realistic representation such as a sketch, so this level must be regarded as an "extra" instead of a sole representation of a landmark. Not exactly just an "extra", because adding it will come with a cost: the additional time it takes the user to process such information [*op.cit*.].

For the first group of building landmarks (i.e., trade chains and other well-known shops) where the trademark logo is famous and considered easy to recognise, an icon representation of such logo is well suited to convey the landmark information [*op.cit*.]. Generally speaking, when the building is somewhat unique, a realistic image representation is often preferred together with its name; otherwise it's function is better represented by an intermediate representation such as a sketch along with its function overlaid onto it [*op.cit*.]. Examples of this are shown below:

Figure 3.32: Example of an image/drawing for a church and icon for a known restaurant – adapted from [Elias et al., 2005]

Based on the previous study, the first proposed *magnitude* for this vector will define in itself, the concept of levels of abstractions for landmarks, according to a scale (from the most abstract, to the least abstract). These concepts are summarised below:

Abstractness Magnitude	**Description**
Image	A representation of a landmark in a nearly (or higher) photorealistic image level.
Drawing	A representation of a landmark as a drawing.
Sketch	A representation of a landmark at the sketch level.
Icon	A representation of a landmark as an icon.
Sign	A representation of a landmark using an abstract map sign.
Words	A representation of a landmark using words.

Table 3.11: Proposed *magnitude* levels of *Abstractness* for assessing *Landmark Symbology*

In the following comparison chart, the chosen state-of-the-art contributions were classified according to the kind of symbology applied in the visualisation paradigm. The totality of the selected contributions only uses three different kinds of symbols: *sign*, *icon*, and *image*. Since the chart does not capture combinations of different levels in an evident manner, the presented trend line may mislead the reader into thinking the tendency is not towards the use of *image*-like landmarks. On the contrary, while some contributions rely on *image*-like landmarks only, most of them prefer a combination of both abstract symbology such as *sign* and *icon* representations with *image*-like landmarks, rather than a unique kind of symbol.

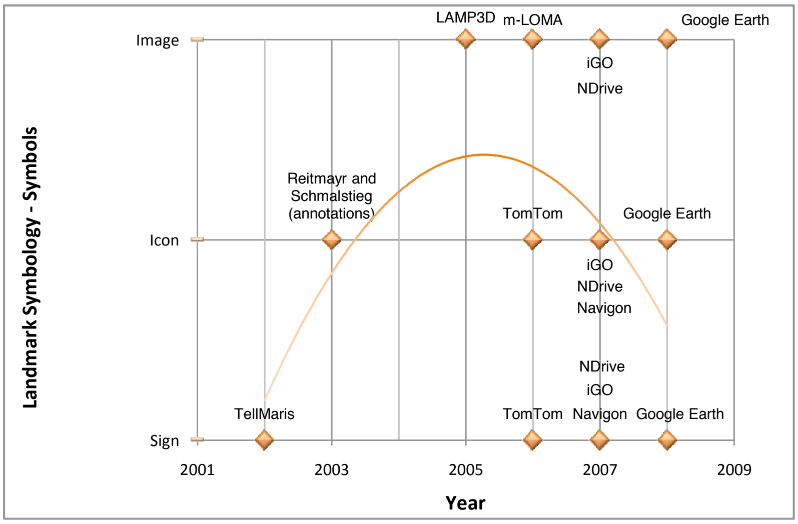


Figure 3.33: Classification of the state-of-the-art contributions in terms of *Landmark Symbology* abstractness levels, according to the proposed evaluation framework

For instance, *m-LOMA* provides location-based information by showing POIs such as city trams and historical landmarks, by means of *icons* and photorealistic *images*, as depicted in the following figure:

Figure 3.34: *m-LOMA* providing information on means of transportation – obtained from [Nurminen, 2006]

In general, several contributions follow the same approach as *m-LOMA*, through the use of photorealistic 3D full-textured landmarks. While most contributions support the visualisation of landmarks through *icon* representations, very few use words and even more rarely *drawing*, *sketch*, and *sign* representations.

There are other parameters that influence the decision of whether an abstraction level should be used in a mobile map for a given situation. For instance, some cartographic generalisation procedures (like scaling down a landmark object to an appropriate size suited for its representation in a map) might raise some problems such as [*op.cit.*]:

Congestion – When too many features are present in limited space.

Coalescence – When the visible details depend on the resolution of the output device.

Imperceptibility – When features are imperceptible below a minimal portrayal size.

The severity of the above-mentioned issues brings forward the need of more abstract rather than more realistic landmark representations. This becomes particularly important when dealing with mobile devices and maps which are hardware-limited to small and low-colour-depth displays; and are subject to limiting environment conditions such as direct sunlight.

These problems can be easily observed in *Google Earth*, when panning an area of the map – within a fixed zoom level – containing lots of signs and icons of landmarks. There is no pruning or simplification involved so the whole view area gets filled with a great amount of iconic information. Not accounting for the overlapping of icons, it is possible to observe this behaviour in the following figure:

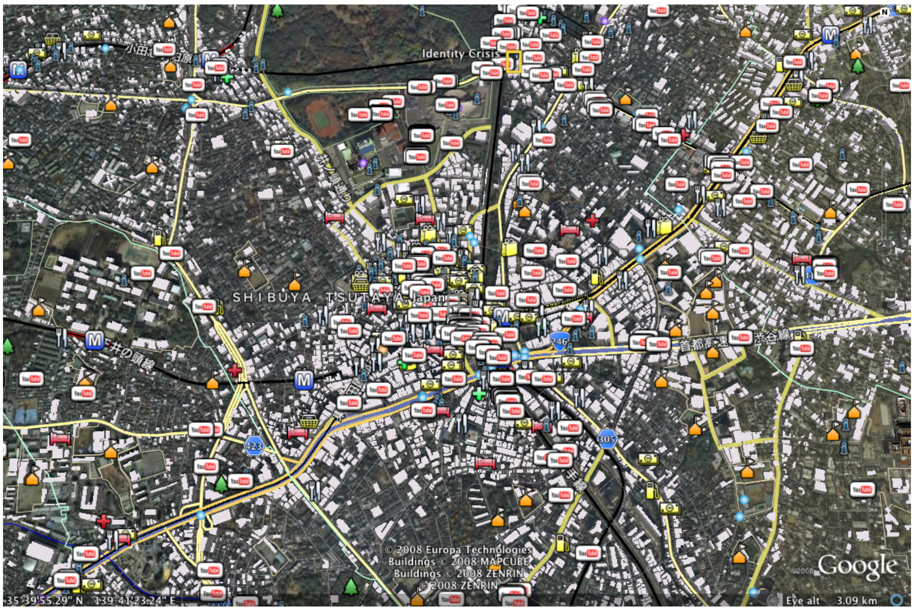


Figure 3.35: A huge amount of iconic information shown by *Google Earth*

To account for these restrictions, the proposed *magnitudes* for this vector reflect the adaptability of the visualisation paradigm to the current zoom level and/or current global complexity of landmark features, and include the concept of level of abstractness, as summarised below:

Magnitude	**Description**
Abstractness	The level of abstraction that is used to represent landmarks.
Adaptive Zoom	When the abstraction level of landmarks adapts to the current map zoom level.
Adaptive Complexity	When the abstraction level of landmarks changes with the varying global complexity of features.

Table 3.12: Proposed *magnitudes* for assessing *Landmark Symbology*

Despite the lack of adaptability to iconic complexity, *Google Earth* supports *Adaptive Zoom*, i.e., depending on the current zoom level, certain symbols may transform into more or less abstract equivalent representations but mainly within the *icon* domain (e.g., light blue dots representing *Geographic Web* information may turn into *Panoramio* icons when zooming in). Nevertheless, when zooming out at a great distance, 3D building landmarks completely disappear, and only iconic representations remain. This should not be confused with *Adaptive Zoom*, because, in this case, both representations are simultaneously displayed at a closer distance, thus no changing of abstraction level takes place.

Both in *NDrive* and *Google Earth*, which support *icon* and *image* representations, there is no adaptive behaviour to decide which abstraction level is best suited for landmarks given the current zoom level. This is to say that a landmark is simultaneously presented in two ways: as an icon and as a photo textured 3D building.

In the case of *iGO* it cannot be said that it supports *Adaptive Complexity*. Instead, it is capable of managing the system load (due to the limited resources of mobile devices) by rendering the landmarks only when possible. The loading process is done in an asynchronous way, and you can watch the buildings being texture mapped "on-the-fly", i.e., the geometry is first rendered on the screen and overlaid with a translucent colour, while the texture is not fully loaded onto memory. This should not be confused with adaptability to global complexity of features as described above.

The following comparison chart summarises the classification of each contribution according to the adaptiveness levels of the visualisation paradigm in terms of *Landmark Symbology*:

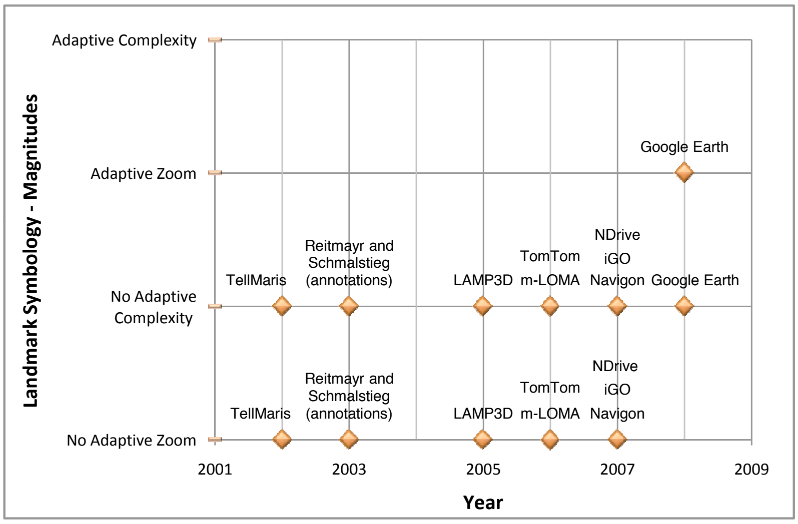


Figure 3.36: Classification of the state-of-the-art contributions in terms of *Landmark Symbology* adaptiveness, according to the proposed evaluation framework

3.8 Contextual Awareness

Contextual Awareness measures the extent or degree to which the visualisation paradigm is applied to get additional information on a contextual or situational basis.

"Context" itself cannot be easily defined using a standard dictionary or encyclopaedia. In the field of *Context-Aware Computing*, it can be roughly defined as the totality of external variables that may condition or influence the application's decision making process. For instance, "context" can be seen as the user's current position in an exploratory navigation experience; as the physical environment's current lighting conditions to automatically adjust the keyboard or display brightness levels; or even the current time to decide which is the most appropriate meal for a given time. In the context of location-based mobile services, there is minimum awareness level intrinsic to each and every contribution, which is, of course, the location context, i.e., there is a tracking of the user's current position, usually without the need of the user's intervention.

The problem often arises when the mobile map is being used for getting context-based information to answer questions like "And now what?". These questions occur frequently in *Event Tasks*, but can be applied to all the others (Section 2.2). For instance, the user may be walking with a pedestrian map and feel the sense of being "lost". In that case, he may activate *Proximity Tasks* to ask "Where am I?". After knowing the exact location where he is, he may ask further questions such as "What about this place?" – to get a historical overview of the place where he is. Even during *Navigation Tasks* the user could be interesting on watching a more scenic route.

It is important to distinguish the three groups of application areas in which virtual urban environments can be valuable, according to the spatio-temporal nature. These groups constitute the proposed *orientations* for this vector, depending on whether they focus on the past, present or fiction, in harmony with the following definitions [Coelho, 2006]:

Orientation	**Description**
Reconstructional	Focus on reconstructing urban environments that were totally or partially lost in the past (See Figure 3.37).
Recreational	Includes areas such as urban design, and urban planning and usually consists on the simulation or evaluation of the impact of urban projects on the present environment.
Fictional	Related to the creation of imaginary realities that interact with the urban environment.

Table 3.13: Proposed *orientations* for assessing *Contextual Awareness*

Figure 3.37: Reconstructing places that no longer exist – adapted from [Coelho, 2006]

The levels of awareness to the current location, time, and situation can vary from contribution to contribution. For instance, in *LAMP3D*, after a user taps an object in PDA's screen, a scrolling list with information regarding the tapped object is presented on top of the application's window, as demonstrated below:

Figure 3.38: User tapping an object in *LAMP3D* – adapted from [Burigat and Chittaro, 2005]

In [Burigat and Chittaro, 2005], it is claimed that a passive contextual-awareness approach is generally more flexible than an active approach. In the latter case, if the user is constantly presented with unwanted information it can become "too obtrusive".

Contrarily, in most automotive navigation systems, direction instructions or location-based information such as nearby POIs are automatically presented, i.e., without the need of the user's intervention.

For instance, in [Narzt et al., 2004], some examples of contextual awareness are also proposed such as displaying information on the nearest gas station when the car needs refuelling, or when a user is facing a building to get location-bound information, as demonstrated below:

Figure 3.39: Improvements to *INSTAR* – adapted from [Narzt et al., 2004]

The second example is somewhat similar to the one proposed by [Feiner et al., 1997], where a user can automatically get information related to the department/building the user is facing to from a campus information system (see Figures 2.19, and 2.20).

Obviously, every application should leverage the awareness levels appropriately, depending on whether the information is considered relevant for the current context, while avoiding and minimising the risk of becoming obtrusive. For these reasons, the proposed *magnitudes* for this vector will reflect the different autonomy levels of "contextual awareness" an application can demonstrate in different contexts and tasks, as previously denoted by [Chen and Kotz, 2000]:

Magnitude	**Description**
Active Awareness	When the visualisation paradigm is applied by adapting to the detected context, without the need of user intervention.
Passive Awareness	When the visualisation paradigm is applied in a passive way, i.e., only when the user shows interest for getting context-based information.

Table 3.14: Proposed *magnitudes* for assessing *Contextual Awareness*

3.9 Summary

In this chapter, a novel generic evaluation framework consisting of *feature vectors* was proposed, allowing the evaluation of new or existing visualisation paradigms regarding map-based mobile services. The following table summarises the evaluation framework, according to the proposed *magnitudes* and *orientations*:

Feature Vector	**Orientations**	**Magnitudes**
Image Realism	3D Buildings, Map Vectors, Surface Model	Physical Realism, Mixed Realism, Photo-Realism, Functional Realism
Object Labelling	Perspective-Adaptive, Point Positioning, Line Positioning, Area Positioning, General Positioning	Static Selection / Dynamic Selection and Static Placement / Dynamic Placement
Visual-Spatial Abstraction	Ground Level, Local-Area Level, Wide-Area Level	Adaptive Level, Adaptive Orientation
Route Indication	Arrows, Cords, Way points, Carpet	Instructive, Simulative
Landmark Symbology	Shops (referenced by name), Shops (referenced by type), Buildings (with unique name / function), Buildings (with unique visual properties)	Abstractness (Words, Sign, Icon, Sketch, Drawing, Image), Adaptive Zoom, Adaptive Complexity
Contextual Awareness	Reconstructional, Recreational, Fictional	Active Awareness, Passive Awareness

Table 3.15: Structure of the proposed evaluation framework

As we could see, at the time of the first studies and experiments of context-aware mobile services, the Augmented Reality seemed to be the "most logical" and intuitive approach to follow for exploring urban environments, since the highest degree of realism could but naturally achieved, but the proposed solutions turned out to be somewhat unsuccessful. In the following years, commercial automotive navigation systems came out with 2.5D and 3D digital maps with fully textured buildings and terrain, orthophotomaps, and even DEMs of entire cities and countries.

Taking into account the current physical limitations and technological barriers of systems solely based on Augmented Reality, it is safe to argue that such kind of paradigm is forcefully limited to just in-car and/or pedestrian navigation tasks, as they can only provide visual information that is within the range of the captured live imagery. This is to say that, even if an AR approach is proved to be the most intuitive and the best choice for navigation tasks, users will not be able to explore a map, to plan an itinerary nor to get map overview with this kind of approach alone. *Enkin*, the most recent contribution on this matter, tries to ameliorate this issue by proposing a new navigation concept which is not solely based in Augmented Reality, but also in 3D computer-generated imagery.

Nevertheless, this study on the state of the art clearly indicates that there has been a significant progression, in these past recent years, towards a growing use of photorealistic imagery, and that most contributions are preferring "realistic" rather than "functionalist" approaches. This tendency is accelerating in an exponential way, and it is expected that in the following years there won't be much space left for more abstract visualisation paradigms.

In terms of *Object Labelling*, one can say that there is no consensus on the visual techniques that are best suited to display the names of cities, rivers, landmarks, and so on. Instead, there is a wide variety of methods being constantly proposed clearly showing a lack of orientation and care for label readability, visibility and aesthetic issues. In many visualisation paradigms, mainly provided by the available products, the "quantity" factor seems far more important than the "quality" factor with regards to object labelling, i.e., it is considered better to have a map where everything is labelled, no matter how good or bad, than to make sure that the labels are practically useful and regarded as an advantage rather than "more content', which is partially motivated by commercial affairs.

With respect to *Route Indication* techniques, the same issues exist. For instance, in the automotive navigation systems industry, most products follow a similar approach, but few or none are able to justify why it is better to use a given visual indicator rather than another, "because the other companies all do it that way".

Similarly, most visualisation paradigms implement all camera altitude levels but there is a great lack of support for an adaptive behaviour. Some solutions that emerged are proposing an adaptive camera altitude level, depending on context variables such as the user's current speed, although there are no significant progressions on this subject.

In terms of *Landmark Symbology*, the majority of approaches generally fall within 2 or 3 choices, ranging from very abstract to very realistic. Few solutions rely on intermediary *sketch* and *drawing* representations or even resort to *words* for symbolising landmarks.

Regarding *Contextual-Awareness*, some studies like [Narzt et al., 2004] and [Feiner et al., 1997] are already providing some hints for future visualisation paradigms. Examples include pedestrian users walking on a street, facing a regular store or building with a device on their hand pointed at it, in order to get information relating to that building / store. Systems like these already exist but they are rather small context-based mobile prototypes, and do not usually integrate with complex maps or tasks.

Chapter 4

Evaluation of *Feature Vectors*

In the previous chapter, a novel generic evaluation framework capable of evaluating different visualisation paradigms was described. *Feature vectors* are proposed as a standard tool for specifying, developing, assessing and comparing new or existing solutions. For that reason, they were applied individually to the selected state-of-the-art contributions, in order to understand the current trends regarding the application of visualisation paradigms.

Nowadays, there is a great offer of free and commercial products each featuring a wide range of visualisation techniques and paradigms. Motivated by commercial, marketing, and political considerations, in most commercial products, such paradigms are often "labelled" as being "the best" in search for a differentiating factor from the competition.

This chapter gives an insight of the real significance of some *feature vectors*, by means of evaluating them individually with the help of an interactive questionnaire, and understanding whether a given orientation / magnitude component is beneficial or not when users are performing various tasks with mobile 3D maps. The proposed questionnaire is not meant to be exhaustive, and will only evaluate the *feature vector* components for which there are no (or few) scientific indications, given by the state of the art, in terms of the most appropriate visualisation paradigms that should be followed.

4.1 Methodology

In order to perform an evaluation on the impact of each *feature vector* component (previously referred to as *orientation* and *magnitude*), a test experiment / questionnaire was conducted with test subjects (check Appendix A.1 for the questionnaire's full list of web pages). Broadly speaking, the impact is measured by means of evaluating the answer correctness and time taken to do the matching between the real environment and the images presented on a mobile device, and to perform frequent tasks such as reading the names of streets, and so on.

Since the typically available free online questionnaires are generally limited to allow users to set their preferences, an interactive online questionnaire was developed specifically for this study, enabling the measuring of time for each answer and a more adequate visual aspect definition.

4.1.1 Overview

The proposed questionnaire can be divided into three parts:

1. The first one is composed of several exercises each of which containing exactly 2 questions. Each exercise focus on a different *feature vector*, and each question measures the impact of the presence or absence of a sole component. There are 10 questions in total, each having 4 possible answers (only one is considered correct).

2. In the second part of the questionnaire, there are no "right or wrong" answers. Instead, this part is specifically used to evaluate how well users perform a given set of tasks for which maps are often used for.

3. In the last part of the questionnaire, the users are asked about their preferences with respect to the visualisation of map elements.

4.1.2 Objectives

The purpose of the interactive questionnaire is to compare and to individually evaluate the impact of *feature vectors* of the proposed framework. The questionnaire is not meant to be very exhaustive, in order to motivate potential test subjects to participate in the questionnaire, and to avoid that they become annoyed after they have decided to start answering the questionnaire, especially if they find it "too extensive".

In the first part (the biggest one), the exercises are mainly based on the *pointing task paradigm* as previously performed in other studies [Nurminen, 2006], i.e., test subjects are asked questions regarding the matching of both virtual and real worlds. Often users don't know where they are or how can they go to a certain place, and that is the reason why they need a mobile map. Thus, the way-finding process is mainly based on the translation from the screen's virtual environment (shown by the mobile device) to the real environment and not the opposite. Users want to know the answer to questions such as "Where in reality is the building shown in the mobile device?" rather than "Where in the mobile map is the building in front of me?", since it is assumed they know little or nothing about the real environment and that they greatly depend on the instructions and imagery provided by the map-based mobile application. Due to such asymmetry, the questionnaire is only focused on the virtuality-to-reality translation. The exceptions to these questions comprise tasks that focus on label readability. Test subjects were be shown a series of images of both reality and virtual environments (as presented by 3D map-based applications), and were asked to perform the matching of realities. The questions exercise each of the three following questions that constitute the *Mobility Equation*:

- 'Where am I?'
- 'Where am I going?'
- 'How do I get there?'

Similarly, each question is associated to one of the four primary user tasks that maps are used for (please refer to Section 2.2 for additional information): *Locator Tasks*, *Proximity Tasks*, *Navigation Tasks*, and *Event Tasks*.

In the second part of the questionnaire, a similar approach is followed, but instead of evaluating the matching of the two realities, the main objective is to measure how well users perform a given task (as previously enumerated).

In the third and last part, users were asked about their preferences regarding the visualisation of map elements such as landmarks. In order to avoid influencing the users' answers, the questions were performed in a particular form rather than general, i.e., without hinting or suggesting the main objective of the questions, by asking them what would be preferable in the practical examples given.

4.1.3 Metrics

For the first part of the questionnaire, the metrics used to evaluate each *feature vector* are both answer correctness and time. When the difference in correctness between both answers, in the absence or presence of a given component, is marginal, the option regarded as being the most beneficial will be the one yielding a shorter answer times, by looking not only to the general statistical data, but also paying attention to the distribution of answer time frequencies. If the difference between both times is not significant, both options will be regarded as having an equivalent impact, since their correctness levels are approximate. Contrarily, if there is a significant difference in answer correctness, it may not be considered relevant whether test subjects are able to answer more quickly if they are not able to answer as correctly. Nevertheless, the time variable will always provide insightful information, such as whether the users felt clueless or found the question difficult to answer. In general, the option yielding higher correctness and / or answer times will be considered as more appropriate to perform the matching of both reality and virtuality.

It is expected that sometimes users don't know the answer to a question or that they have many doubts between one or another choice. In such situation, and to avoid that users randomly pick the correct answer, a "I have no idea" button is included with each question of the first part of the questionnaire. This kind of answers are recorded along with the correct and wrong answers.

In the second part of the questionnaire, only time is taken into account when users are performing a given task. Example tasks include “Please read the following 7 street names (from 1 to 7), as fast as you can.”. There is therefore no “right or wrong” answers.

In the last part of the questionnaire, since preferences are directly indicated by the users, no measurements will be performed. Some conclusions will be taken regarding each question and the corresponding users’ choices.

4.1.4 Security and Preventive Measures

Several preventive measures were taken, in order to easily detect and to make ineligible any negative effects from eventual malicious behaviour. Firstly, instead of making the website address easily available in a public forum, mailing list or search engine, it was made private by notifying a chosen group of people:

1. Computer Science and Informatics students and professors from the Faculty of Engineering of the University of Porto, and from the Department of Engineering of the University of Trás-os-Montes and Alto Douro, Portugal.

2. Workers at the place of internship (*NDrive Navigation Systems, SA*).

The web address was notified by email to this group of people, in order to avoid unauthorised people from accessing the website. Secondly, the name and age duple make up the identification of each previously answered questionnaire, i.e., a *primary key*, using database terminology. Such measure prevents users who have previously answered, but who wanted to improve their scores, from filling up a new questionnaire. This is not a very sophisticated system since it is always possible to use a fake name or identification to bypass this restriction. Nevertheless, it is believed that the distribution of questions over several webpages (1 question per webpage, in a total of 14 questions, 3 training questions and a few introductions) would make the users less motivated to do such thing. To further detect fraudulent accesses, computer IP[1] addresses (including those behind non-anonymous public proxies), dates and times were recorded attached to each answers form.

4.1.5 Test Procedure and Assumptions

The interactive questionnaire was available as an online web application for any user entering the correct website address. It was developed in an effort to achieve portability in

[1] Internet Protocol

different families of browsers. Nevertheless, it is expected that users have a *Javascript*-enabled browser capable of interpreting XHTML[2] 1.0 and CSS[3] level 2.1. The web application is 100% compliant with these two standards and is known to run without any issues in *Mozilla Firefox* (v2.x and 3.x), *Safari* (v2.x and 3.x), and *Internet Explorer* (v6.x and 7.x).

The main page asks for common personal data, including age, gender, occupation and proficiency levels regarding the use of maps, GPS navigators, and knowledge of Computer Graphics, as demonstrated in the following screenshot (in Portuguese):

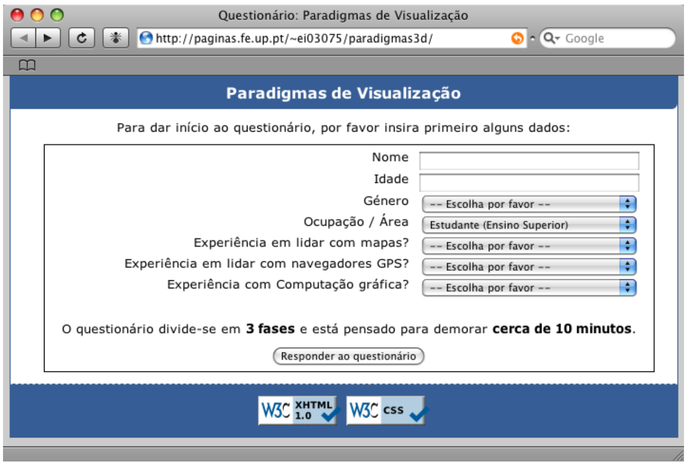


Figure 4.1: Online questionnaire's entry page (in Portuguese)

In each question of the first part, an image of a virtual environment and the corresponding question is presented. As soon as the user reads it, and feels confident enough, he/she will click a "Get Possible Answers and Answer" button, and will be shown a set of images that represent the set of possible answers. After this, the user must click the image which he/she thinks as being the correct answer. If the user still has doubts, he can scroll up the webpage to review the question.

Once any image appears, it will remain visible until the question is correctly or incorrectly answered. Summarising what was above mentioned, the procedure can be defined in three steps:

1. An image of a virtual environment and a question are presented.

2. The possible answers are shown after the test subject clicks "Get Possible Answers and Answer".

3. The user chooses the correct answer.

The answer times are measured in milliseconds as a client-side operation, using *JavaScript* to measure the interval between the instant the user clicks the button and the time it choses

[2]Extensible Hypertext Markup Language
[3]Cascading Style Sheet

a possible answer. This three-step mechanism allow us to accurately measure the time required for each test subject to answer each question, while avoiding that the time they require to read or to understand a question and the time it takes the client browsers to exchange information with the server influences the total time.

Prior to the execution of the first part, the users are informed that the time and correctness of each answer will be reflected in the final results of the questionnaire (see Figure 4.2). It is also assumed that they are not informed of more abstract questions such as to know what are *feature vectors* and/or what *feature vectors* are being evaluated for each question.

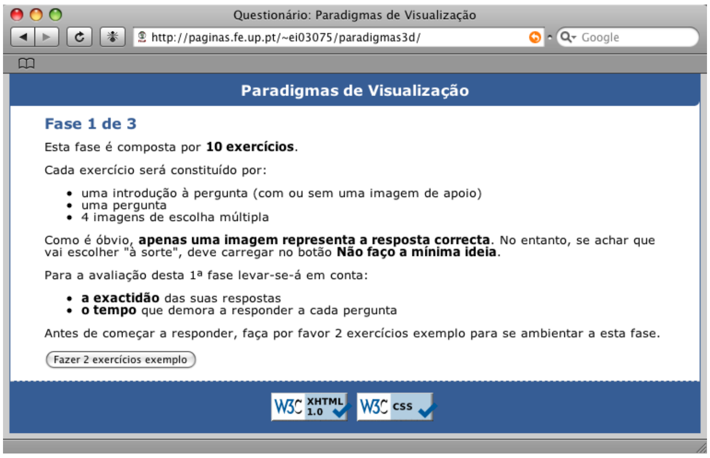


Figure 4.2: Introduction to the first part of the online questionnaire (in Portuguese)

Before answering the real questionnaire, they are asked to answer a couple of sample questions, in order for them to get used to the conditions, and to start fully prepared. Each sample question includes explanations on the user interface, with respect to the three-step mechanism described above, as shown in the following figure:

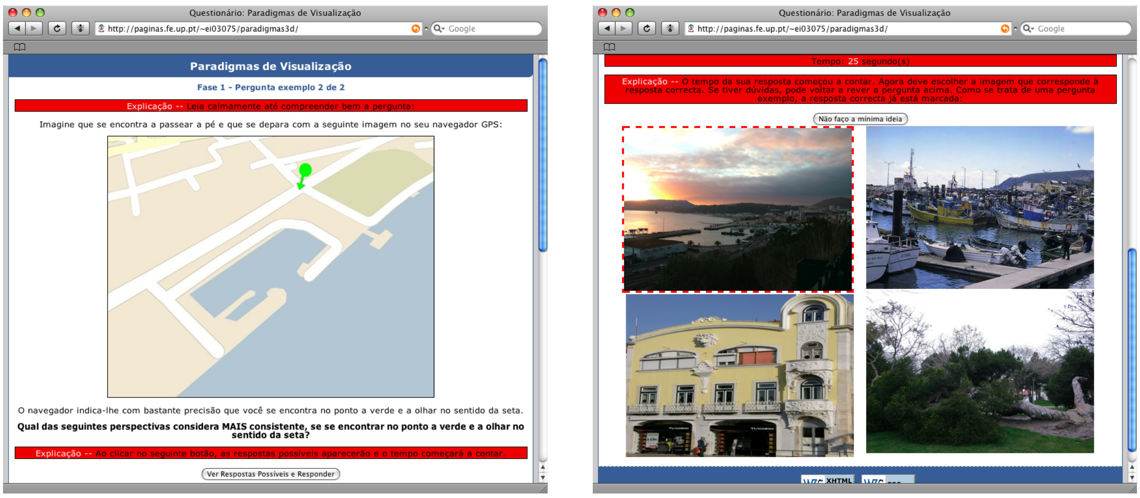


Figure 4.3: A sample question for the first part of the online questionnaire (in Portuguese)

The vectors that are not being evaluated in a given exercise are, as much as possible, excluded from the questions. Superposition or combination of different vectors is avoided or, alternately, only one component of the vector being evaluated is changed within the same context. For instance, it is regarded as valid to evaluate *Image Realism* without the use of *Map Symbology* or, alternately, if and only if *Map Symbology* is used in questions where both absence and presence of *Image Realism* components are tested. Additionally, and since there are 10 questions in total, each group of two questions that evaluate a component in its presence or absence are separated by other questions in the middle; the orientations depicted by the questions' images are modified, and the set of 4 possible answers is shuffled, therefore test subjects will have more difficulty matching the current question with previous questions. Such restrictions will avoid measurement bias, and will contribute to more precise results.

The second part is very similar to the first one, but instead of having 4 possible answer images for each question, the user is presented with an image which should be used to perform the required task. When the user completes the task, it is asked to click the image itself. Similarly to what happened in the first part, test subjects are informed that time is the only variable that will be taken into account and that there are no "right or wrong answers", but a task to perform. Since there are only 2 questions in this part, only one sample question is used for training before starting to answer the real questionnaire, as demonstrated in the following figure:

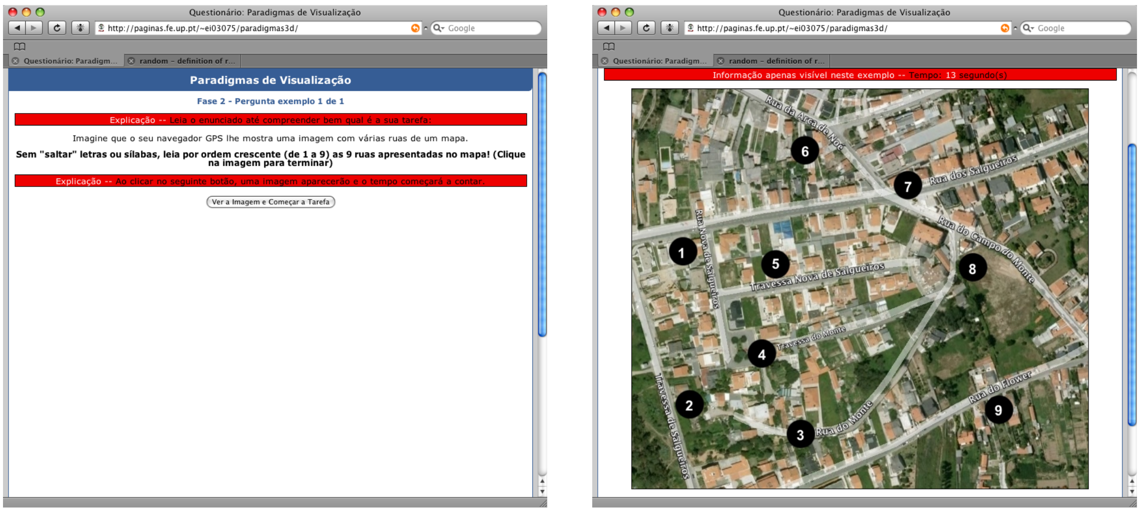


Figure 4.4: A sample question (task) for the second part of the online questionnaire (in Portuguese)

In the third part of the questionnaire, the users are informed that they are being asked about their preferences, and therefore there are no "right or wrong" answers nor the counting of time they take to answer. They are presented with a question, and two possible images that represent the possible preferences. They are expected to click the image which represents their preference, as demonstrated in the following figure:

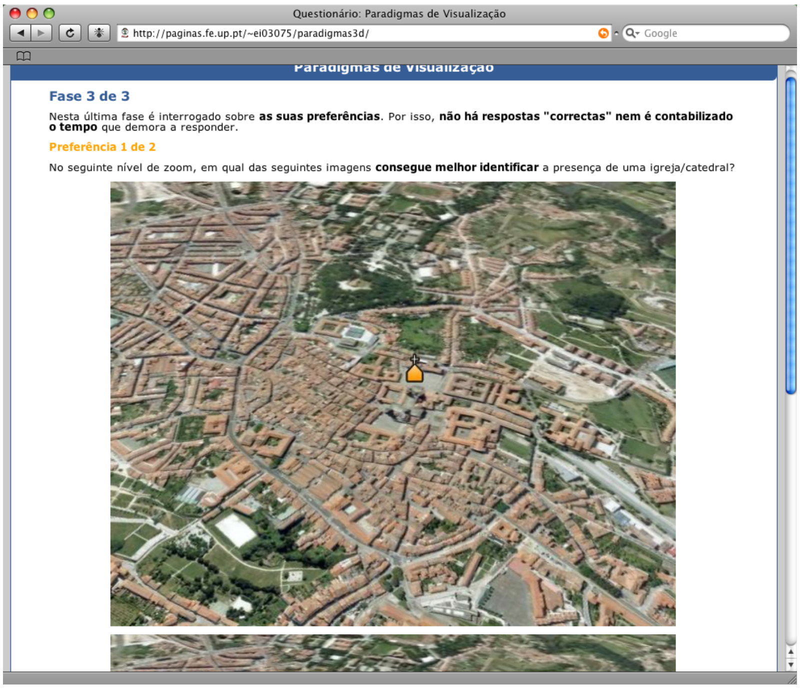


Figure 4.5: The third part of the online questionnaire: User preferences (in Portuguese)

After the user indicates his/her preferences, the questionnaire is completed.

4.1.6 Feature Vectors

In the following sections, each *feature vector* is discussed individually, and the questions (belonging to the questionnaire) that evaluate them are presented along with the map tasks they exercise (as mentioned in Section 4.1.2).

As previously mentioned, this questionnaire is not meant to be perceived by users as "too extensive". For these reasons, only the *feature vector* components for which there are no (or few) suggestions – indicating the most appropriate visualisation paradigms that should be followed – given by the state of the art, will be studied and evaluated. At the same time, there are some components that are not possible to evaluate given the limitations imposed by the kind of questionnaire that was prepared and proposed. Nevertheless, the vectors that are not evaluated with the help of the questionnaire will be indicated.

Image Realism

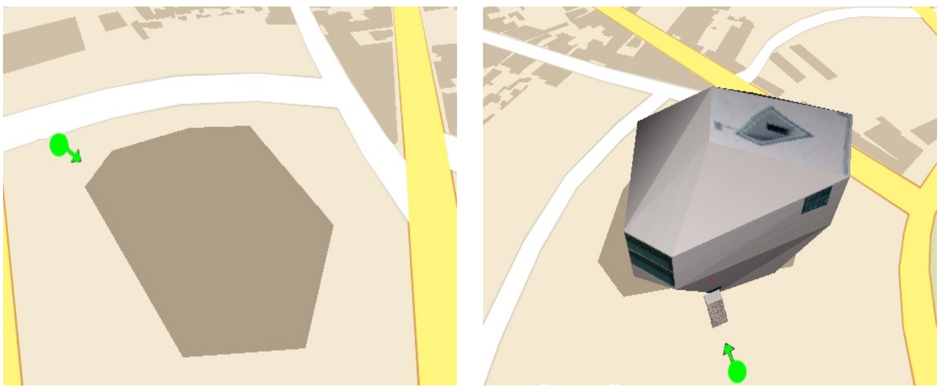
All *Image Realism* orientations (i.e., *3D Buildings*, *Map Vectors* and *Surface Model*) are evaluated with the help of the questionnaire. They are tested along with the various degrees of *Image Realism* magnitudes, in accordance with the vector instances (*orientations* and *magnitudes* combined) found in the state-of-the-art contributions (for a description of each instance, please refer to Table 3.3). These instances of *Image Realism* were considered eligible for the evaluation through the questionnaire, since there are no (or few) indications indications, from the state of the art, with regards to their impact:

- *Simple Textured Buildings* and *Photo Textured Buildings*
- *Coloured Map* and *Orthophotomap*
- *Flat Model* and *Terrain Model*

Each exercise is presented in this section by merging the two questions that together evaluate the absence and presence of one of the above-enumerated components. As one will notice, the textual information and answer images are the same for both questions. In conformity to the assumptions taken in Section 4.1.5, the only element that changes between both questions is the question image (one for the presence and the other for the absence of the corresponding component) along with the user's perspective depicted in it. In all the following exercises, test subjects are supposed to exercise *Locator Tasks* to answer the question "Where am I?", by guessing their own and other objects' positions.

In this study, it is hypothesised that, in the absence of *Simple Textured Buildings*, test subjects will have to rely on their ability to match the 3D geometry of the real building with the geometry of the its 2D polygon representation on the map. At the same time, it is supposed that by providing the three-dimensional (yet simple) geometry of the whole building, in the presence of this component, test subjects will make fewer mistakes and, as a consequence, will require less time matching both realities. The following two questions will evaluate the impact of the presence and absence of *Simple Textured Buildings*:

> *"Suppose you are taking a walk and see the following image on your GPS navigator."*



(a) Absence (b) Presence

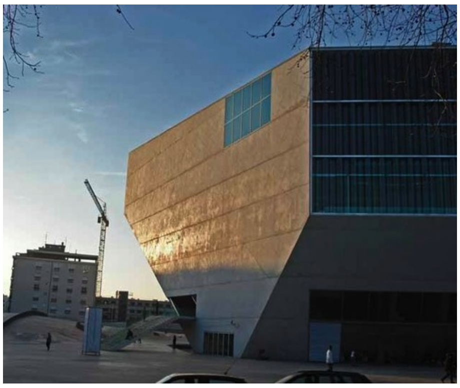
Figure 4.6: The 2 questions that evaluate the impact of *Simple Textured Buildings*

"The GPS navigator accurately indicates your position with the green point and that you are looking in the direction pointed by the arrow.

Which of the following 4 perspectives do you consider MORE consistent?"

(a) Not a valid answer

(b) Answer to the question with Figure 4.6b



(c) Not a valid answer

(d) Answer to the question with Figure 4.6a

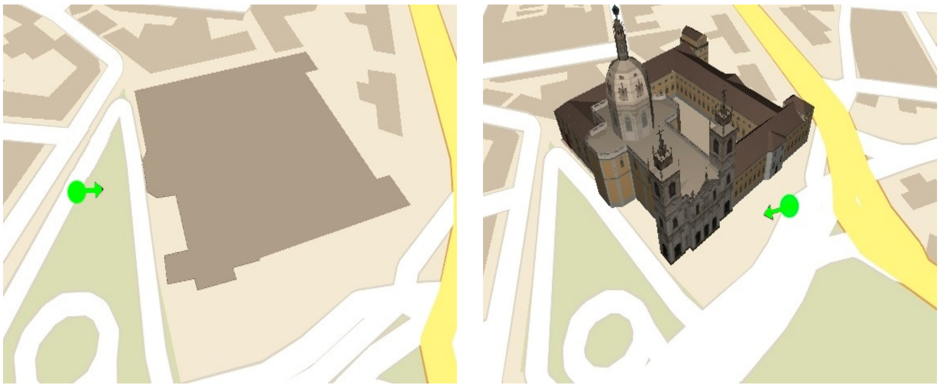
Figure 4.7: The 4 possible answers for the questions that evaluate *Simple Textured Buildings*

Using Figure 4.6a, the absence of *Simple Textured Buildings* is tested. On the other hand, Figure 4.6b evaluates the presence of *Simple Textured Buildings* with a texture mapped building that uses simple texture patterns in its façades.

Despite the fact that the *Coloured Buildings* component was not tested, there are already some indications in the state-of-the-art about its use. In [Laakso, 2002], several test subjects complained that non-textured houses are "not always easy to recognise". They have commented that it isn't possible to make sure that the buildings that are in front of them correspond to the same in the device, and that it isn't simple to distinguish buildings sharing the same colour, when they have a different appearance in reality.

In the case of the *Photo Textured Buildings* component, it is hypothesised that, by simultaneously providing the 3D geometry of a building along with photographic façades, test subjects will be able to detect features (e.g. windows, doors, unique wall patterns, etc.) more accurately and faster than in the case of *Simple Textured Buildings*. The following two questions will evaluate the impact of the presence and absence of *Photo Textured Buildings*:

> *"Suppose you are taking a walk and see the following image on your GPS navigator."*



(a) Absence (b) Presence

Figure 4.8: The 2 questions that evaluate the impact of *Photo Textured Buildings*

> *"The GPS navigator accurately indicates your position with the green point and that you are looking in the direction pointed by the arrow.*
>
> *Which of the following 4 perspectives do you consider MORE consistent?"*

(a) Not a valid answer (b) Answer to the question with Figure 4.8b

(c) Answer to the question with Figure 4.8a

(d) Not a valid answer

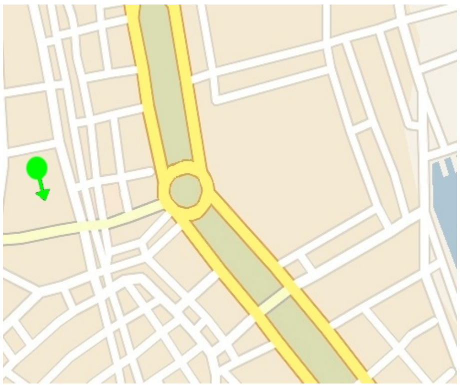
Figure 4.9: The 4 possible answers for the questions that evaluate *Photo Textured Buildings*

It is assumed that the photographic detail will greatly help users identifying and confirming that the building in front of them corresponds, without any doubt, to the building depicted on the mobile device. In order to confirm the hypothesis, this component will be compared against *Simple Textured Buildings* and the differences in between both answer accuracies and times will be evaluated.

The *pointing task paradigm* was also applied, in order to assess the presence of the *Orthophotomap* component and its absence (a *Coloured Map*). It is assumed that an *Orthophotomap* can provide subjects a much more enriching visualisation experience than the one provided by a *Coloured Map*.

The hypothesis rests on the belief that an *Orthophotomap* component can make easier for users to discern the true features of the map's surface, by giving a realistic view rather than a rough generalisation. There are many situations were coloured vector polygons are not enough to represent features like a tiled pavement; a group of trees arranged in a special and unique way; and several "static" features like public benches, zebra crossings, and many others that are impossible to find in a coloured vector map. If a user cannot find a given feature in a *Coloured Map*, the users' confidence level will drop, and they will require more time to get other reliable reference points (if available). The following to questions evaluate the impact of the *Coloured Map* and *Orthophotomap* components:

> *"Suppose you are taking a walk and see the following image on your GPS navigator."*



(a) *Coloured Map*

(b) *Orthophotomap*

Figure 4.10: The 2 questions that evaluate the impact of *Coloured Map* and *Orthophotomap*

"The GPS navigator accurately indicates your position with the green point and that you are looking in the direction pointed by the arrow.

Which of the following 4 perspectives do you consider MORE consistent?"

(a) Answer to the question with Figure 4.10a

(b) Not a valid answer

(c) Answer to the question with Figure 4.10b

(d) Not a valid answer

Figure 4.11: The 4 possible answers for the questions that evaluate *Coloured Map* and *Orthophotomap*

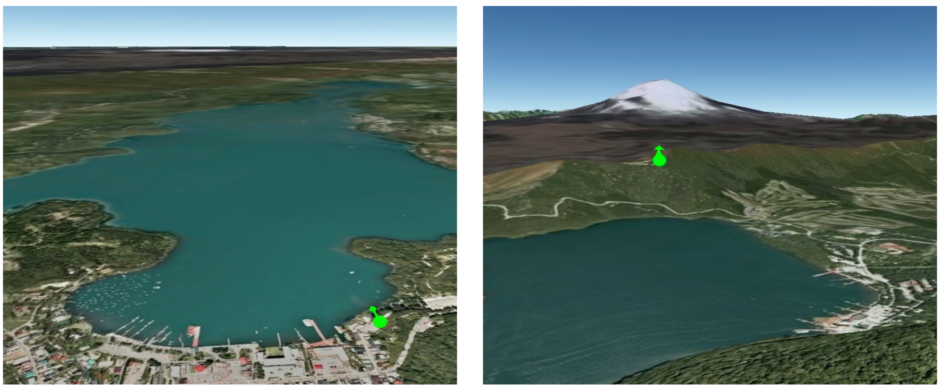
It is expected that a map like Figure 4.10b can help users performing their tasks faster and more accurately than 4.10a. For instance, if we suppose a user is looking at Figure 4.10a, but instead of being in the position indicated by the green point of the same figure, he/she is in the position indicated in Figure 4.10b. An obvious conclusion is that, just by looking at the map, the user will be completely unable to discern the presence of a garden bench right in front of him/her. The same could be applicable for singular trees, lakes, pavements, and so on.

In this study, it is hypothesised that by using a *Terrain Model* rather than a *Flat Model* component, users will be able to perform the spatial matching of both reality and virtuality in a much more immersive and natural way. It is expected that by providing the *Terrain Model* component, users will be able to:

- use elevated reference points such as mountain peaks;
- understand and visualise occlusions caused by the varying landscape elevation.

In the end, it is expected that users will be able to perform their tasks in less time, since they just need to think "outside the box". On the other hand, by using a *Flat Model*, users would have to understand that the image on the device does not account for occlusions, and therefore, they will have to do that job themselves. The questions that evaluate the impact of *Terrain Model* component's presence and its absence (*Flat Model*) are shown below:

> *"Suppose you are taking a walk and see the following image on your GPS navigator."*



(a) *Flat Model* (b) *Terrain Model*

Figure 4.12: The 2 questions that evaluate the impact of *Flat Model* and *Terrain Model*

> *"The GPS navigator accurately indicates your position with the green point and that you are looking in the direction pointed by the arrow.*

Which of the following 4 perspectives do you consider MORE consistent?"

(a) Answer to the question with Figure 4.12a

(b) Not a valid answer

(c) Not a valid answer

(d) Answer to the question with Figure 4.12b

Figure 4.13: The 4 possible answers for the questions that evaluate *Flat Model* and *Terrain Model*

As one can easily notice by looking at Figure 4.12a, the peak of mount Fuji cannot be grasped at all. The only feature that definitely helps a bit is the whitish ground near the horizon, which corresponds to the cap of snow on top of mount Fuji. On the contrary, the *Terrain Model* component, represented in Figure 4.12b, allows the spatial matching of both realities in a consistent way.

Although Figure 4.12a lacks information regarding the elevations of the terrain, it provides information that a user's eyes cannot reach. For instance, if a user is positioned and looking as indicated in the figure, he/she will be given visual information that concerns what is behind the hillcrest and its trees, but which is not possible to obtain in reality.

Depending on the results of the questionnaire, the magnitude of realism that maximises the accuracy and response of the majority of users will be chosen. The questionnaire does not specifically test which degree of realism is considered best in such conditions. Provided the possibility of multiple degrees of realism in different groups of elements (as explained in Section 3.3), the purpose of these tests is to individually measure the degree of realism desired for the buildings, vectors, and surface model.

Due to the limitations of this questionnaire and in the context of this dissertation, no other *Image Realism* magnitudes were evaluated, apart from *Functional Realism* and *Photo-Realism*. To evaluate a *Mixed Realism* component it would be more interesting to have a dynamic experiment (e.g., test subjects in a driving simulator) rather than a static approach provided by the online questionnaire.

Object Labelling

In the context of this dissertation, and with respect to *Object Labelling*, only the presence and absence of *Perspective-Adaptive Labelling* was evaluated, in the second part of the questionnaire. When comparing this component with the rest that were not evaluated, the former is considered the most relevant variable, because not much is known about its impact. Furthermore, it is believed that a more dynamic experiment, which is not the case of this questionnaire, could provide valuable results for the analysis of the other components.

The main purpose of this evaluation is to confirm whether the lack of *Perspective-Adaptive Labelling*, only featured by *Google Earth* (check the classification chart in Figure 3.21), is a positive step towards the improvement of users' performance.

In this study, it is hypothesised that, when users are analysing labels (e.g. of streets, rivers, cities, and so on) which are not oriented towards the current viewing direction depicted in the device, they will feel much more difficulty reading the words, due to the decreased visibility, especially when looking in a direction which is parallel to the map surface. In such case, users will not be able to read labels as faster, and will pan the map closer to the camera so it becomes easier to read. Particularly in the case of labels which are almost parallel to the camera's viewing direction, some users will wish to skip words, if they find them "too difficult" to read.

For this component, the *pointing task paradigm* was not applied at all. Instead, in order to assess the impact of both presence and absence of *Perspective-Adaptive Labelling*, the following exercise was used:

> *"Suppose your GPS navigator is showing you several names of streets of a map.*
>
> *Without skipping letters or syllables, read in ascending order (from 1 to 7) the 7 street names presented in the map! (Click the image, when you finish reading)"*

(a) *Perspective-Adaptive Labelling*

(b) No *Perspective-Adaptive Labelling*

Figure 4.14: The 2 tasks that evaluate the impact of *Perspective-Adaptive Labelling*

The previous exercise was carefully elaborated, for the purpose of providing two questions with approximately the same difficulty. Both have 7 street names and about the same number of uncommon words (12 in Figure 4.14a vs. 13 in Figure 4.14b), i.e., excluding prepositions (e.g. “of”) and words like “Street” and “Avenue”.

With regards to *positioning* and *placement* of labels, these components were not evaluated with the help of the questionnaire, since there are already several indications from the state-of-the-art studies. Broadly speaking, *General Positioning* is considered the best approach since it covers a larger variety of types of labels, being more appropriate to describe a map according to the type of feature (point, line, or area). Currently, in the research field of Cartography, one of the most important objectives is to achieve completely dynamic maps. The reason is that the *Dynamic Selection* and *Dynamic Placement* of labels provides better readability and usability of mobile maps.

Visual-Spatial Abstraction

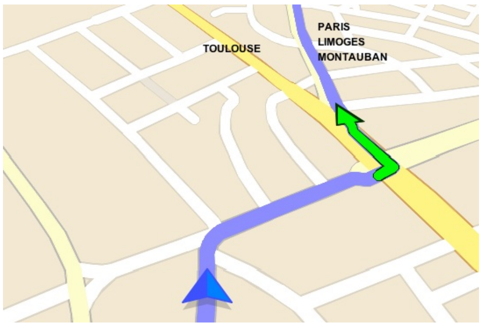
In the context of this dissertation and due to the restrictions of the proposed questionnaire, no components of this *feature vector* were tested. It is believed that only a dynamic experiment, which is not provided by this questionnaire, is capable of evaluating and measuring the users' ability to perform visual-spatial mental operations. Examples of such experiment could include engaging in a pedestrian experience with test subjects and measuring their responsiveness to the proposed tasks. It is assumed that only a dynamic experiment, like the one described, could provide meaningful results of the components of this vector.

Route Indication

In the first part of the questionnaire, the two proposed immersion levels of *Route Indication* were evaluated: the *Instructive* and *Simulative* components.

In this study, It is hypothesised that, when a user is presented with an image which looks more familiar to him/her, given the current context, the user will be able to perform his task with little effort. It is assumed that users won't make more mistakes using one approach or the other, but that a significant difference in the time they require to complete their task may arise, i.e., that a *Simulative* component will result in faster responsiveness than an *Instructive* approach. The following question was used to evaluate the *Instructive* component:

> *"Suppose you are driving a car to CASERTA with the help of a GPS navigator.*
>
> *Which of the following 4 images indicates the route in the direction of CASERTA?"*



(a) Not a valid answer

(b) Not a valid answer

(c) Not a valid answer

(d) Answer to the question

Figure 4.15: The 4 possible answers for the questions that evaluate *Instructive Route Indication*

A similar question was used, but instead of the images above, several sample screenshots of *Navigon*'s *Reality View*^{TM} (see Section 2.3.4) were used. The original images used in the previous example were modified in order to present exactly the same destinations represented in the screenshots obtained from *Navigon*. Moreover, "CASERTA" was replaced by "LIMOGES", as shown below:

> *"Suppose you are driving a car to LIMOGES with the help of a GPS navigator.*
>
> *Which of the following 4 images indicates the route in the direction of LIMOGES?"*

(a) Not a valid answer

(b) Answer to the question

(c) Not a valid answer

(d) Not a valid answer

Figure 4.16: The 4 possible answers for the questions that evaluate *Simulative Route Indication*

Given the two previous questions, the purpose of such exercise is to measure how accurately and quickly people can read and understand which way to go.

Regarding the range of components that may be used to indicate the route, as discussed in Section 3.6, there is no clear state-of-the-art definition on what should be the most appropriate set of visual indicators (*Arrows*, *Cords*, *Way Points*, *Carpet*, or any combination of the previous). It is believed that, if a dynamic experiment was used, it would be possible to evaluate, for example, a user's reflex response time, given a situation where the he/she is approaching a manoeuvre, and deciding which way to go, depending on the visual indicators that are presented.

Landmark Symbology

As previously discussed in Section 3.7, there are several state-of-the-art studies providing guidelines for the use and design of landmarks, by means of using a wide range of abstraction levels for different situations. Despite the studies that were performed with test subjects, some of the provided hints are based on practical use experience, and because of this, it would be interesting to perform evaluation tests to confirm their validity. For that purpose, it would be required a great amount of questions, in order to validate all levels of abstraction, making the questionnaire “too extensive”, and affecting negatively the users’ motivation to answer it. Instead, since little is known about the significance of the *Adaptive Zoom* component, its evaluation was performed in the third and last part of the questionnaire, by asking users their preferences, instead of “right or wrong” questions, or measuring their performance.

In this study, it is hypothesised that users will express their need for an *Adaptive Zoom* behaviour, i.e., that the majority of them will choose an abstract landmark representation of a given building, when a map which is zoomed out far from the ground is used, and a more concrete representation when the map is used at close range. The basis of such hypothesis rests on the various issues raised by the cartographic generalisation procedures [Elias et al., 2005], as previously explained in Section 3.7: *congestion*, *coalescence*, and *imperceptibility*. For instance, even if a concrete landmark is used, instead of an abstract representation, there are certain zoom levels of a map which do not allow users to perceive enough features of that landmark, and consequently, to able to identify it with a significant confidence level. For this component, two questions were used, in order to assess its impact. The first question asks users for their preferences, regarding the preferred abstraction level for a map which is a little zoomed out far from the ground:

> *“Given the depicted zoom level, in which of the following images can you better identify the presence of a church/catheral?”*

(a) High degree of landmark abstractness

(b) High degree of landmark concreteness

Figure 4.17: The preference that evaluates the users’ need for an *Adaptive Zoom* approach, when a map which is zoomed out far from the ground is used

The second question is analogous to the first one, but a map which is zoomed in close to the ground is used instead:

"Given the depicted zoom level, in which of the following images can you better identify the presence of a church/catheral?"

(a) High degree of landmark abstractness (b) High degree of landmark concreteness

Figure 4.18: The preference that evaluates the users' need for an *Adaptive Zoom* approach, when a map which is zoomed in close to the ground is used

Like previously explained, the questions of the third part were constructed without hinting or suggesting their main objective, by asking users what they would prefer given some practical examples that can happen in real-life situations.

In the first preference (Figure 4.17), it is believed that a high degree of landmark concreteness (Figure 4.17b) makes it very difficult for a user to distinguish a church/cathedral from other possible buildings like an old hospital, university, etc., especially when nothing is suggested about the kind of building. Contrarily, when a high degree of landmark concreteness (Figure 4.18b) is used for identification and orientation in *Locator* and *Proximity Tasks*, it is expected that users will have an easier task in matching the two realities, provided a close up given by an *image* representation of a landmark.

Contextual Awareness

Contextual Awareness was not evaluated at all, since the proposed *orientations* for this vector (*Reconstructional*, *Recreational*, and *Fictional*) can be regarded as application and scope-bound features, so there is no point in evaluating "which is better" to perform any of the tasks that maps are used for. Moreover, in terms of *Active* or *Passive Awareness*, there are also several indications from the state of the art, but the option of choosing one or the other is context-dependent, and would require a dynamic experiment to evaluate the users' reaction to the level of awareness provided by a mobile application.

4.2 Results

In the previous sections, the scientific methodology which aims to assess the impact of each *feature vector* individually, was described through a set of hypothesises. An online web questionnaire was developed, and before administering it to test subjects, the results were discussed and evaluated in anticipation.

In the following sections, the results of the questionnaire are analysed and presented, while comparing them against the previous expectations.

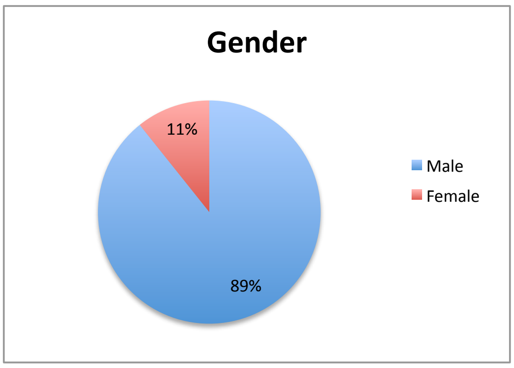
4.2.1 General Information

In total, 149 test subjects answered the questionnaire, and none of them were found to exhibit any kind of malicious behaviour[4], according to the security considerations and preventive measures thoroughly described in Section 4.1.4.

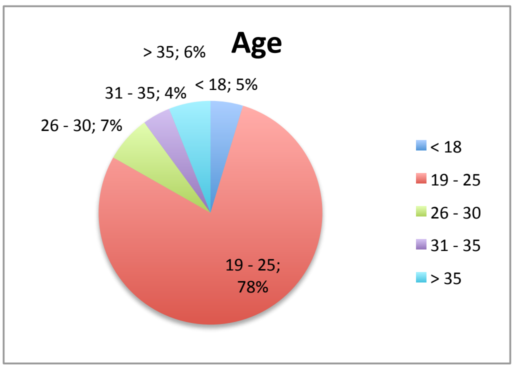
In terms of usability, no significant barriers were found, since all persons who accessed the questionnaire and have gone past the *Entry Form* (in Appendix A.1), actually ended up answering the whole questionnaire. In fact, one of the users found the online questionnaire “very appealing”. Furthermore, the number of people who answered “I have no idea” was generally quite low, as we will see in the following sections, which is indicative that the questionnaire was perceived and understood in appropriate conditions.

4.2.2 Demographics

Most of the 149 subjects were male, and in the 18 to 25 age group (see Figure 4.19a). The low number of female participants was already anticipated, due to the great prevalence of male students in Computer Science and Informatics (the majority of participants).



(a) Percentage of subjects across Gender



(b) Percentage of subjects across Age groups

Figure 4.19: Proportion of subjects across Gender and Age Groups

[4]Although several concurrent accesses were detected coming from *NDrive Navigation Systems, SA*, this was later explained due to the fact that there is a single IP address visible from the outside of the organisation, thus being shared among its workers. All those accesses were confirmed as coming from different workers within the organisation.

Nevertheless, it is expected that the performance demonstrated by male and female participants, will result in the same conclusions, i.e., irrespectively of the performance demonstrated by each gender separately.

The prevalence of young-adult subjects can be easily justified by taking into account the subjects' occupations, as shown in the following chart:

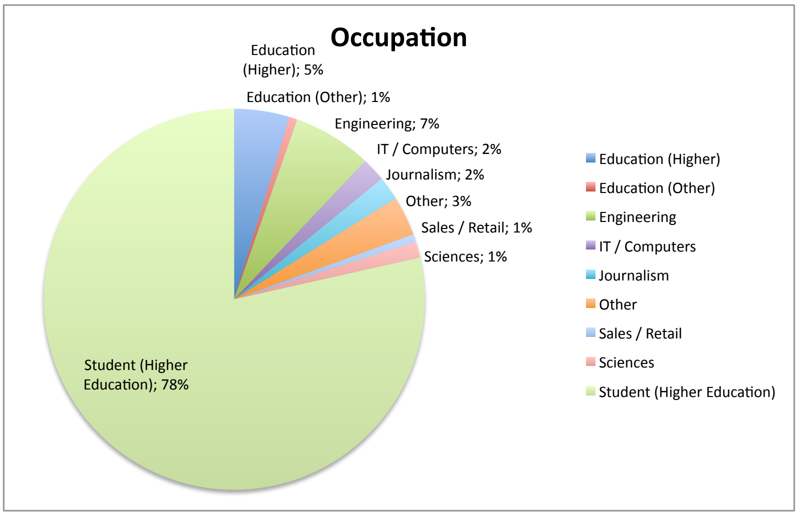
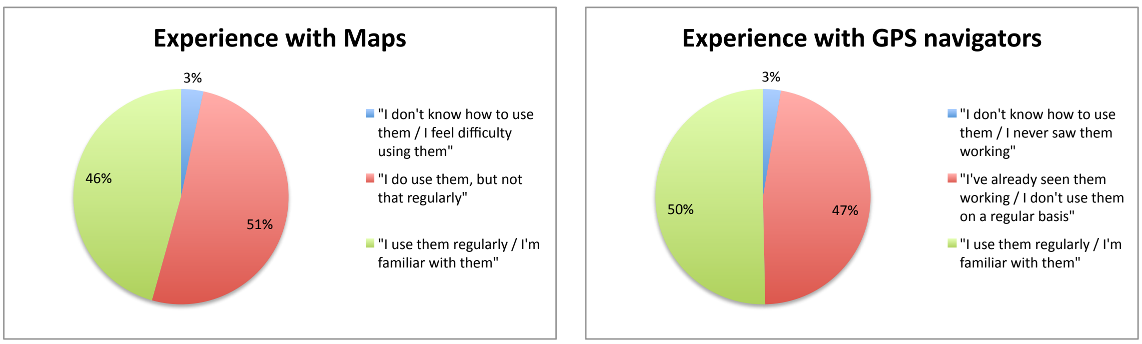


Figure 4.20: Subjects' Occupations

By looking at the previous chart, it can be observed that the majority of subjects were Higher Education students, corresponding to the first group of people – enumerated in Section 4.1.4 – who received a notification by email mentioning the questionnaire's existence, and stating its private web address.

4.2.3 Users' Self-Assessment

Broadly speaking, prior to answering the questionnaire, subjects considered themselves fairly capable of using maps, and familiar with GPS navigators, as shown below:



(a) Use of maps (b) Use of GPS navigators

Figure 4.21: Subjects' self-assessment regarding the use of maps and GPS navigators

To help us identify the groups of participants according to their experience regarding both the use of maps and GPS navigators, the following comparison chart is presented:

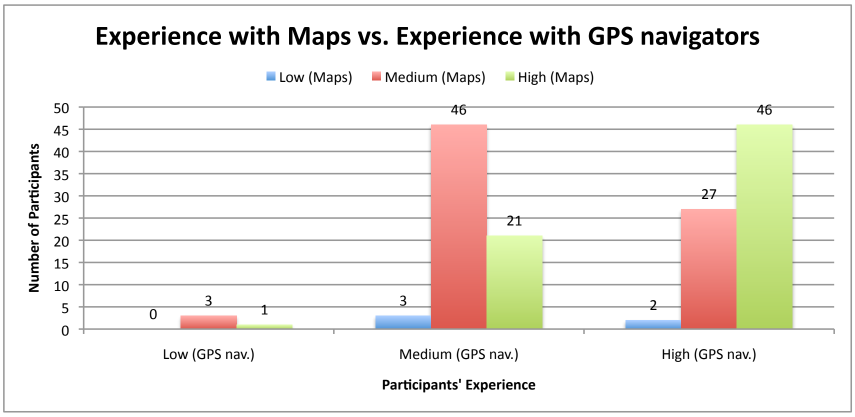


Figure 4.22: Distribution of subjects according to their experience with maps and GPS navigators

The previous chart clearly distinguishes four major groups of subjects:

1. Subjects that use maps and GPS navigators on a regular basis;
2. Subjects that sometimes use maps and GPS navigators;
3. Subjects that use maps on a regular basis / GPS navigators sometimes;
4. Subjects that use GPS navigators on a regular basis / maps sometimes.

As we can see, the number of subjects who assumed that they feel a great deal of difficulty using maps or that never saw / used a GPS navigator, is quite low. Since test subjects assumed that they have at least some familiarity with GPS navigators and average experience regarding maps, it is expected that the results of the questionnaire give us confidence in the conclusions we can take.

4.2.4 Feature Vectors

In the following sections, the results of the subjects' answers to each question evaluating a *feature vector* are presented individually, and their impact is finally assessed. Along each *feature vector*, a comparison with the initial expectations is performed.

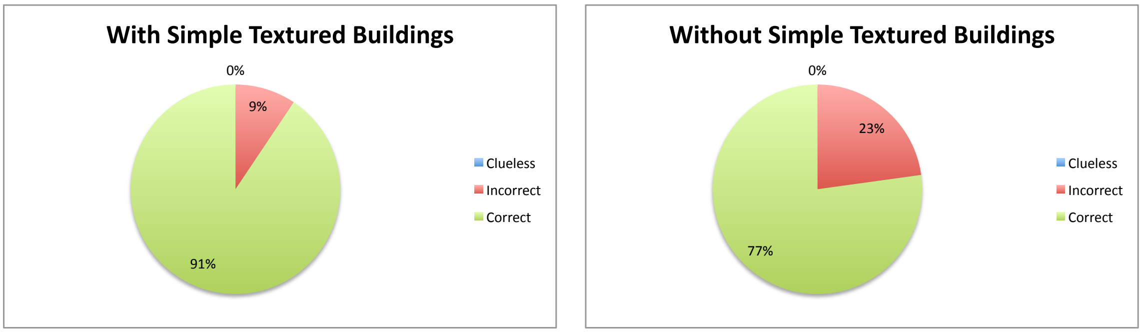
Image Realism

According to the proposed methodology for this *feature vector* (see Section 4.1.6), the following instances were evaluated:

- *Simple Textured Buildings* and *Photo Textured Buildings*

- *Coloured Map* and *Orthophotomap*
- *Flat Model* and *Terrain Model*

The following charts summarise the subjects' answers to the two questions that together evaluate the impact of *Simple Textured Buildings* component, i.e., one for its presence and another for its absence:



(a) With *Simple Textured Buildings* component (b) Without *Simple Textured Buildings* component

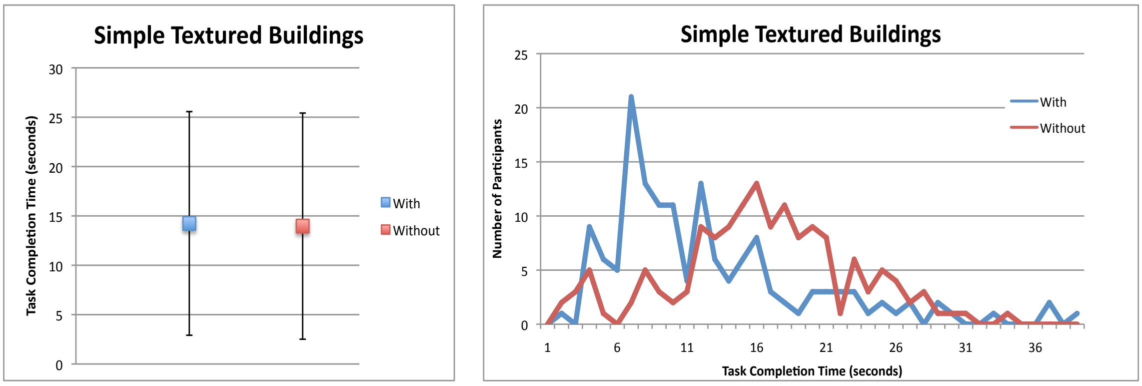
Figure 4.23: Subjects' answers in the presence and absence of *Simple Textured Buildings*

As one can see in the previous chart, there is a 14% difference in the number of correct answers between the two situations. Although slight, the difference between the two cases shows the advantage of the presence of *Simple Textured Buildings* over its absence. In terms of answer times, some general statistical data is provided:

Time (milliseconds)	**Presence**	**Absence**
Minimum	266	510
Maximum	37315	32348
Standard Deviation	7314	6407
Mean	10976	14985
5% percentile	2910	2509
95% percentile	25566	25418

Table 4.1: General statistical data regarding the answer times in the presence and absence of *Simple Textured Buildings*

Looking at the previous statistical data, one can conclude that subjects required, in average, 37% additional time (approx. 4 seconds) to answer when *Simple Textured Buildings* component was not provided. Apart from the mean, all other variables are quite approximate, including the ranges that define the 90% central interval limits in both situations. To have a better overview about the distribution of frequencies regarding answer times, the following comparison charts are presented below:



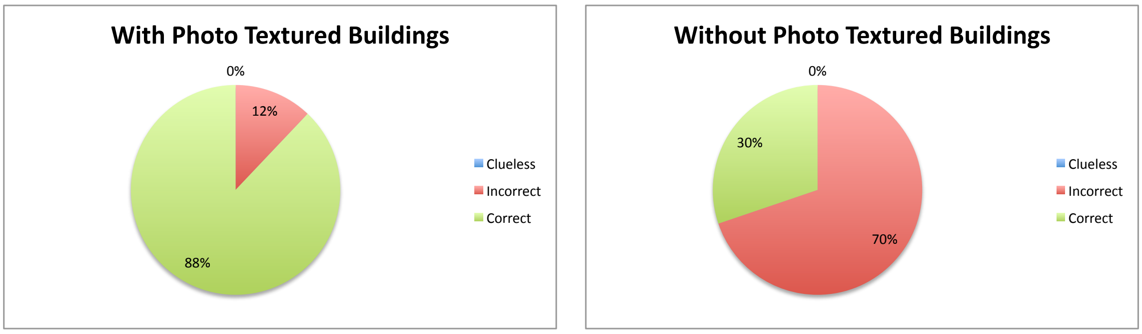
(a) 90% central interval limits

(b) Distribution of frequencies

Figure 4.24: Distribution of frequencies regarding answer times in the presence and absence of *Simple Textured Buildings*

Although the spectrum of frequencies looks quite wide in both cases (Figure 4.24a), in the presence of *Simple Textured Buildings* there is a greater concentration of subjects providing shorter answer times than in its absence (Figure 4.24b).

In the case of *Photo Textured Buildings* component, the results of the answers to the two questions that together evaluate its presence and absence, demonstrate a more significant difference in terms of impact than in the previous case, as the following charts show:



(a) With *Photo Textured Buildings* component

(b) Without *Photo Textured Buildings* component

Figure 4.25: Subjects' answers in the presence and absence of *Photo Textured Buildings*

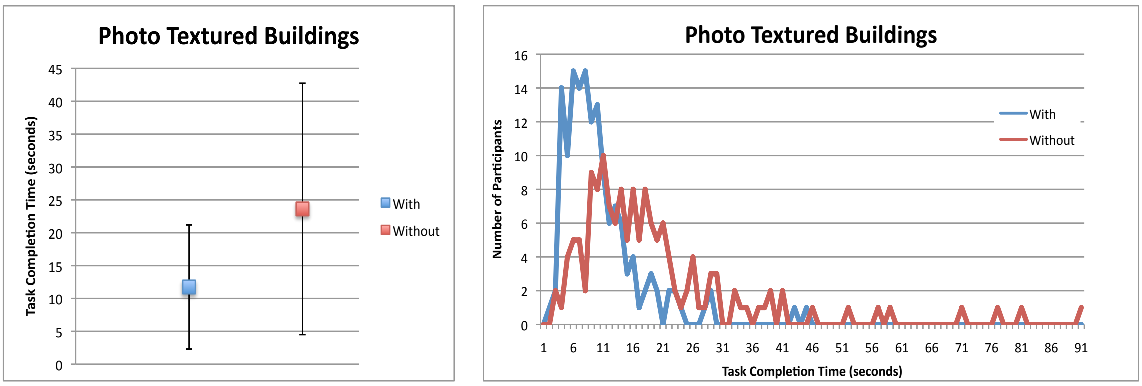
By comparing the two previous charts, one can notice a huge difference in the number of correct answers between the presence and absence of *Photo Textured Buildings*. While in the case of *Simple Textured Buildings* there were 91% and 77% correct answers in its presence and absence, in this component there were 88% and 30% correct answers respectively. This is indicative of an increase in difficulty – felt by subjects when answering – from the previous exercise to this one. Despite this exercise being considered more difficult than the previous one, the number of correct answers in the presence of *Photo*

Textured Buildings (88%) was almost the same as in the case of *Simple Textured Buildings* (91%). Because of this, the following general statistical data will allow the comparison of the subjects' performance (in terms of answer times) between the presence of *Photo Textured Buildings* and *Simple Textured Buildings* components:

Time (milliseconds)	**Presence**	**Absence**
Minimum	840	1264
Maximum	43702	89793
Standard Deviation	6679	14446
Mean	8936	17815
5% percentile	2307	4497
95% percentile	21183	42749

Table 4.2: General statistical data regarding the answer times in the presence and absence of *Photo Textured Buildings*

Despite this exercise being different and considered more difficult than the one regarding *Simple Textured Buildings*, instead of presenting longer answer times, the results generally demonstrate a faster average answer time (approx. 2 seconds of difference) between the presence of *Photo Textured Buildings* and *Simple Textured Buildings*. The following charts illustrate the distribution of frequencies regarding answer times:



(a) 90% central interval limits (b) Distribution of frequencies

Figure 4.26: Distribution of frequencies regarding answer times in the presence and absence of *Photo Textured Buildings*

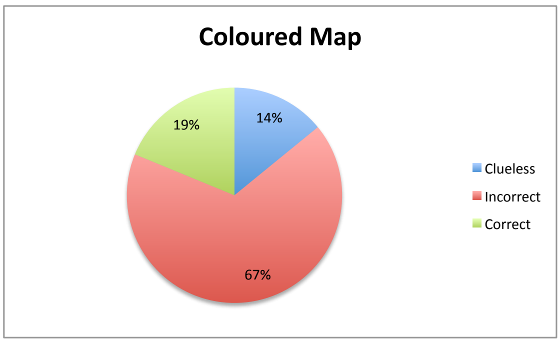
As we can see, the time required for subjects to answer this exercise in the presence of *Photo Textured Buildings* is much narrower than in its absence.

When comparing Table 4.1 with Table 4.2, and including the respective charts, there is a clear indication that, despite the difference in difficulty between *Photo Textured Buildings* and *Simple Textured Buildings* components, the former provides more "stable" and shorter answer times. For instance, by looking at the definition of the 90% central interval limits in the presence of *Photo Textured Buildings* and *Simple Textured Buildings*, there is an increase from 2.3 and 21.1 seconds to 2.9 and 25.6 seconds. Obviously the exercises are different but it should be noted that the opposite happened in the absence of components, i.e., a decrease from 4.5 and 42.7 seconds to 2.5 and 25.4 seconds, respectively, indicating a high stability when *Photo Textured Buildings* is present, irrespective of the difficulty of the exercise.

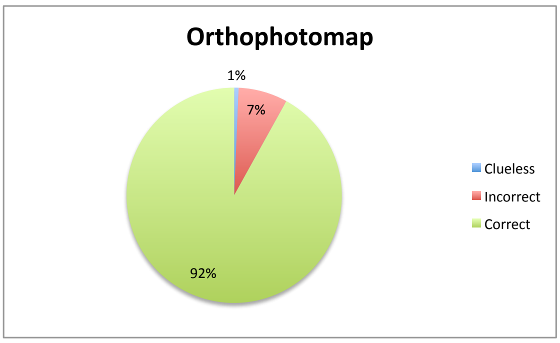
In general, since the spectrum of frequencies is much narrower and positive-skewed in the presence of *Photo Textured Buildings*, it shows that the component in question can result in shorter answer times, while keeping approximately the same answer correctness level.

With respect to the colouring of map vectors, the impact of using either a *Coloured Map* or an *Orthophotomap* component is greatly different, and more significant than in the previous components. Although the difficulty between both questions was quite similar, the results demonstrate that an *Orthophotomap* generally produces a better overview of the environment, allowing for an easier identification of features of the ground.

The two following charts give an overview of the subjects' answers to the questions that evaluate the presence of components:



(a) *Coloured Map* component



(b) *Orthophotomap* component

Figure 4.27: Subjects' answers in the presence of *Coloured Map* and *Orthophotomap* components

As one can see, the number of participants who were unable to answer this question was quite high (14%), in the case of the *Coloured Map* component. The same happened with the number of wrong answers being quite different (67% and 7%). To help us clarify this difference, and in order to understand whether subjects had difficulty with one specific answer that they though as being correct, instead of the correct one, the following chart is presented:

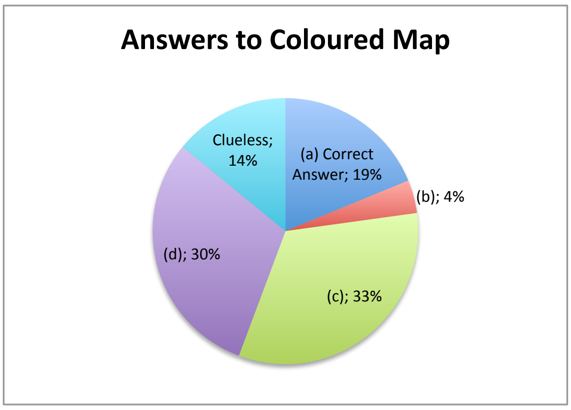


Figure 4.28: The answers to the question which evaluates the presence of the *Coloured Map* component

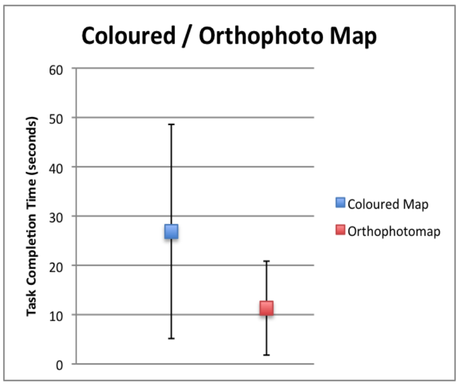
The correct answer to this problem (Figure 4.10a) is answer *(a)* (Figure 4.11a). As we can see, the subjects' opinion was not divided between two possible answers, but between three, not accounting for the ones who had no idea of the correct answer. Please notice that although the majority of subjects (63%) chose answers *(c)* (Figure 4.11c) and *(d)* (Figure 4.11d), they could be logically excluded since the depicted user's position is not indicated in a greenish polygon (check Figure 4.10a) which would be indicative of trees. The correct answer would be possible to identify not only by using the exclusion principle, but also by confirming the presence of a street and a somewhat large square (the large empty square in Figure 4.10a) in front of the user. Nevertheless, subjects had no apparent difficulty in finding the correct answer, in the presence of the *Orthophotomap* component, as 92% chose the correct answer in similar conditions.

Regardless of this considerable difference in correctness between one component or another, the answer times will be analysed. The following table summarises some statistical data for this exercise:

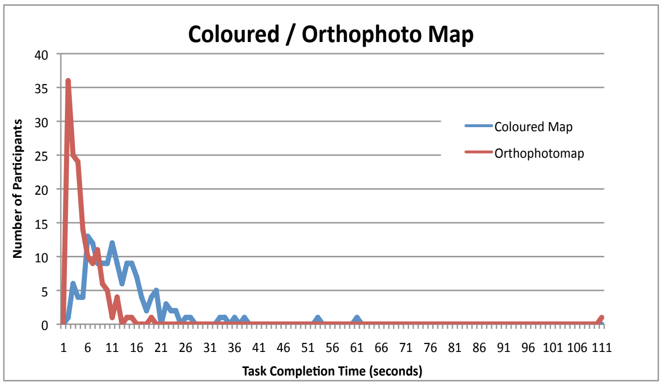
Time (milliseconds)	**Coloured Map**	**Orthophotomap**
Minimum	1216	728
Maximum	119106	219861
Standard Deviation	16768	18422
Mean	23471	9306
5% percentile	5150	1797
95% percentile	48590	20848

Table 4.3: General statistical data regarding the answer times in the presence of *Coloured Map* and *Orthophotomap* components

The average time it took subjects to answer this question is much lower in the case of the *Orthophotomap* component than in the case of the *Coloured Map* component which represents an increase of 150% additional time. To better understand the distribution of frequencies represented by the percentiles included in Table 4.3, the following charts are provided:



(a) 90% central interval limits

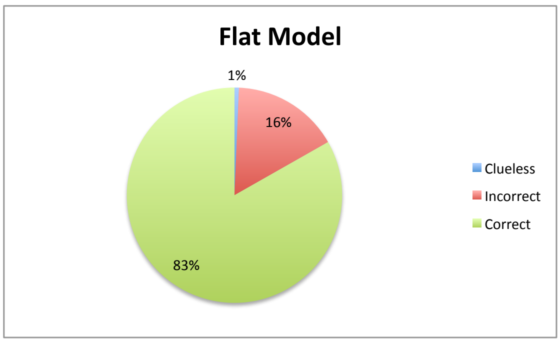


(b) Distribution of frequencies

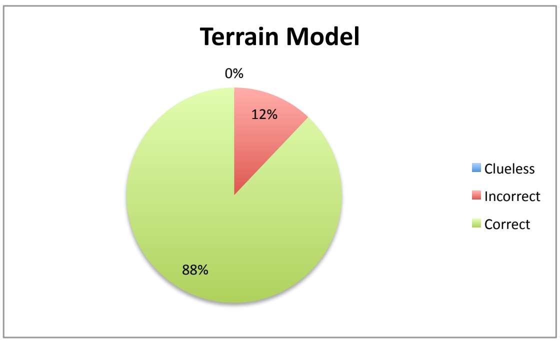
Figure 4.29: Distribution of frequencies regarding answer times in the presence of *Coloured Map* and *Orthophotomap* components

Due to a greater asymmetry in the case of the *Orthophotomap* component, it is possible to conclude that there is a higher concentration of subjects answering more quickly than in the case of the *Coloured Map* component. In the later case, subjects start answering later and the spectrum of frequencies is much wider, extending roughly to 49 seconds, when comparing to the 21 seconds in the former case (Figure 4.29a).

Speaking of map surface models, the results generally matched the initial expectations. The charts that summarise the subjects answers in the presence of *Flat Model* and *Terrain Model* components is shown below:



(a) *Flat Model* component



(b) *Terrain Model* component

Figure 4.30: Subjects' answers in the presence of *Flat Model* and *Terrain Model* components

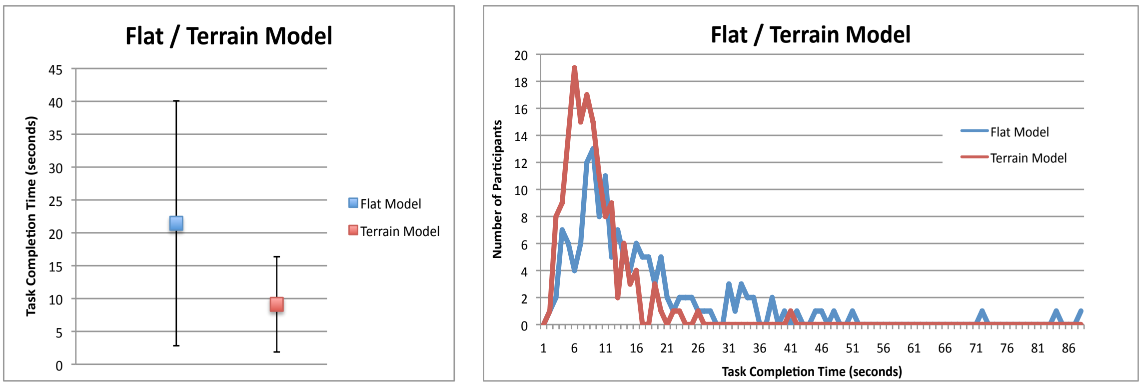
Although just 5% of difference in the number of correct answers between the two questions, this result is not conclusive of which component is more adequate. For this reason, an analysis regarding the time it took subjects to answer each of these two questions is of considerable interest:

Time (milliseconds)	**Flat Model**	**Terrain Model**
Minimum	840	737
Maximum	86074	39455
Standard Deviation	13830	5023
Mean	15283	7474
5% percentile	2825	1872
95% percentile	40079	16368

Table 4.4: General statistical data regarding the answer times in the presence of *Flat Model* and *Terrain Model* components

Just by observing that, in average, subjects take about twice the time to answer with a *Flat Model* (15.3 against 7.5 seconds), it becomes obvious that the *Terrain Model* component results in a better alternative. In terms of maximum times and standard deviation, *Terrain Model* yields much lower values, indicating that subjects feel much more confident that their answers correspond to the correct one. In the *Flat Model* component, subjects appear to be confident on their choice but they probably take more time "taking measures" and acquiring more reference points.

Although the difference in wideness of spectrum seems very significant, according to Table 4.4, the following charts provide a graphical overview of this situation:



(a) 90% central interval limits

(b) Distribution of frequencies

Figure 4.31: Distribution of frequencies regarding answer times in the presence of *Flat Model* and *Terrain Model* components

As we can confirm, there are more subjects answering quickly in the presence of the *Terrain Model* than in the *Flat Model* component. Figure 4.31a shows that 95% of subjects answer approximately before the first 16 seconds, in the case of the *Terrain Model* component, while in the case of the *Flat Model* component this borderline time increases to about 40 seconds.

Object Labelling

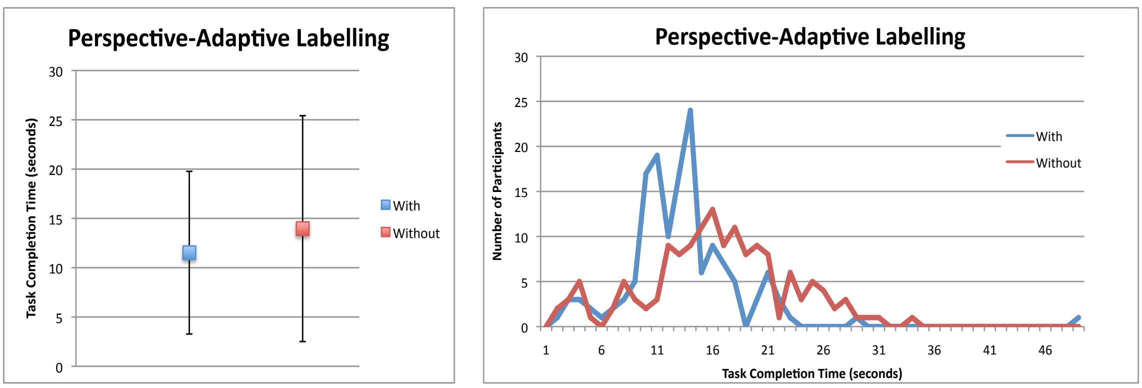
According to the methodology (see Section 4.1.6), the only component of this *feature vector* that was evaluated with the help of the questionnaire was *Perspective-Adaptive Labelling*. As mentioned before, the proposed exercise does not focus on "right or wrong" answers, but instead on the time required by test subjects to complete a given task.

The following statistical data summarise the ability of test subjects to read the names of streets in a couple of questions, either when the labels are oriented towards the camera's viewing direction, and when they are just laid down along the street vectors:

Time (milliseconds)	**Presence**	**Absence**
Minimum	574	510
Maximum	47474	32348
Standard Deviation	5224	6407
Mean	11778	14985
5% percentile	3273	2509
95% percentile	19772	25418

Table 4.5: General statistical data regarding the answer times in the presence and absence of *Perspective-Adaptive Labelling* component

As we can see, when labels are not oriented towards the camera's viewing direction there is a maximum answer time much lower than in the presence of this component. However, there is a significant 27% increase (more than 3 seconds) in the average answer time. In order to clarify this situation, the spectrum of answer times is analysed:



(a) 90% central interval limits (b) Distribution of frequencies

Figure 4.32: Distribution of frequencies regarding answer times in the presence and absence of *Perspective-Adaptive Labelling* component

As we can see in Figure 4.32a and according to Table 4.5, when labels are oriented towards the camera, 95% of test subjects have already finished reading after approximately 20 seconds. When labels are not oriented according to the camera, they finish reading about 6 seconds later, which represents a 29% increase, approximately.

In the spectrum of answer times (see Figure 4.32b), the two distributions are quite different from each other, in terms of answer peaks. When labels are oriented towards the camera, the were two high peaks at 10 and 13 seconds approximately, and then there are almost no answers in the following seconds. In the opposite case where labels are not oriented towards the camera, there are no significant peak times, and the distribution is quite homogeneous.

These results are the confirmation of the initial hypothesis that rests on the belief that a user will read labels faster, if they are oriented according to the camera's viewing direction.

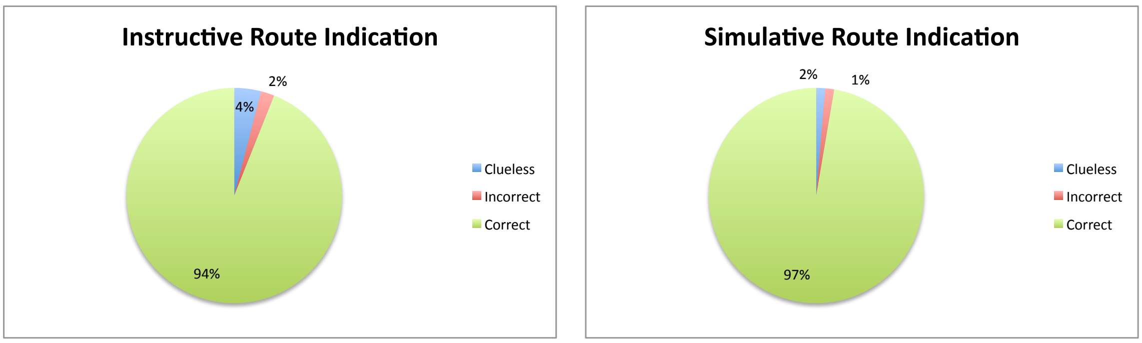
Route Indication

Taking into consideration the proposed methodology for this *feature vector* (see Section 4.1.6), the following components were evaluated:

- *Instructive Route Indication*
- *Simulative Route Indication*

The proposed questions for these components evaluate the users' ability to read the indication of the route, displayed on the device as a life-like signpost (in the case of the *Simulative* component) or simply as a label over the route (*Instructive* component), taking into account the correctness of their answers, and the time they take to perform the task.

The two following charts show the distribution of the subjects' answers according according to these two components:



(a) *Instructive Route Indication* component (b) *Simulative Route Indication* component

Figure 4.33: Subjects' answers in the presence of *Instructive Route Indication* and *Simulative Route Indication* components

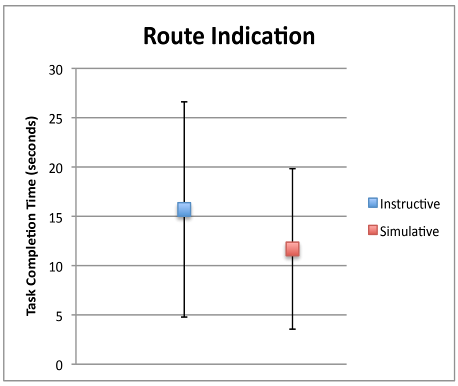
As we can see, there is no relevant difference in terms of answer correctness between *Instructive* or *Simulative* components. Because of this, a study on the time required to answer the questions, in the presence of one or the other component, becomes of uttermost importance. The following general statistical data about answer times is provided:

Time (milliseconds)	**Instructive**	**Simulative**
Minimum	776	1064
Maximum	60080	42091
Standard Deviation	7901	5948
Mean	11787	8618
5% percentile	4781	3555
95% percentile	26606	19831

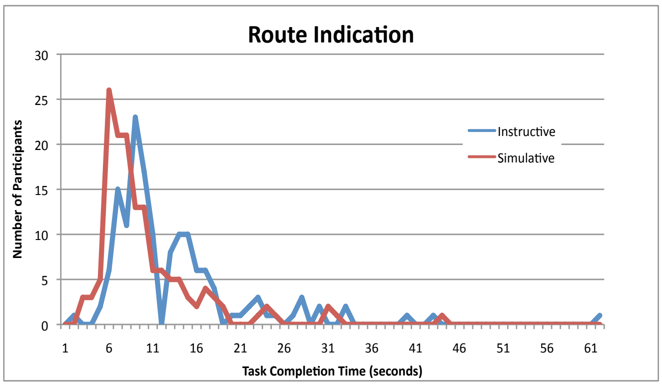
Table 4.6: General statistical data regarding the answer times in the presence of *Instructive Route Indication* and *Simulative Route Indication* components

Except regarding the minimum time, the *Simulative* component completely outperformed the *Instructive* approach. In terms of average answer time, the *Instructive* component results in 37% additional time (more than 3 seconds of difference). The same tendency can be observed in the standard deviation, with an increase of 33%, approximately.

Although the percentile values indicate a considerable difference in the rightmost part of the spectrum of answer times, the following charts are presented to illustrate the distribution of answers, according to the time variable:



(a) 90% central interval limits



(b) Distribution of frequencies

Figure 4.34: Distribution of frequencies regarding answer times in the presence of *Instructive Route Indication* and *Simulative Route Indication* components

As we can see in Figure 4.34a, when a *Simulative* approach is used, people start answering a bit sooner than in the *Instructive* component. The most evident difference, in the same chart, is that 95% of the participants have already found the matching route indication, after passing approximately 20 seconds. Using an *Instructive* approach, the same amount of subjects have only finished answering 7 seconds later, approximately.

These effects can be observed in Figure 4.34b, where there is only one big peak time near the 7 seconds. After this happens, the number of participants answering drops quickly until just a few are left. In the case of the *Instructive* approach, there are two considerable peak times and the distribution of people answering along the time variable is a bit wider than in the case of the *Simulative* component.

Again, these results confirm the initial expectations that users can better understand where they have to turn to continue their itinerary, if they are provided with an image that resembles reality in some way (e.g., by displaying an image of a highway with life-like sign posts), rather than if they are just provided labels on the screen telling them where to go.

Landmark Symbology

As described in Section 4.1.6, the only component of this vector that is subject to evaluation is the *Adaptive Zoom* magnitude. Since this component is evaluated in the third part of the questionnaire, no "right or wrong" answers or task completion times will be taken into account. Instead, users are expected to indicate their preferences in two questions that evaluate the need of the *Adaptive Zoom* behaviour, i.e., if users indicate that they prefer a considerably abstract landmark when the map is zoomed out very distant from it, and, on the contrary, if they prefer a highly concrete landmark when the map is zoomed in enough, so the landmark fills a wide proportion of the screen.

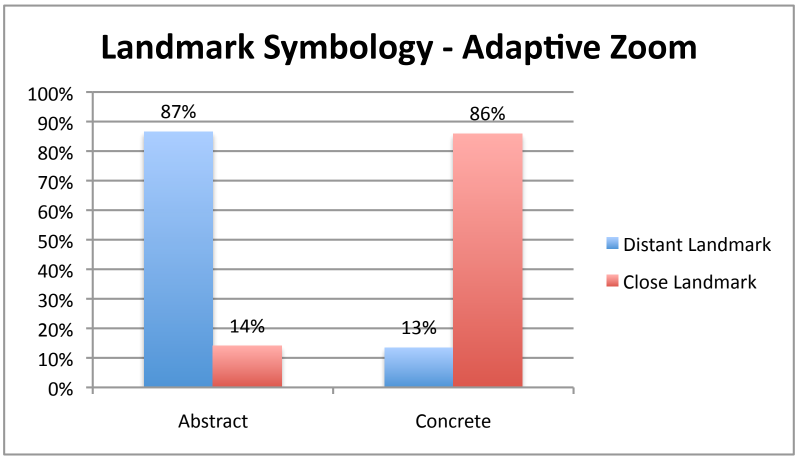


Figure 4.35: Subject's preferences regarding *Landmark Symbology*

As we can see, a vast majority of participants (87%) answered they would more easily identify and recognise the presence of a given distant landmark, when an abstract representation of that landmark. was used. Almost the same percentage of subjects (86%) indicated their preference towards the use of concrete landmarks, when they are displayed from a very close position.

These results confirm the initial hypothesis that users feel the need to get the appropriate abstractness level to represent a landmark, depending on the current zoom level, indicating that this should be done continuously along a monotonic zoom operation.

4.3 Summary

In this chapter, the evaluation of *feature vectors* was conducted, through the help of an online questionnaire. Because of its limitations, some components were not evaluated, and, as already mentioned before, the questionnaire was not to be perceived by users as "too extensive" or "annoying", if questions evaluating all possible components were included as part of it. Instead, the questions that have received less attention, from the state of the art studies, were the focus of the proposed questions. Moreover, it is considered that some of the components that were not evaluated with this questionnaire, would be more interestingly tested using a more dynamic experiment (e.g., a driving simulation).

During the conception of all the questions of the questionnaire, and before administering it to potential participants, these questions were discussed and the scientific methodology for the evaluation of *feature vectors* was described by formulating a set of hypothesises.

A considerable number of test subjects have answered the questionnaire, providing very insightful results. In fact, all the initial hypothesises were confirmed positively:

1. *Photo Textured Buildings* rather than *Simple Textured Buildings*;
2. *Orthophotomap* rather than *Coloured Map*;
3. *Terrain Model* rather than *Flat Model*;
4. *Simulative Route Indication* rather than *Instructive Route Indication*;
5. *Perspective-Adaptive Labelling* rather than its absence;
6. *Adaptive-Zoom* rather than its absence.

In general, it is observed a greater tendency towards the need of *Image Realism* rather than *Image Functionalism*, according to the best approaches that resulted from this questionnaire: *Photo Textured Buildings*, *Orthophotomap*, and *Terrain Model*.

In terms of *Perspective-Adaptive Labelling*, it was proved that users are at disadvantage, if they are given the task to read labels of a map, when these labels are not oriented towards the camera's viewing direction.

The results also demonstrated that users can more easily identify the presence of a distant landmark with an abstract representation, and a close landmark with a concrete representation, which is indicative of the need of an *Adaptive-Zoom* behaviour.

Chapter 5

A Visualisation Paradigm for 3D Map-Based Mobile Services

Feature Vectors – the building blocks of the proposed *Evaluation Framework* – were evaluated in the previous chapter, by means of assessing and comparing the impact of the presence and absence of its components, with the help of an online questionnaire.

Due to the intrinsic limitations of the proposed questionnaire, and in order not to make it perceived by potential participants as “too exhaustive”, only the *feature vector* components for which there are no significant indications from the state-of-the-art (regarding their impact and relevance) were evaluated with the questionnaire. The results were analysed, and the best approaches for each evaluated *feature vector* component were outlined.

This chapter completes the evaluation of the whole framework, by combining the results of the questionnaire, and discussing the *feature vector* components that were not evaluated, based on state-of-the-art studies, experience in practical use and empirical knowledge of 3D map-based mobile services

In this chapter, the totality of the *feature vectors* that compose the proposed *Evaluation Framework* are discussed as a whole, and a new visualisation paradigm for 3D map-based is introduced. In this chapter, the high-level requirements of a general prototype for 3D map-based mobile services are outlined, taking into account not only the ideal approach for each component individually, but also eventual conflicts or design issues that may arise in their interaction.

5.1 *Feature Vector* Analysis

In this section, the best approaches to follow are discussed, regarding the individual impact of each *feature vector* component.

5.1.1 Image Realism

It is undeniable that there is a need of all the proposed *orientations* for this vector: *3D Buildings*, *Map Vectors*, and a *Surface Model*. With regards to this, the results of the questionnaire clearly identified the three best approaches, by means of identifying instances (combining *orientation* and *magnitude*) of *Image Realism*:

1. *Photo Textured Buildings* rather than *Simple Textured Buildings*;
2. *Orthophotomap* rather than *Coloured Map*;
3. *Terrain Model* rather than *Flat Model*.

It is safe to assume that *Mixed Realism* or *Photo-Realism* cannot be used interchangeably at any time, i.e, it cannot be affirmed that their use does not affect users' performance nor is limited by any restriction.

Virtuality alone is enough to allow a user to perform every task, although not as immersive as the experience provided by an *Augmented Reality*. However, a 100% AR-based approach quickly fails to provide the users the ability to "see" past the first 50 meters. As explained before in Section 3.3, there is an intrinsic limitation to this kind of paradigms, because they cannot provide information apart from what the built-in cameras can capture. Like [Narzt et al., 2006] argued (see Section 2.3.10), this kind of paradigm is ideal when the user is driving a car, i.e., performing a *Navigation Task*. The problem arises when the user tries to apply this paradigm outside the reduced visibility range provided by the live imagery. In such situation, the user won't be able to plan an itinerary, to get a route overview, and so on. Therefore, it is believed that the merging of both paradigms could prove to be the best choice. An example of this is *Enkin* which is unique in the sense that it tries to ameliorate this limitation by bridging the gap between both reality and virtuality, using not only AR but also three-dimensional virtual maps that can be used away from the current location.

The advantage given by *Mixed Realism* can make users' tasks easier, but the scope of these tasks is very limited. That's where *Photo-Realism* comes in, providing a visualisation paradigm that cannot be achieved, by any means, with a *Mixed Realism* approach. In general, it is believed that the combination of both *Photo-Realism* and *Mixed Realism* magnitudes, similarly to what *Enkin* does, will provide the best results.

5.1.2 Object Labelling

With regards to *label positioning*, it can be observed (see Figure 3.22) that the current tendency is towards the adoption of *General Positioning* algorithms. Irrefutably, rivers and other polygonal chains are best described using a *Line Positioning* approach; countries and other polygonal features are more easily recognised using an *Area Positioning* approach; and, finally, cities and municipalities are better perceived if they are indicated with a *Point Positioning* approach. Additionally, and provided that most applications have evolved from simple city guides to general purpose mobile maps, the combination of the 3 strategies – represented by the *General Positioning* algorithms – becomes the most appropriate choice.

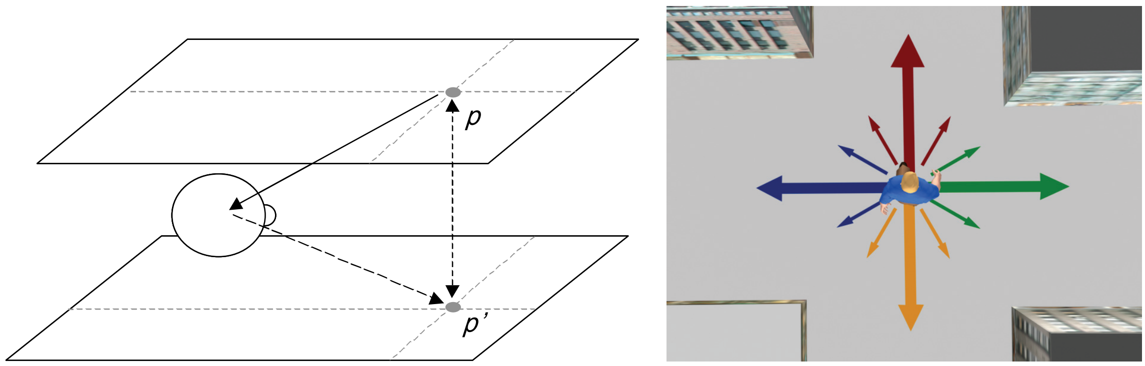
Speaking of *Static/Dynamic Selection/Placement*, the desiderata described in [Been et al., 2006] should be taken into account when creating dynamic maps, in order to maximise readability and comprehension. It is believed that maps that do not achieve any of these desiderata, but still provide continuous zoom and panning operations (i.e, they provide *Static Selection* and/or *Static Placement*), makes it very difficult for users to perform the matching of labels with the corresponding point, line or polygonal features of the map. For example, suppose a user is reading a given city name label; he/she pans the map around just a bit, and then the city label vanishes completely or suddenly "pops up" (i.e., in a discontinuous manner) in a completely different position on the screen. For these reasons, according to the state-of-the-art studies in the field of *Object Labelling* (see Section 3.4), the current tendency is to find stable and fast algorithms, while pursuing *Dynamic Selection* and *Dynamic Placement* of labels.

The results of the questionnaire also demonstrated that a *Perspective-Adaptive Labelling* approach results in faster responsiveness from the users than in its absence. The reason for this advantage, is that users generally feel a higher degree of difficulty reading labels that, instead of being oriented towards the camera, are laid down along the street vectors, and have therefore, reduced visibility and readability. When labels are not oriented according to the camera's viewing direction, they usually pan the map, so they can see labels closer enough to make them readable, or, alternately, they may skip reading some of their words, especially when labels' vectors are nearly parallel to the camera's viewing direction.

5.1.3 Visual-Spatial Abstraction

There are already several directions provided by the state-of-the-art contributions, with regards to *Visual-Spatial Abstraction*. First of all, as analysed in Section 3.5, there is an evident tendency towards the use of all the camera levels in mobile map applications. To understand when to use which level, one needs to understand the difficulties and requirements expressed by test subjects when performing tasks with mobile maps. For instance, due to the nature of the *Ground Level* perspective, one can argue that the *walking view mode* in *TellMarisGuide* (see Figure 3.23) is among the best choices for *Locator Tasks*. In the *top view mode*, since buildings cannot occlude other buildings, it becomes easier to search for nearby facilities which is the purpose of *Proximity Tasks*. On the other hand, both *flying* and *top view* modes can be used for orientation purposes, as the users are able to get a better overview of the surroundings and will more likely spot a landmark or reference point which is part of their spatial knowledge. In fact, test subjects already mentioned that when they are performing a *Navigation Task*, it is sometimes very useful to zoom out (i.e., to raise the camera level) just enough to get a better overview of the surroundings, and possibly spot a landmark or some feature that is part of their spatial knowledge [Laakso, 2002].

Speaking of adaptiveness, it is believed that an *Adaptive Orientation* approach is generally the best to follow. This approach is advocated in most AR-based prototypes and studies, which is considered an essential requirement in order to have the live imagery coherent with the mobile map information that augments the real environment. For instance, in [Oulasvirta et al., 2007] a test experiment was conducted to study the impact of the *virtual-physical mapping problem* (see Figure 5.1a). First of all, test subjects had to navigate along a predefined route in both *Virtual Environment* and *Physical Environment*, using either 2D or 3D maps. Half of the participants were given the task to navigate the route in a counter clockwise direction.



(a) The *Virtual-Physical Mapping Problem* (b) Possible viewing directions in a crossing

Figure 5.1: The *Virtual-Physical Mapping Problem* and a common problematic situation – adapted from [Oulasvirta et al., 2007]

The results not only demonstrated that the 3D maps provided shorter completion times, but also that the worst problematic misalignments between the 2D and the 3D maps could be found at the conditions of 90 degrees. Provided that misalignments and the wide range of possible viewing directions (see Figure 5.1b) can pose a big problem to the success and effectiveness of a user task, by causing a lot of confusion among users, it is believed that an *Adaptive Orientation* approach is an important requirement, for the purpose of solving such issues.

Regarding the *Adaptive Level* component, there are already some options available that take contextual variables into account. For instance, when a user is driving slow, and suddenly presses the accelerator to achieve a higher speed, the automotive navigation system will generally adapt to this situation by increasing the camera altitude, providing a better overview of what is ahead. When a user is moving "very fast" (e.g., 100 km / h), it is safe to assume that he/she is probably in a highway, where such speeds are allowed by law. In this example, where the user is moving at 100 km / h (or approximately, 28 meters per second), it won't be enough if the mobile map only shows him/her the first 10 meters. This is where the *Adaptive Level* comes in, by not only showing the appropriate extent of map ahead of the user, but also providing the next exits in a highway, like in the example given.

Despite being demonstrated the need for an *Adaptive Level* behaviour, it would be interesting to study an expansion of possibilities.

5.1.4 Route Indication

In terms of *Route Indication*, the results of the questionnaire proved that a *Simulative Route Indication* can result in faster responsiveness from users than a *Instructive Route Indication*. This happens because users can more easily change their "mental context" into processing the image shown in the device, if it resembles real route indications, like the signposts with the names of exits in the next major interchange, which is only provided by a *Simulative Route Indication* component.

In terms of visual route indicators, nothing relevant is mentioned in the state-of-the-art, except a greater attention towards the use of audio instead of visual travel indications, which is not the purpose of this study. Nevertheless, there are some conclusions that can be taken, capturing experience from practical use. First, a *Cord* or a *Carpet* are believed to be the most appropriate indicators to provide guidance, when a user is moving between a line segment. On the other hand, an *Arrow* can provide useful "turn right", "turn left" indications, or even "go straight" manoeuvre indications. In terms of *Way Points*, and when comparing it to the other 3 components, it is believed that don't provide any additional information that helps improving the users' performance, since it is just a discrete point along the route. If we think in a more "mathematical" way, we can argue that a *Way Point* is to a point, as a *Cord* is to a line. The only possible advantage of a *Way Point* is for collaborative navigation, where users can mark and uniquely identify a given point for posterior recognition.

5.1.5 Landmark Symbology

Similar to what happened in the case of *Image Realism* and *Object Labelling* orientations, in the case of *Landmark Symbology*, all kind of buildings are necessary for a more complete map representation, namely:

- Shops (referenced by name);
- Shops (referenced by type);

- Buildings (with unique name / function);
- Buildings (with unique visual properties).

The main question here is how and when should each building be represented. To answer this question, the *Adaptiveness* magnitude for this vector should be taken into account. According to the experience in practical use of maps, all the various abstraction levels are considered relevant, depending on the type of building, as demonstrated by the following figure [Elias et al., 2005]:

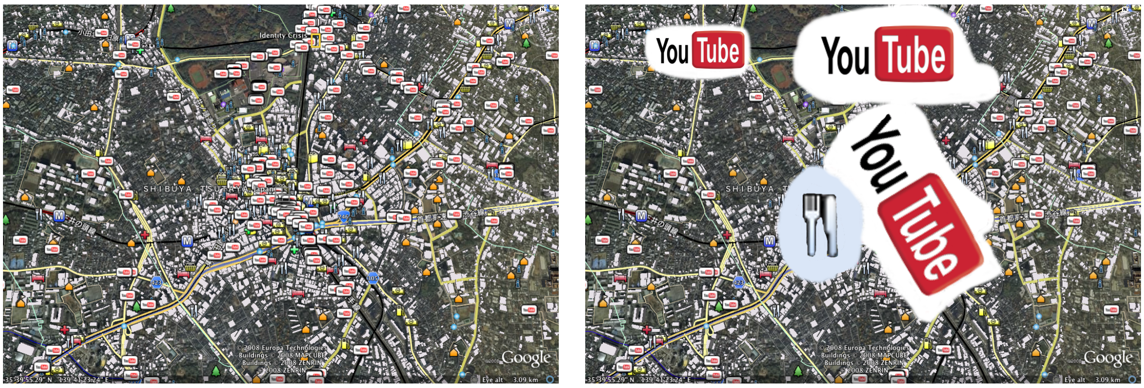
	Image	**Drawing**	**Sketch**	**Icon**	**Sign**	**Words**
Shop (Name)			(+)	+		
Shop (Type)				+	+	+
Function/Name	+	+	+			+
Visual Aspect	+	+				

Figure 5.2: Design proposals for landmarks – adapted from [Elias et al., 2005]

Speaking of *Adaptive Zoom*, the results of the questionnaire clearly indicated that users prefer highly abstract representations for a landmark, when its features are not perceptible by the human eye, which may occur when the map is zoomed out so much that a given landmark is not possible to identify as a church, hospital, or whatever it represents in reality. On the other hand, an abstract representation may not be enough, especially in locator tasks, when users are trying to compare a close view from a landmark which is right in from of them. In such case, a highly concrete landmark representation is preferred. These circumstances indicate the need and advantage of an *Adaptive Zoom*, i.e., the need of continuously adapting the current landmark abstraction level, as a function of zoom.

Regarding *Adaptive Complexity*, and looking at a typical view of a map provided by *Google Earth* (see Figure 5.3a), like many other visualisations, there is a huge amount of *icons* and *signs* overlapping mutually, and filling the whole view area. Because of this, it can be easily argued that the task of "decoding" all the represented information constitutes a very difficult and time-consuming "painful" headache.

To solve this problem, one needs to understand that the issue rests in the huge amount of landmark information, a symptom of a visualisation lacking *Adaptive Complexity*. Many solutions could be thoroughly studied and analysed but in the context of this dissertation, only a possible "workaround" is proposed. The workaround consists of grouping / merging similar symbols which are close to each other into hierarchically more abstract representations; or grouping equal symbols into increasingly bigger ones (representative of a cluster of that symbol). The visual effect is somewhat similar to the one observed in Physics: mercury droplets merging together into bigger droplets, when they are close enough to each other. This process is roughly exemplified by the following figure:



(a) Before

(b) After roughly applying the concept to the map's centre

Figure 5.3: A proposed change to *Google Earth* to implement a kind of *Adaptive Complexity*

Figure 5.3b is a modified version of Figure 5.3a that illustrates this concept. Figure 5.3b may not seem very convincing of the impact of the proposed concept, due to the low quality handmade modification that was performed. Nevertheless, the reader should focus mainly on the map's centre, where the modification was roughly applied. Please note that many aggregations could still be performed, given that just a few were considered to illustrate the concept.

In the resulting figure, *You Tube* icons that were in the centre of the map were grouped into bigger clusters of *You Tube* icons. The same can be said about the restaurant *signs*. It is possible observe that the number of icons that were grouped from the original figure, influence the final size of the corresponding cluster icon. Although not illustrated in the previous figure, similar symbols (e.g. bus, tram, train, metro) could be grouped by proximity into more abstract representations (e.g. public transportation).

Provided that any zoomed out map contains a lot more symbolic information than its zoomed in version, the proposed "workaround" would be able to reduce (to some extent) the level of complexity observed in the previous or similar examples, and to keep the landmarks' global complexity level with little variance under monotonic zoom operations. For instance, in a zoomed out map, users would see few but big "droplets" of clustered symbols, which in turn would suffer a "desegregation" process when zooming in, since the area of visible map would become smaller, and thus less information would be shown. When zooming out again, symbols would suffer the reverse process, i.e. they would be "aggregated" into bigger symbols like the example given regarding droplets of mercury fusing together.

5.1.6 Contextual Awareness

The proposed *orientations* for *Contextual Awareness* (*Reconstructional*, *Recreational*, and *Fictional*) should be chosen according to the context and scope of the mobile application. For instance, a mobile guide that aims to rebuild the ancient city of *Atlantis* will provide a strong *Reconstructional* approach rather than the other two, because it is related to the scope of the application. Similar examples can be given for the other two *orientations*.

In terms of *magnitudes*, there is a contextual awareness variable that is common to all mobile map applications (or they wouldn't be called "mobile"), i.e. the location context. Apart from this, the other contexts can be "processed" in a passive (when the user asks for more information) or in an active way (i.e., automatically) by adapting to the detected context.

As already discussed in Section 3.8, it is argued in some studies that an *Active Awareness* approach can become very obtrusive, especially when the detected context does not correspond to the real context and, thus, opposes the users' expectations. Nevertheless, it is believed that every mobile map application should leverage the awareness levels appropriately, depending on whether the information is considered relevant or not, and hopefully provide means to toggle back and forth between both *Active Awareness* and *Passive Awareness* modes. For example, suppose a given application feature which decides when to toggle between "in-car" and "pedestrian" modes activates "in-car" mode in an automatic way, after incorrectly supposing that the user is driving a car (but in reality he/she is walking the sidewalk). In this case, the user should be given the ability to change back to "pedestrian" mode, or he/she will feel frustrated and think that the application is trying to be "too smart". In such case, the application should be able to detect whether a user is feeling annoyed by it (for instance, the application receives 5 consecutive "not interested" inputs from the user in the past 3 hours, every time the application tried to offer a scenic visualisation along a long-distance route). Additionally, it should be able to learn with its mistakes and become more "conservative"/"clever" in its decision making process, before the user feels irritated at it.

5.1.7 Summary

With respect to what was mentioned in the previous sections, the following Table summarises the best approaches for each *feature vector* individually:

Feature Vector	**Orientations**	**Magnitudes**
Image Realism	3D Buildings, Map Vectors, Surface Model	Mixed Realism, Photo-Realism
Object Labelling	Perspective-Adaptive, General Positioning	Dynamic Selection and Dynamic Placement
Visual-Spatial Abstraction	Ground Level, Local-Area Level, Wide-Area Level	Adaptive Level, Adaptive Orientation
Route Indication	Arrows, Cords, Carpet, Way Points[1]	Simulative
Landmark Symbology	Shops (referenced by name), Shops (referenced by type), Buildings (with unique name / function), Buildings (with unique visual properties)	Abstractness (Words, Sign, Icon, Sketch, Drawing, Image), Adaptive Zoom, Adaptive Complexity
Contextual Awareness	[Reconstructional, Recreational, Fictional][2]	Active Awareness, Passive Awareness

Table 5.1: The ideal set of *feature vector* components that individually maximise user experience and performance with mobile 3D maps

5.2 A Visualisation Paradigm for 3D Map-based Mobile Services

In this section, a visualisation paradigm for mobile 3D maps design is presented, taken into account the interactions that may arise between *feature vector* components. The combination of components is important to analyse, since it may happen that some of them conflict with others, lose their meaning, or become incomplete if used alone. In an ideal case, no conflicts would arise, and the entirety of *feature vectors* would compose a puzzle where every single piece would fit in a decided place.

In this section, a general specification of the most common high-level features is outlined for 3D map-based mobile services, taking into account the interactions between *feature vector* components and eventual conflicts that may arise.

5.2.1 Visualisation Layers

In this section, a general specification of 3D map-based mobile services is outlined, regarding the multiple layers of visualisation elements. These layers, as the name implies, can be turned on or off to compose the final image presented on a device.

[1]Ideal for collaborative navigation only
[2]The choice of the component should be based on the scope of the application

Regular buildings

Buildings are one of the most important layers of a map, since they often correspond to the source and destination in a navigation task. For a better user responsiveness in identification tasks, the buildings should be depicted as *Photo Textured Buildings*.

When it is not possible to model every building as a high-quality *Photo Textured Building*, users will also be able to achieve an acceptable level of performance in identifying *Simple Textured Buildings*, as demonstrated by test subjects in the questionnaire.

Similarly, for some circumstances where there are no models of the 3D geometry for most buildings, the questionnaire proved that the difference between providing the third dimension (even with simple textured or coloured façades) and not providing it (i.e., just showing a 2D polygon) results in a complete disparity of user performance.

Even if there are no 3D models of buildings available, it is still preferable to depict buildings somehow different from each other, and from other urban features, in order to maximise the user ability to recognise their presence. For instance, if there are data regarding the heights of buildings but no geometry at all, it will be considered a better option to show these buildings as extruded 3D blocks with the heights of the corresponding buildings, than not showing the building at all (or showing it in 2D). Alternately if there is at least information indicating the presence of a building, regardless of its height, buildings can be represented with a standard height, just to make a clear distinction between what is a building and what is not, like *TomTom* does.

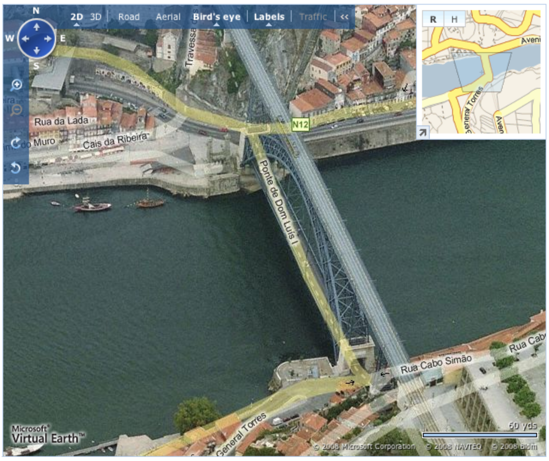
There are also cases where 3D buildings can cause occlusions along the route, making the navigation task more difficult. For instance, in the most pessimistic case, a user can be driving a car in a narrow one-way street, with lots of buildings (like houses) on both sides, and approaching a manoeuvre where he/she has to perform a 90-degree turn (or more, for even worse cases). If the occlusions are not taken into account, it will very difficult to visualise the route, and to prepare the next manoeuvre with anticipation, with this kind of visualisation paradigm. One solution for this can include rendering buildings near a manoeuvre point, in a translucent way, so that the route becomes visible, while keeping the presence of such buildings perceptible to the human eye.

Roads and Polygonal Features

Roads are an important part of a mobile 3D map, allowing us to find our way through an urban environment. Polygonal features, comprising urban, water and vegetation features, often represented by polygons, allow us to identify and to recognise the surrounding environment, while comparing it to the image presented on a device.

For these two elements, the best approach would consist of using the *Orthophotomap* component, since it allows a faster and more reliable identification of the ground features that surrounds the users.

One possible conflict can arise in combining the *Orthophotomap* with the *3D Buildings* component. Depending on the kind of orthophotograph which is used for the map, some 3D buildings may look like “shifted” from their true position. In practise, this effect can be observed, when an oblique orthophotograph is used along with 3D buildings. According to the definition of *orthophotograph*, it is a photograph of the ground surface which has been geometrically corrected, so it can be used with an uniform scale. To illustrate the differences, the following two screenshots are provided:



(a) Oblique orthophotograph – obtained from *Microsoft Virtual Earth*

(b) Perpendicular orthophotograph – obtained from *Google Earth*

Figure 5.4: The difference between oblique and perpendicular orthophotographs

As we can see, if we consider Figure 5.4a as the map’s surface, and overlay a bridge or any 3D buildings over this surface, several artefacts will arise near the point where the bases touch the map’s surface.

For these reasons, it is believed that if the *Orthophotomap* is used in combination with the *3D Buildings* component, the orthophotograph should be of perpendicular type (as in Figure 5.4b). If the *Orthophotomap* component is used alone, for some reason, it is considered better to use an oblique orthophotograph (as in Figure 5.4b), since it produces a visual effect similar to the one provided by *Photo Textured Buildings*, at the same computational cost of using a perpendicular orthophotograph, but obviously having a limited use.

Another problem that may arise, when using the *Orthophotomap* component, is that it may be more difficult to visualise the road network, under certain conditions. For instance, when oblique orthophotography is used for the map and the road vectors are behind the buildings in the photograph; or when the visual features of a road disappear (under monotonic zoom out), the solution can consist of colouring the vectors with a translucent colour, over the photograph, so the presence of a road network becomes more evident.

The labels of roads should be, as much as possible, oriented towards the camera (*Perspective-Adaptive Labelling*) for higher readability, so it makes no difference if we are reading labels in the horizon or the label of the current street.

Roads and polygonal features should be labelled using a *General Positioning* approach, i.e., for roads, a *Line Positioning* approach is the most indicated, because a road is a linear feature; while polygons, like countries, cities or wards are better labelled with an *Area Positioning* strategy. Some problems may affect readability, when displaying a label of a street along its line, depending on the angle used to represent the road vector. If labels are considered difficult to read in such circumstances, it may be preferable to adjust its rotation angle a bit different from the road vector angle, so this problem disappears.

Rivers and mountains

There must be a clear difference between elevations of the ground surface. This is possible through the use of a *Terrain Model*, which must be combined with the *Orthophotomap* component, for a higher degree of *Photo-Realism*. When this layer is turned on, it will be possible to see a clear distinction between the altitude of rivers and the altitude of the peaks of mountains.

In certain circumstances, especially when the user is in a place containing a lot of mountains, many occlusions may block him/her from observing what's ahead of them, using a *Terrain Model*. In such case, this can constitute both an advantage and a disadvantage, depending on the user's task: a disadvantage if the user is performing a *Proximity Task* to find nearby facilities, but an advantage if the user is trying to answer the question "Where am I?" (i.e., performing a *Locator Task*).

However, extending this example to a *Navigation Task*, we can suppose that the user decided to go to a nearby facility. Without a *Terrain Model*, the user might be deluded into thinking that the distance is much shorter than in reality, just by looking at the visual route overview from his/her current position to the destination facility. This may happen because of the vertical distance that is not accounted for, when producing a visual route overview with a *Flat Model*.

Because of these restrictions, the ability to turn on and off this component may become an advantage for the user, depending on whether there are many occlusions caused by high elevations from the terrain that make it impossible to see far ahead.

Points Of Interest

Points of Interest, also known as landmarks, refer to buildings with historical significance or other prominent objects in a given landscape. Users must be able to find all kinds of Points of Interest, including shops referenced by name and/or type, and buildings with unique name / function / visual properties.

For many specifications of a mobile map, it may be difficult to provide all the possible abstraction levels. Nevertheless, at least 2 or 3 levels of abstraction should be used, from the most abstract to the most concrete:

1. *Sign*, *Icon* or *Sketch* for the most abstract representations;
2. *Drawing* or *Image* for the most concrete representations;
3. *Words* as an addition, especially in the case of landmarks referenced by their unique names.

However, when it is not possible to model all landmarks with an *Image* symbol, then it should be given particular attention to modelling at least the most famous buildings and monuments. By modelling famous buildings instead of less important ones, the probability of providing guidance for a random user will be maximised.

5.2.2 Visualisation Functions

In this section, the general specification of high-level user features which are considered a requirement for the great majority of 3D map-based mobile services is outlined.

Panning the map

It should be possible to pan the map around and see the labels in a continuous way, i.e., *Dynamic Placement* of labels should be achieved. The user should not be confused with visual artefacts of labels popping in or out, especially in the limits that define the view area of the screen.

Zooming the map

Under monotonic zoom, the labels of the map should appear in a continuous way, i.e., *Dynamic Selection* should be supported. This allows, for example, that labels do not appear, disappear, and then reappear when continuously zooming in or out. This implies that, for example, when zooming in, labels that are visible should not suddenly "vanish", but instead slide out of the view area. The same reasoning can be applied for the opposite circumstance, i.e., when zooming out, labels that are not visible should not suddenly "pop in", but instead slide into the view area [Been et al., 2006].

The size of labels should be decided as a function of zoom as, for example, when a label of a city occupies the entire polygon that defines its borders, the name should be reduced when zooming out, or enlarged when zooming in, until it is not selected visible for a given zoom level.

Showing Points Of Interest

When showing POIs, some care should be taken regarding the choice of the represented abstraction level. It is believed that when a landmark is far from the camera, an abstract symbol such as a *Sign* or an *Icon* should be used, rather than an *Image*. The opposite is also true, i.e., when the camera is close to the landmark, a more concrete representation like an *Image* should be used instead. In general, the abstraction level for a landmark representation should be higher, when its visual features are not visible enough to allow an appropriate recognition; and lower, when the addition of visible visual features could improve identification of nearby landmarks. The *Adaptive Zoom* component can help the visualisation paradigm selecting the appropriate abstraction level of a landmark as a function of zoom.

At far distances, there are cases where the number of overlapping POIs becomes so high that is impossible to recognise what is where. For this reason, the visualisation paradigm should be capable of aggregating close or overlapping *POI*s into abstract clouds representative of the group of *POI*s that were aggregated. This "clouds" will be broken into smaller clouds as we zoom in the map, since the number of *POI*s will be reduced along with the size of the view area.

Navigation

It is unthinkable not to use an *Active Awareness* approach, especially in an automotive navigation experience, to provide users route indication instructions, since they are concentrated driving and paying attention to the road, and thus not as willing to receive turn-by-turn instructions in a passive way as if they were a passengers.

There are several situations where a *Passive Awareness* approach can be used during an automotive or pedestrian navigation task. If we suppose a user is taking a walk or driving a car, in an ancient part of a city, he / she can indicate the desire to observe the same city as if it was 100 years before. This concept introduces the need of a *Reconstructional* approach, i.e., to provide the ability to visualise a given location that does no longer exists. The choice will obviously depend on the scope and context of the mobile map, and there is no limit to the combination of the three possible approaches (*Recreational*, *Reconstructional* or *Fictional*).

In terms of *Route Indication*, it can be argued that a *Cord* or a *Carpet* may not provide enough visual information, when used alone. In a pedestrian navigation experience, it is believed that their use may not affect negatively the users' task, but in an automotive navigation experience, where drivers have to follow more strict rules, and therefore pay more attention to their actions, the presence of one of these two components alone may result negatively. For instance, suppose the user is driving fast in a highway, and that there is a major interchange in the next 20 meters. In this case, if the driver is attentively relying on the instructions provided by the mobile map, he/she may fail to understand soon enough that there is an exit to the right (or to left) right ahead, by reducing the current speed and performing the appropriate manoeuvre. This means that, an *Arrow* is considered the best approach to visually mark the presence of manoeuvres, in order for the users to understand what actions to take with appropriate anticipation. For the same reason, an *Arrow* indication alone is not enough to indicate the route, especially if there is a great distance between to consecutive manoeuvres, when that's where a *Cord* or *Carpet* can provide guidance, i.e., during the interval between two manoeuvres.

When coming closer to a major interchange, drivers will be able to read (on the device) life-like signposts with destinations written on them, along with manoeuvre indicators provided by a *Simulative Route Indication* approach, allowing them to identify – much faster and accurately – the correct way to follow.

The previous example also introduces another problem: when a user is driving fast, it should be possible to see "more ahead", in order to properly anticipate manoeuvres. In a pedestrian navigation, users will be interested in a *Ground Level* perspective for identifying buildings around them; in a *Wide-Area* perspective for acquiring an overview or planing their itinerary; and an intermediate *Local-Area Level* perspective for confirming the presence of a landmark in the surroundings, especially when coming near a point where they have to take the decision where to go next, which is analogous to a manoeuvre in the case of an automotive navigation experience. Ideally, this change should be performed automatically by the map, i.e., it should provide an *Adaptive Level* camera.

In a pedestrian navigation experience, it should be of extreme importance that the visualisation adapts to match the same orientation than in reality, i.e., that it supports *Adaptive Orientation*. For instance, if a user is standing still, but looking to the buildings around him/herself, the visualisation should reflect what in reality the user is facing to. In the end, the user will have less difficulties matching the perspective of both realities, when identifying the buildings around.

5.3 Summary

In this chapter, the set of *feature vector* components that individually maximise usability and user experience, with regards to mobile 3D maps, was presented and discussed, considering the ideal situation where the components do not influence each other, i.e., that the final result comprises the sum of the parts.

The interactions between components were analysed, with particular interest on conflicts that may prevent their practical application. Several suggestions were presented, with the purpose of solving these issues, and a specification for generic 3D map-based mobile services was outlined and discussed, through a set of practical examples.

Chapter 6

Prototype

In this chapter, the visualisation paradigm for 3D map-based mobile services (specified in Chapter 5) was used for the requirements specification of a prototype, and tailored to meet the specific needs of an automotive navigation system developed at *NDrive Navigation Systems, SA*.

In the following sections, a study on the issues and challenges that may arise in the development of such prototype are considered, given the current hardware limitations of mobile technology. After that, the prototype is developed and presented in this study. Finally, some conclusions and notes for future work regarding the prototype are outlined.

6.1 Visualisation Specification

Based on the set of "ideal" *feature vector* components (see Table 5.1), and taking into consideration the discussion on eventual conflicts that may arise (see Section 5.2), the novel paradigm defined in the previous chapter was applied for the specification of an automotive navigation system prototype.

In this section, the list of high-level user features is outlined, and the relevant system constraints that capture the conditions for the use of this prototype are elicited. Each requirement will be classified in terms of priority of its implementation, according to the following scale (from the most important to the least):

- Essential – Due to the existing technical challenges and mobile hardware restrictions that the requirement in question represents, its implementation is considered vital for unlocking doors for future development, and allowing the successful implementation of the novel paradigm, using current mobile technology.

- Necessary – The implementation of the requirement in question does not directly represent an important step in the applicability of the novel visualisation paradigm nor it solves any technical challenge, but it allows other essential requirements to be implemented.

- Desired – The requirement in question would bring an added value to the implementation of the novel visualisation paradigm, but its implementation is not considered vital for the feasibility of the novel visualisation paradigm, given the limitations imposed by the current mobile technology.

6.1.1 Layer Requirements

According to the proposed visualisation paradigm, the following table captures the list of high-level user requirements, in terms of visualisation layers, for this prototype.

Layer	**Priority**
Regular buildings	Essential
Roads and Polygonal Features	Important
Rivers and mountains	Desired
Points Of Interest	Essential

Table 6.1: High-Level requirements for the prototype, regarding visualisation layers

For the prototype developed at *NDrive Navigation Systems, SA*, regular buildings were considered the most important visualisation layer, since there are no mobile 3D maps available, in the Automotive Navigation Systems Industry, capable of rendering regular buildings of an entire city, using photographic façades (i.e., *Photo Textured Buildings*). There are some applications that are capable of rendering regular buildings with simple texture patterns (i.e., *Simple Textured Buildings*)), but cannot or do not render, in simultaneous, more than 5 of these buildings. The possibility of watching an entire city with all its regular buildings represented in the screen, using photographic imagery for the façades, irrespective of the development challenges and difficulties that may arise, is believed to constitute a breakthrough in the Automotive Navigation Systems Industry.

Roads and polygonal layers were considered important but not essential, for this prototype, since *NDrive* navigation system already features these two layers, using the proposed approach, i.e., an *Orthophotomap* is used to depict the roads and areal features of a map. Given that these layers are already implemented, it is not considered essential to demonstrate its applicability, because it has been already implemented in the commercial product of the enterprise.

A *Terrain Model*, which allow us to visualise altitude differences from rivers to mountain peaks, was not considered an important feature, but instead a desired layer, which should be possible to turn on or off, at any time. There are already some mobile applications that are able to do this, so the implementation of the requirement in question is not believed to constitute a major challenge.

Similar to the considerations regarding regular buildings, Points Of Interest are essential to be depicted, especially at the photorealistic level representation. Apart from the visual features that distinguish a regular from a landmark building, it is not expected any noticeable difference in the highest visual quality between the two of them, since they will be both mainly implemented in the form of photorealistic buildings. The only difference concerns the possibility of changing the current abstraction level. The levels that were chosen for the implementation of Points Of Interest in this prototype are *Words*, *Icons* and *Images* (*Photo Textured Buildings*), provided that there is available data for the three of them, and none for the rest of abstraction levels.

6.1.2 Feature Requirements

According to the proposed visualisation paradigm, the following table captures the list of high-level user requirements, in terms of visualisation features, for this prototype.

Feature	**Priority**
Panning the map	Necessary
Zooming the map	Essential
Showing Points of Interest	Desired
Navigation	Essential

Table 6.2: High-Level requirements for the prototype, regarding visualisation features

Panning is considered a necessary feature, since it will allow exploring the map to get an overview of the city, allowing the implementation of zoom and navigation features.

Zoom is considered an essential feature, because it is believed to demonstrate the ability of the application to deal with the massive amount of 3D buildings, terrain geometry and photographic imagery that together are constantly being loaded into and unloaded from memory, during monotonic zoom in and out. Moreover, it will allow the visualisation of the different abstraction levels specified for Points of Interest.

Navigation is considered an essential feature, or this wouldn't be considered an automotive navigation system. The most important aspect of the navigation considered for this prototype, is the ability to see a continuous animation (i.e., with an "acceptable" frame rate, as defined in the following section), along with indications like "turn left" or "turn right" arrows, and a carpet-like shape covering the route.

6.1.3 System Constraints

The following is a list of constraints that affect the operation and the development of the prototype:

Constraint	**Priority**
The prototype should be developed using OpenGL ES	Necessary
The prototype must be able to run on a PC and/or Mac platform	Necessary
The prototype must be able to run on a Symbian, Windows CE/Mobile or Pocket PC	Essential
In order to convey the feeling of animation, the prototype must be able to run at more than 5 frames per second in a mobile device with some graphics hardware acceleration functionality	Essential
The application should be lightweight and load the necessary buildings on the fly, during a navigation experience, without affecting the minimum refresh rate.	Essential

Table 6.3: System Constraints for the prototype

6.2 Technical Challenges

There are several issues that must be addressed before proceeding to implementing a prototype like this. These issues that may represent a drastic decrease in the frame rate; preventing the visualisation paradigm from responding for long periods of time; making it impossible to achieve the expected image quality on a mobile device, due to memory restrictions; or even making the process of building a map an incompatible and unfeasible task for large maps, considering the requirements that were elicited before.

6.2.1 Automatically vs. Manually Generated Maps

There are several existing state-of-the-art contributions (e.g., *m-LOMA*, *Google Earth*, *iGO*, etc.) that are capable of representing a considerable amount of regular buildings in a given scene, but with some restrictions and limitations.

Many of the applications that provide an acceptable refresh rate (for interactive use) can only achieve such results in a very constrained environment or set of conditions. Examples of this include modelling a small part of a city, generally not bigger than 1 square kilometre, using a manual process, instead of an automated process which uses a farm of computers to build the map. In such conditions, since the number of buildings is very small when comparing it to the total number of buildings in a whole country, it is possible to decide, for each building, what are the most appropriate levels of quality regarding the textures for the façades, their geometry detail or developing LOD[1]s for

[1] Level Of Detail

each of them. Some studies even consider a manual approach for building a PVS[2] of buildings that maximises the effectiveness of occlusion tests [Oulasvirta et al., 2007], i.e., by increasing the probability of not drawing a building which, in fact, is completely occluded by other buildings, thus achieving a higher refresh rate.

In general, commercial maps tend to include more and more regular 3D buildings and landmarks. For this reason, the success of the implementation of the novel visualisation paradigm greatly depends on the automation level of the processes that are responsible for the generation of the mobile 3D map, since it becomes impracticable to model every 3D building individually by hand.

6.2.2 Visibility Testing

Broadly speaking, there are two possible approaches, when rendering a given scene comprising 3D models of objects:

1. rendering every object that composes the 3D world;
2. render the currently visible objects in the 3D world, only.

For obvious reasons, rendering every object, without taking into account whether they are visible or not, is a computationally impracticable task, especially for maps with cities completely modelled using 3D objects.

There are several different approaches to follow, to determine in advance whether a given building is visible or not:

- Face Culling – when the normal vector of a given object's face points away from the current viewing direction, it is safe to assume that such face won't be visible in the final image, in the case of single-sided faces.
- View-Frustum Culling – by testing whether objects are inside or outside the current view-frustum which defines the space for potentially visible objects ("pottentially" because can occur between objects), it is possible to safely avoid rendering objects that are outside of this volume.
- Occlusion Culling – by using a PVS, Portals, or other appropriate techniques for a given scene, it is possible reduce the number of tests by cutting off entire nodes of the scene graph.

The combination of these techniques will greatly reduce the graphics pipeline overhead, and will provide much faster refresh rates.

[2] Potentially Visible Set

6.2.3 Collision Detection

Collision detection is an important feature, in order to disallow users to move “through the walls” of buildings, as if these walls did not have a physical appearance in reality. Especially when panning an area of a map, where users can move it around freely, collision detection can help preventing them of seeing what is inside of the the 3D buildings. Since these buildings are generally modelled as being hollow, i.e., without nothing inside of them, there is no point in allowing the users to go inside them. Moreover, it can cause a lot of disorientation, if such action is allowed.

6.2.4 Data Input/Output

With regards to data input/output operations, it is very easy to make the application not to respond for several seconds, using a naive approach for loading the buildings and textures on the fly, during a navigation experience or when panning/zooming a map with considerable speed, for areas of the map that are not loaded into memory.

Given that a view of a 1 square kilometre area can consist of several tens of megabytes of building and terrain geometry, not accounting for the hundreds of megabytes that can be used for high resolution building façades or for the orthophotography that covers the terrain surface, the problem of loading this amount of contents, from the memory card to the physical memory, while providing an acceptable frame rate, can constitute a serious threat to the successful implementation of the proposed visualisation paradigm. Even if the loading is performed on the fly and concurrently on a separate thread of execution, users will still be interested in getting a quick and continuous visualisation when they pan or zoom the map.

One workaround can be followed, in order to alleviate the impact of this issue, for providing a more continuous animation during navigation. When an automotive navigation process is initiated, the start and destination points, along with the route, will become decided for the rest of the travel (except when the user does not follow some indication, in which case the route will be reprocessed). During the navigation experience, since the route is already determined, it is possible to automatically calculate the urban areas through which the user will navigate. Using this knowledge, it is possible to load – in anticipation – the data related to the 3D geometry of buildings and terrain, and associated photographic imagery, that will become visible in a near future. Using this strategy, it is possible to ignore the loading of areas for which it is guaranteed that they won’t become visible, and to stream the contents of the following visualisation iterations, before they are actually reached, during the navigation experience. A similar strategy is used for transmitting audio and video over a low-bandwidth computer network, by streaming the first seconds of information and then starting to view or listen those parts, while the rest is being downloaded.

In order to efficiently reduce the negative impact of this issue for panning or zooming operations, a strategy that focus on the way data is structured and organised must be carefully analysed and developed. By taking into account the proposed evaluation paradigm, and *Adaptive Zoom / Complexity* of landmarks in particular, one can argue that the problem of imperceptibility of visualisation features is applicable to 3D buildings, terrain, and photographic imagery. For instance, even if a typical high-resolution orthophotography, having 3600x4800 pixels, is used for a small portion of terrain, having 36x48 square meters of area, and if this area is being totally observed in a typical 240x320 screen of a mobile device, we can say that the original high-resolution image is being reduced to 15 times its original size, in order completely fit the screen. These issues imply the need for:

1. a concept of LODs for buildings, terrain and photographic imagery, as a function of distance to them;

2. a concept of the hierarchical structure and organisation of the LODs.

The first concept, allow us to have versions for buildings, terrain and photographic imagery that are appropriately small enough to cover a few pixels on the screen, so that their memory footprint is not significant. On the other hand, it will be possible to have versions for these elements, that are appropriately big enough to cover a wide proportion of pixels on the screen. In the end, we can select the appropriate level of detail that minimises memory footprint, while keeping a perceptually indistinguishable level of detail which covers a given proportion of the view area.

However, if we are to test, for every building, whether they are visible or not – using occlusion / frustum culling tests, or performing a spatial subdivision of the virtual world, where each individual object, comprising a set of LODs, occupies a given position in a cell – it can become computationally unfeasible. A solution for this includes building a hierarchy for LODs, so that it is possible to extract a small set of big LODs of the current scene, rather than a LOD for each visible building. Using this strategy, it will be possible to perform less visibility tests, and alleviate this issue.

Moreover, by allowing the computation of entire city LODs of cities or countries, including their constituent parts, in a hierarchical way (also known as HLOD[3]s), it will be possible to perform more drastic simplifications than the ones that can be achieved individually for each building [Erikson et al., 2001]. When comparing the frame rate of both alternatives, HLODs will result in a significant improvement of the frame rate, especially when displaying a lot of distant 3D buildings.

[3]Hierarchical Levels Of Detail

6.3 Results

The prototype was implemented for a small portion of the city of Madrid (Spain), covering an area of, approximately, 2.4 square kilometres. The following table summarises which requirements have been implemented:

Layer Feature	**Implemented**
Regular buildings	Yes
Roads and Polygonal Features	Partially (no labelling is performed)
Rivers and mountains	Yes
Points Of Interest	Partially (no *Adaptive Zoom/Complexity*)
Panning the map	Yes
Zooming the map	Yes
Showing Points of Interest	Yes
Navigation	Partially (no visual indicators to indicate the route)

Table 6.4: Implemented high-level requirements, regarding visualisation layers and features

The prototype is capable of running on the Nokia N95 at 8 frames per second (see Figure 6.1). It was originally developed for the Mac OS X, but later ported to FreeBSD/Linux and Symbian. On a MacBook Pro Intel Core 2 Duo at 2.2 GHz with a GeForce 8600M GT (128 MB), the prototype was able to run at more than 40 frames per second (see Figure 6.2). These results can be considered fairly good, since none of the above-mentioned visibility testing strategies were followed, with the exception of face culling which was automatically provided by OpenGL.

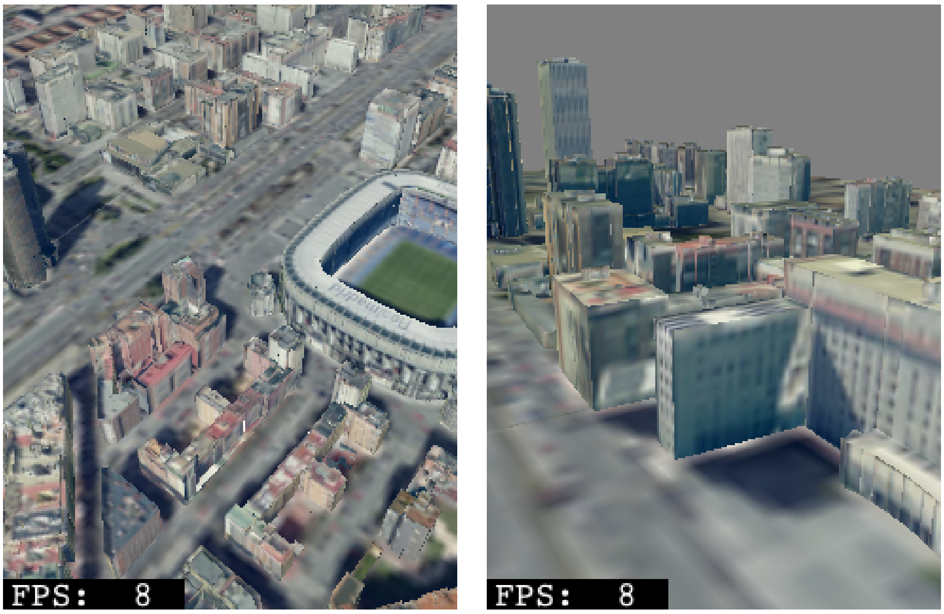


Figure 6.1: Prototype running on a Nokia N95

By looking at the previous figures, it is easy to notice that the textures look somewhat blurry. This is because the orthophotographic imagery had to be downsampled, in order to make it fit into the physical memory of the Nokia N95, as the city was not partitioned into a set of LODs.

It is also possible to observe a simulation of an automotive navigation experience, since GPS functionality is not yet implemented. This is illustrated below, through a set of successive screenshots of an animation:

(a) (b)

(c) (d)

Figure 6.2: Navigation experience provided by the prototype running on Mac OS X

Because the orthophotographs of the buildings were taken from an airplane, there are some façades for which several artefacts exist, especially in the lower part (see Figures 6.2a and 6.2c).

Another feature that was not implemented was the ability to see the road vectors with a translucent colour over the orthophotographic polygons that compose the map, along with the labels of streets and other objects. Another interesting feature that many people missed was the ability to see a carpet-like shape indicating the route, and arrows at the crossings telling the driver to "turn left" or to "turn right".

The initial 3D geometry data for the buildings and terrain consisted of about 70000 and 200000 triangles, respectively. These models were roughly optimised, simply by removing repeated or invalid vertices. The final results of this process resulted in the following statistics:

Geometry	**Vertices**	**Triangles**
Buildings	41806	24526
Terrain Model	38025	73728

Table 6.5: Statistics about the geometric detail of buildings and terrain model

Especially for the terrain, which is similar to a perfectly planar surface in this prototype (there are some slight elevation differences), it is believed that its geometry could be greatly optimised by using a LOD algorithm.

The following table summarises the implemented requirements, in terms of system constraints:

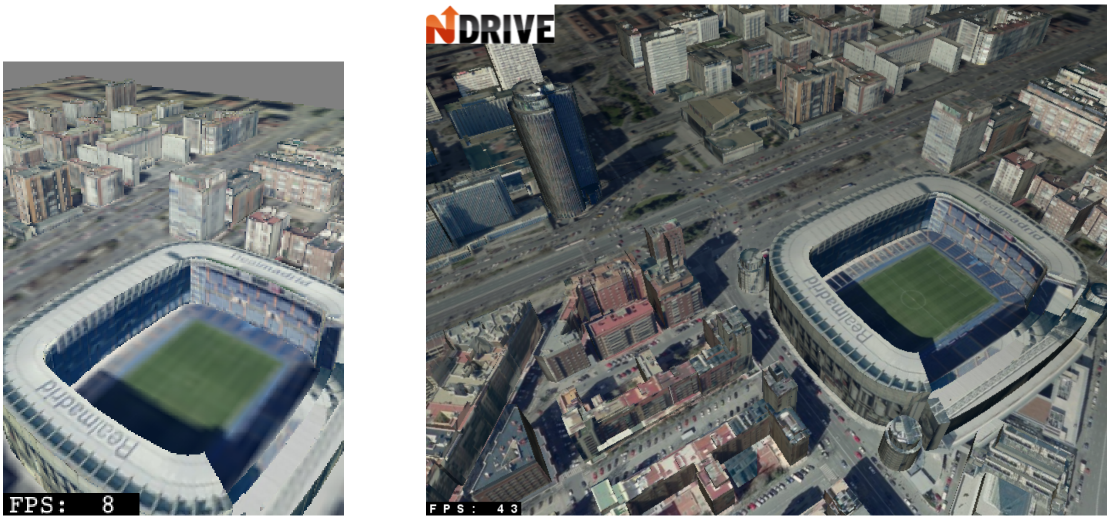
Constraint	Implemented?
The prototype should be developed using OpenGL ES	Yes
The prototype must be able to run on a PC and/or Mac platform	Yes
The prototype must be able to run on a Symbian, Windows CE/Mobile or Pocket PC	Yes
In order to convey the feeling of animation, the prototype must be able to run at more than 5 frames per second in a mobile device with some graphics hardware acceleration functionality	Yes
The application should be lightweight and load the necessary buildings on the fly, during a navigation experience, without affecting the minimum refresh rate.	No

Table 6.6: Implemented system constraints for the prototype

6.4 Summary

In this section, the major challenges for the development of 3D map-based mobile services and the possible strategies to solve them were discussed.

The requirements for a specific automotive navigation system were elicited, and a prototype was implemented. The prototype was developed for various platforms including Symbian and Mac OS X (see Figure 6.3), and the majority of essential requirements were implemented, including others not so important.



(a) Prototype running on Nokia N95 (b) Prototype running on Mac OS X

Figure 6.3: Screenshots of the prototype

For future work it is planed that the prototype will include GPS functionality, in order to be able to test the visualisation paradigm in a real situation. Moreover, the application should be capable of loading buildings and photography on the fly, by using a HLOD to avoid sudden bottlenecks, and maintaining a more homogeneous Input/Ouput transfer rate between the physical memory and the memory card. By solving this issue, it should be possible to obtain high quality orthophotographs in the Nokia N95, similar to what it is possible on the Mac OS X platform.

The prototype is currently being ported to the Windows CE/Mobile and Pocket PC platforms, but it is expected that the strategies for visibility testing, which were outlined before, become implemented, so that the hardware requirements, in terms of graphics processing power, can suffer a drastic reduction.

Chapter 7

Conclusions and Future Work

The LBMS technology, namely in the form of GPS-based navigation systems, has just recently reached a state of technological maturity, enabling the development of 3D map-based graphical interfaces. A great disparity of ideas and a complete disorientation in the *Mobile Industry* can be observed throughout the various propositions for visualisation paradigms that are labelled as “the best visualisation experience ever”. Provided these circumstances, it became of uttermost importance to study the different issues that improve the user experience and performance, in order to maximise the usability of the navigation experience with mobile 3D maps.

In this dissertation, due to the lack of a state-of-the-art conceptual framework for assessing the different visualisation aspects regarding 3D map-based mobile services, a conceptual evaluation framework was proposed.

The state-of-the-art contributions on visualisation paradigms for mobile 3D maps were outlined and discussed, by means of applying the generic evaluation framework to them, and comparing visual elements and properties between each other. The initial directions given by the evaluation of the state of the art, indicated a clear tendency, since the last decade, towards an increasing use of photorealistic environments.

An online questionnaire was developed and several hypothesises were formulated, in order to evaluate the impact of each visualisation feature described in the evaluation framework.

Finally, the visualisation paradigm was applied in the implementation of a prototype, which was tailored to the needs of a specific automotive navigation system.

7.1 Conclusions

The results of the questionnaire were analysed from a total of 149 participants, clearly confirming all the previous expectations.

With respect to the identification and recognition of buildings in the real environment, it can be concluded that just by giving the 3D geometry of a given building, will allow the users to correctly perform their tasks. The task completion times vary, depending on the degrees of realism that are used for buildings. If façades from the building are texture mapped with photographic imagery, users are able to detect key elements such windows with a peculiar shape and walls with a unique pattern, much faster than if just the buildings are colour shaded.

It was also demonstrated that the use of photorealistic imagery to cover the map's surface allowed the identification of surface features, like a pavement with a unique tile pattern; a group of trees arranged in a peculiar way; and several urban features like public benches and zebra crossings, resulting in a much higher accuracy and responsiveness from users than the typical coloured polygons and road vectors, which can only be used, by means of applying the principle of exclusion, and other logical rules, in order to be able to answer correctly. Many times it won't be possible to make assessments about the surroundings, using just the principle of exclusion or logic, since this implies finding a higher amount of geometric features (e.g., a roundabout, a large square with a unique shape, etc.), which may not be available for a given situation, to perform the matching between the virtual environment with the real environment

One of the ideas that are emerging in the state of the art, namely the use of photorealistic images depicting a highway interchange with life-like signposts with destinations written on them, confirmed the initial hypothesis that this approach will allow the users to identify the way they should go to proceed their itinerary, in a faster way, but neither more nor less accurately, than a functional approach using vector maps with the destination labels written over the vectors.

Similarly, it was shown that if the labels of a map (e.g., of roads, rivers, cities, etc.) are laid down over the map's surface like *Google Earth* does, users will take a considerable amount of time reading them, and will skip some of their words if they find them difficult to read, rather than if these labels are oriented towards the viewing direction represented in the mobile device, which represents a better alternative.

A visualisation paradigm was specified through a set of high-level user requirements (grouped by visualisation layers and by visualisation features) for 3D map-based mobile services. It was demonstrated that several issues may arise, after combining the different visualisation layers that compose the final image. It was shown that the use of an orthophotomap consisting of oblique photographic imagery can impose several limitations to the use of 3D buildings, because when they are placed over this surface, the photography that covers it will include more than just the roads, parks, and rivers, i.e., they will include the walls of buildings seen at an oblique perspective, causing strange artefacts near the junction points between the surface and the base of the building. Furthermore, oblique photography can prevent a correct visualisation of road vectors that are occluded by the buildings observed using a birds-eye perspective. However, when using oblique photography alone, i.e., without 3D buildings, they can provide a considerably good simulation of the visualisation of 3D buildings, despite not being possible to obtain different perspectives than the ones provided by the photographic imagery.

Regarding the development of the prototype, it was demonstrated that the implementation of the visualisation paradigm is possible, using current mobile technology, but that the existing hardware limitations and restrictions can pose serious key challenges to the development.

7.2 Future Work

In this section, some directions that allow us to open doors to future works are highlighted, divided by subject, accordingly.

7.2.1 Expanding the *Evaluation Framework*

In this dissertation, a generic *Evaluation Framework* was proposed as the main methodology for the specification, development and evaluation of new or existing solutions in the visualisation problem domain for 3D map-based mobile services. However, the usefulness of this framework is limited to the scope of its constituent parts, i.e., *feature vectors*.

Feature Vectors can individually describe a set of choices (*orientations*) and degrees of applicability (*magnitudes*). The proposed framework focuses on 6 *feature vectors* namely, *Image Realism*, *Object Labelling*, *Visual-Spatial Abstraction*, *Route Indication*, *Landmark Symbology*, and finally *Contextual Awareness*, but it is not believed to be already complete.

A future line of research would consist in analysing the totality of features that address visualisation aspects, in the context of exploration of urban environments, using 3D map-based mobile services as guidance. This would allow us to define new *feature vectors* (e.g., "Illumination") along with their respective *orientations* and *magnitudes*.

7.2.2 Refining the Ideal Visualisation Paradigm

During this dissertation, an online questionnaire was developed, in order to assess the individual impact of each visualisation feature. This questionnaire was not meant to be perceived as "too exhausting" by potential participants, and therefore some *feature vectors* components could not analysed. Furthermore, the questionnaire imposed several restrictions on the kind of measurements that could be performed to evaluate *feature vectors*.

The future line of research would consist in performing other kinds of tests, with particular focus on dynamic experiments. An example of these experiments would include using a driving simulator to test the participants' reflexes, given a situation where the they are approaching a manoeuvre, and deciding which way to go, depending on the visual indicators that are presented on the screen.

Another future line of research would consist in using all the kinds of dynamic experiments that would allow us to evaluate the conflicts that may arise in the interaction between visualisation layers and / or visualisation features. An example of this situation would involve measuring the impact of showing nearby *POI*s / indicating a route, in the presence of a highly occluded environment. These tests could be performed with the help of the prototype whose development was discussed in the previous chapter.

Given that the proposed visualisation paradigm still has a lot of empirical knowledge within itself, the future investigation would focus on studying the interactions between *feature vectors*, to understand eventual conflicts that may arise, and how can they be combined to maximise usability and user experience.

7.2.3 Improving the Prototype

In this dissertation, a novel visualisation paradigm for generic 3D map-based mobile services was proposed. This visualisation paradigm was applied to a mobile prototype, tailored to the specific needs of an automotive navigation system.

The future line of development would consist in applying the state-of-the-art knowledge in the field of Computer Graphics, to solve the current issues that affect the prototype that was created. Firstly, the 2 algorithms for visibility testing that were not accounted for during the development of the current prototype, namely *View-Frustum Culling* and *Occlusion Culling*, should be implemented in the near future, so that higher refresh rates can be achieved.

Another line of research would consist in building a hierarchical representation of buildings and terrain elevations of a map, defined through a set of LODs. These HLODs would allows us to cut off significant portions of geometry from the scene graph, and simultaneously, perform drastic optimisations of the city as a whole, instead of focusing on a particular building.

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Glossary

Augmented Reality Associated to *Mixed Reality*, AR is a kind of virtual reality that combines real and computer generated imagery 20

Digital Elevation Model A digital representation of the Earth's surface elevations . . 35

Enkin A pilot prototype that aims to introduce a new concept of navigation systems for mobile devices 24

geospatial Relating to terrestrial and geographic attributes 14

Geographic Information System A system that is capable of manipulating and managing Earth's geospatial data 16

Google Earth A virtual globe application that mainly uses orthophotomaps and a terrain model of the earth 19

Head-Mount Display Similar to a HUD but attached to a helmet, eyeglasses or visor 21

Head-Up Display A transparent display that is positioned in front of the user's view (traditionally found in fighter aircrafts) 23

iGO The name of one of the leading automotive navigation systems 18

INSTAR *Information and Navigation System Through Augmented Reality* 30

LAMP3D A study and prototype to evaluate the location-aware visualisation of VRML models in mobile guides 19

m-LOMA One the first applications to provide full-featured mobile 3D maps 13

Mixed Reality The Mixed Reality is the space in-between the Real and the Virtual Environments 10

Mobility Equation An informal expression given to the representation of the problem of mobility, intrinsic to every map-based mobile application 11

Navigon The name of one of the leading automotive navigation systems 16

NDrive The name of one of the leading automotive navigation systems, being notably famous for the orthophotomaps 17

Orthophotograph An aerial/satellite photograph that has been geometrically corrected, in order to be equivalent to a map 6

Orthophotomap A map comprising of orthophotographs 2

photorealistic Resembling a photograph, i.e., it must produce the same *visual response* as the depicted scene 8

Reality View™ A Navigon's technology that provides static photorealistic images of signposts and lanes from major interchanges 16

road vector Vector data representing a road in a GIS database 15

TellMaris One of the first studies to evaluate the impact of three-dimensional mobile maps 12

Traffic Message Channel A radio-based and language-independent technology for delivering real-time traffic and weather information code messages that can be decoded – for instance – by navigation systems 16

TomTom The name of an automotive navigation system of the leading manufacturer in Europe 15

vector map The vector-based collection of geospatial data of Earth at different levels of detail, from a worldwide scale to a less than 1 meter resolution scale 15

Virtual Cable™ The name of an Augmented-Reality-based display for car navigation systems, in which an image of an imaginary cable – indicating the route – can be seen through the windshield 23

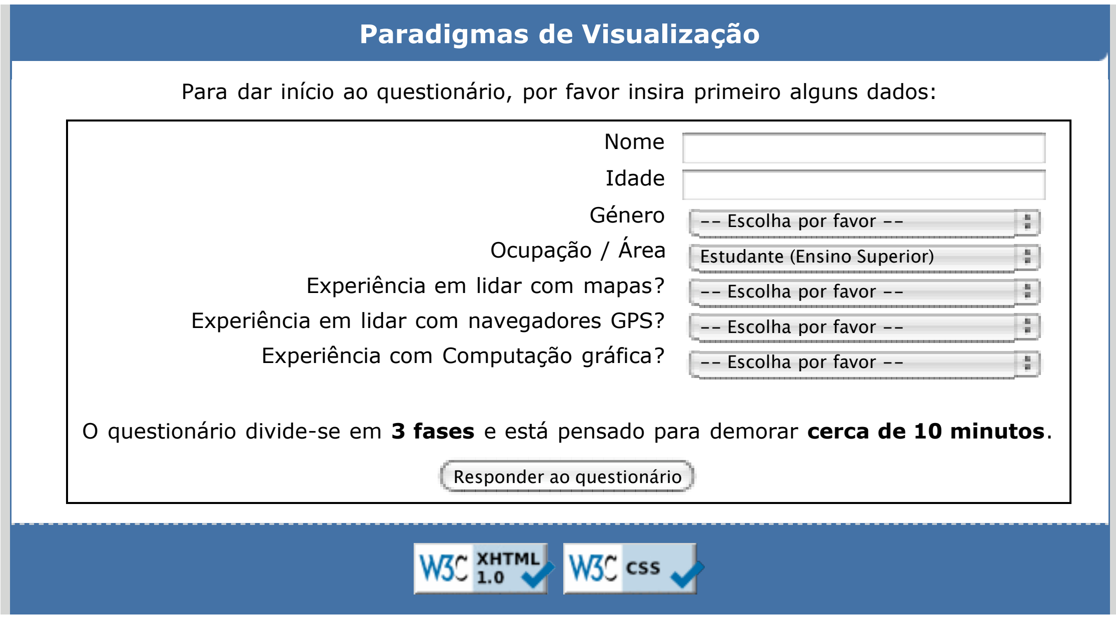
visual-spatial The connection between sight (visual sense) and space, often associated to the ability of mentally manipulating 2D or 3D figures 14

Appendix A

Questionnaire

A.1 Web Pages

A.1.1 Entry Form



A.1.2 Introduction to the 1st Part

Paradigmas de Visualização

Fase 1 de 3

Esta fase é composta por **10 exercícios**.

Cada exercício será constituído por:

- uma introdução à pergunta (com ou sem uma imagem de apoio)
- uma pergunta
- 4 imagens de escolha múltipla

Como é óbvio, **apenas uma imagem representa a resposta correcta**. No entanto, se achar que vai escolher "à sorte", deve carregar no botão **Não faço a mínima ideia**.

Para a avaliação desta 1ª fase levar-se-á em conta:

- **a exactidão** das suas respostas
- **o tempo** que demora a responder a cada pergunta

Antes de começar a responder, faça por favor 2 exercícios exemplo para se ambientar a esta fase.

Fazer 2 exercícios exemplo

A.1.3 1st Part: Training Question #1

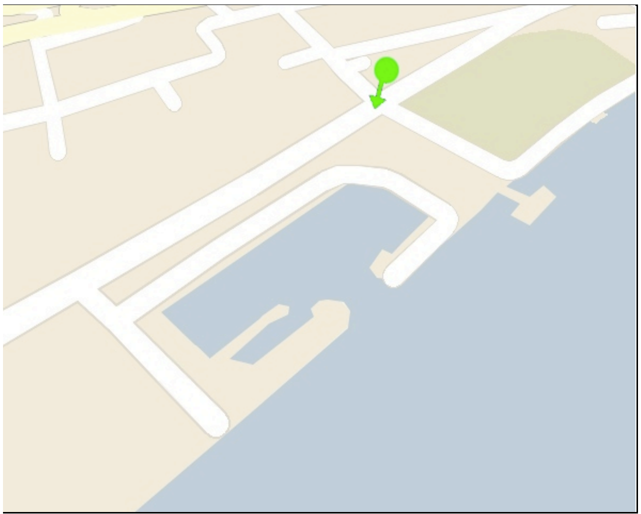
A.1.4 1st Part: Training Question #2

Paradigmas de Visualização

Fase 1 - Pergunta exemplo 2 de 2

Explicação -- Leia calmamente até compreender bem a pergunta:

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:



O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

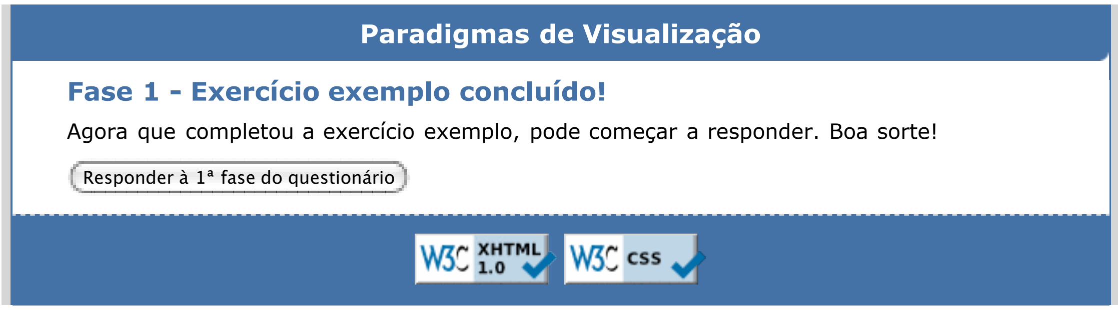
Qual das seguintes perspectivas considera MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

Tempo: 18 segundo(s)

Explicação -- O tempo da sua resposta começou a contar. Agora deve escolher a imagem que corresponde à resposta correcta. Se tiver dúvidas, pode voltar a rever a pergunta acima. Como se trata de uma pergunta exemplo, a resposta correcta já está marcada:

Não faço a mínima ideia

A.1.5 1st Part: Training Completed

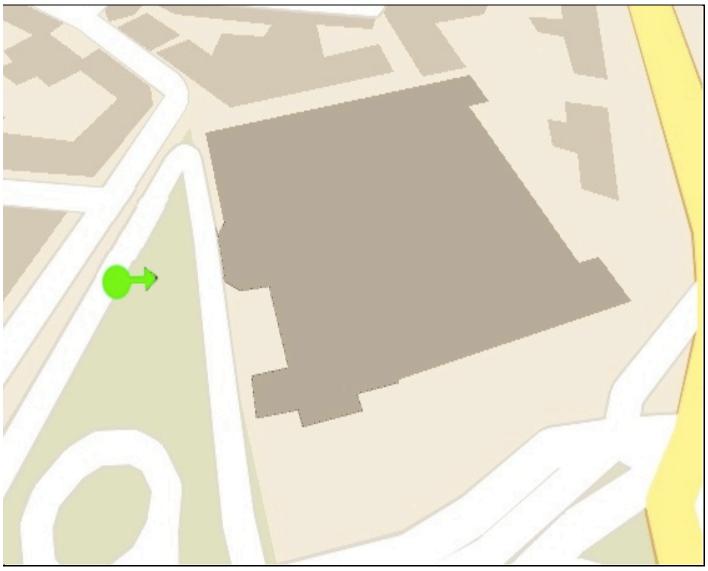


A.1.6 1st Part: Question #1

Paradigmas de Visualização

Fase 1 - Pergunta 1 de 10

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:



O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

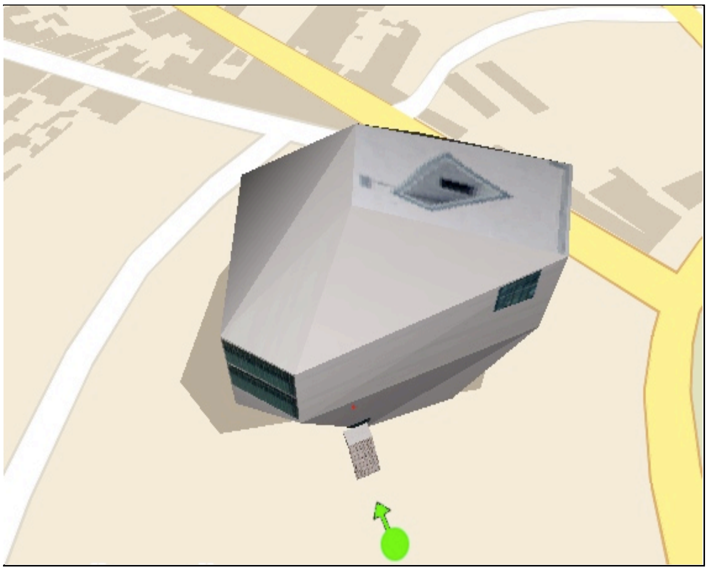
Não faço a mínima ideia

A.1.7 1st Part: Question #2

Paradigmas de Visualização

Fase 1 - Pergunta 2 de 10

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:



O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

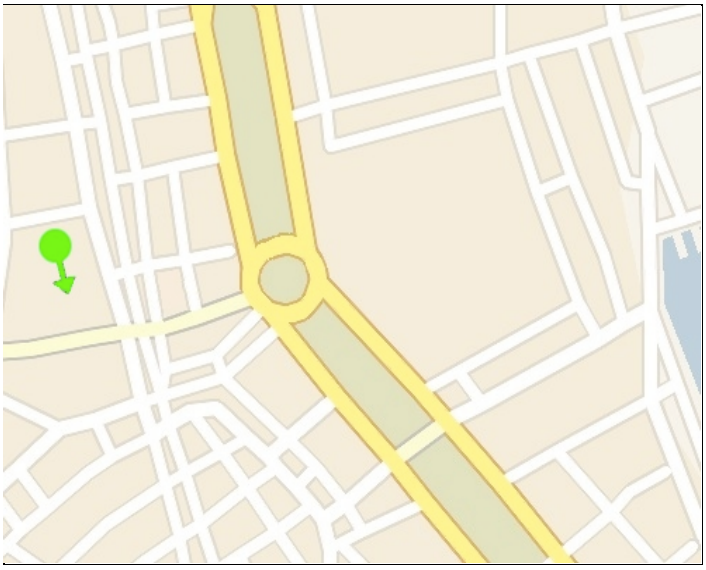
Não faço a mínima ideia

A.1.8 1st Part: Question #3

Paradigmas de Visualização

Fase 1 - Pergunta 3 de 10

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:



O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

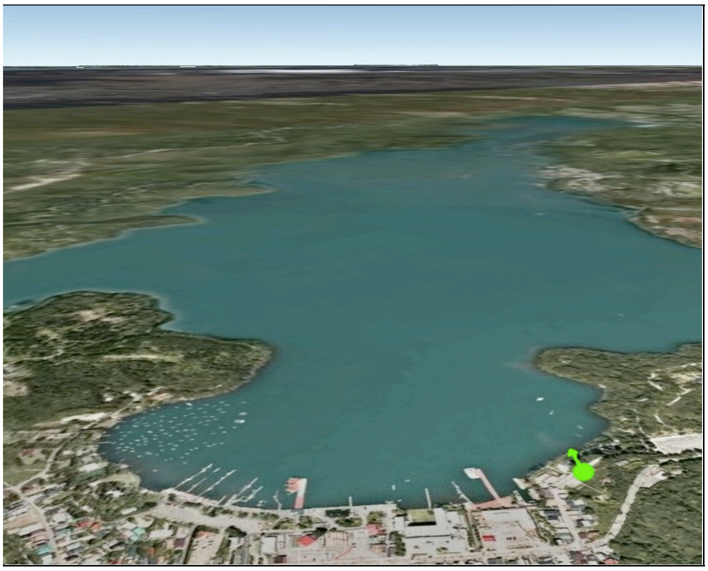
Não faço a mínima ideia

A.1.9 1st Part: Question #4

Paradigmas de Visualização

Fase 1 - Pergunta 4 de 10

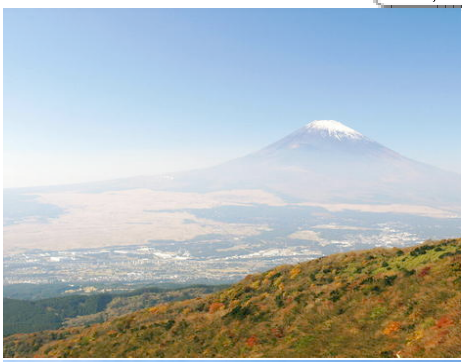
Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:



O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

Não faço a mínima ideia



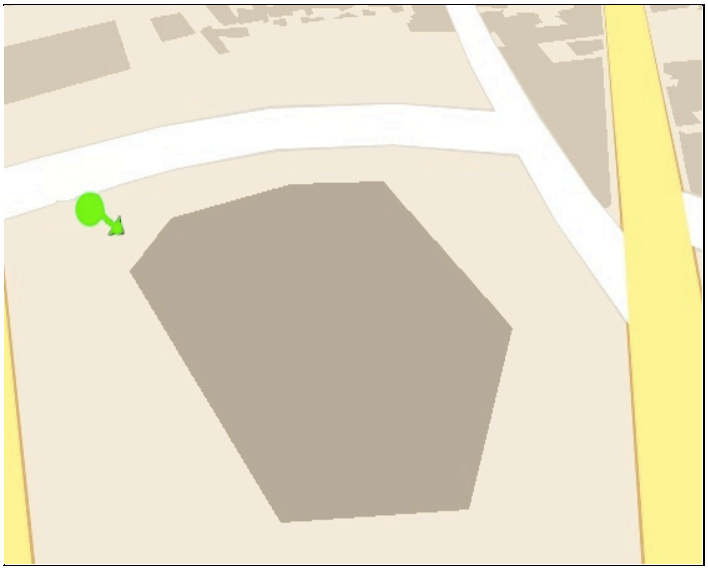

A.1.10 1st Part: Question #5

A.1.11 1st Part: Question #6

Paradigmas de Visualização

Fase 1 - Pergunta 6 de 10

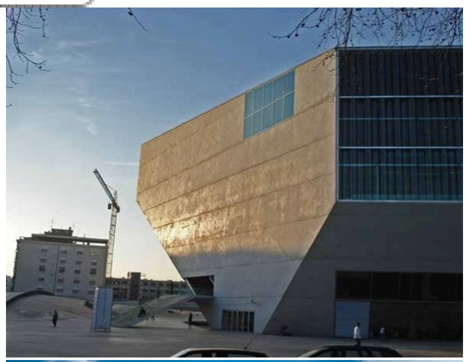
Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:



O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

Não faço a mínima ideia



A.1.12 1st Part: Question #7

Paradigmas de Visualização

Fase 1 - Pergunta 7 de 10

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:

O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

Não faço a mínima ideia




A.1.13 1st Part: Question #8

Paradigmas de Visualização

Fase 1 - Pergunta 8 de 10

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:

O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

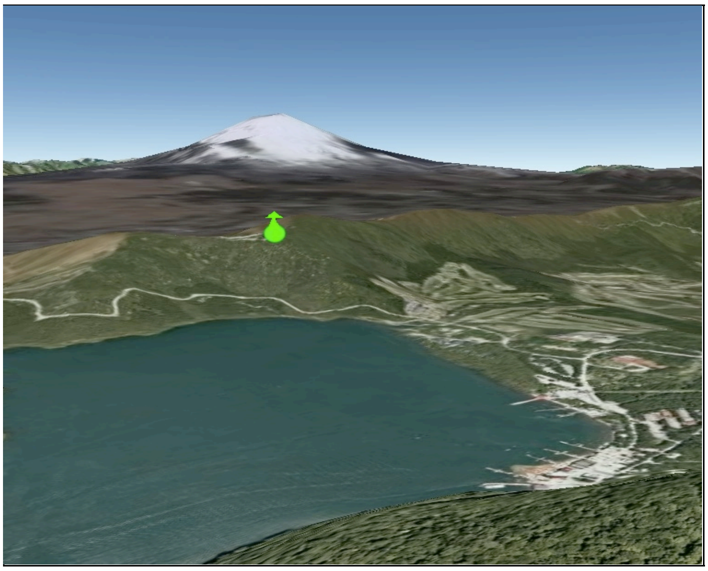
Não faço a mínima ideia

A.1.14 1st Part: Question #9

Paradigmas de Visualização

Fase 1 - Pergunta 9 de 10

Imagine que se encontra a passear a pé e que se depara com a seguinte imagem no seu navegador GPS:

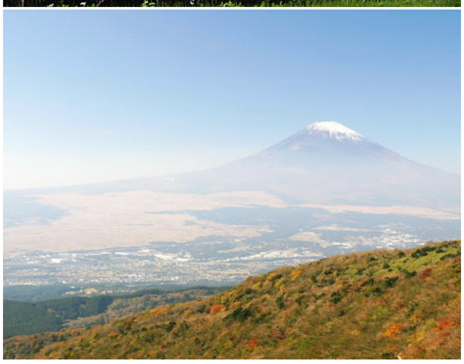


O navegador indica-lhe com bastante precisão que você se encontra no ponto a verde e a olhar no sentido da seta.

Qual das seguintes 4 perspectivas considera a MAIS consistente, se se encontrar no ponto a verde e a olhar no sentido da seta?

Não faço a mínima ideia

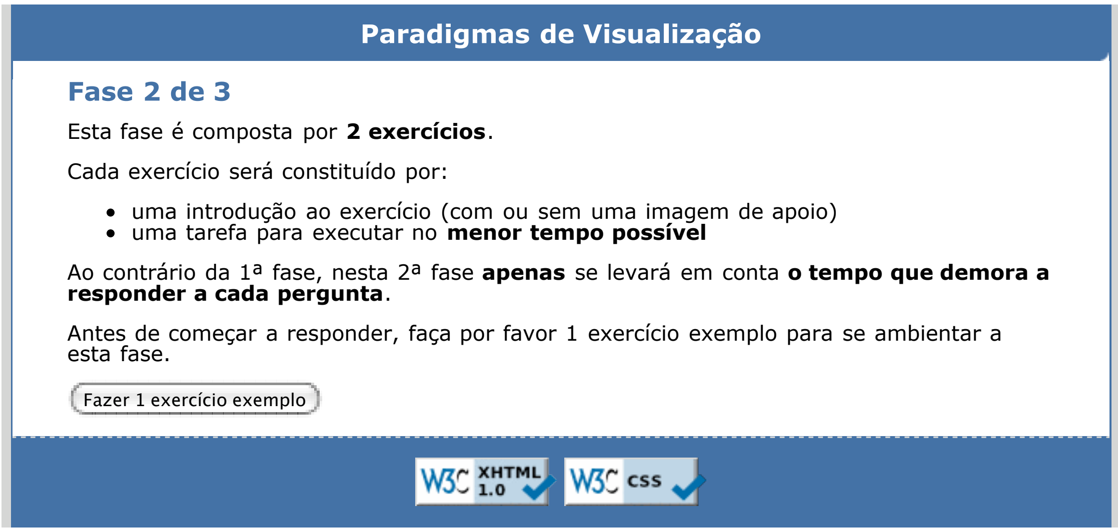


W3C XHTML 1.0 W3C CSS

A.1.15 1st Part: Question #10

A.1.16 Introduction to the 2nd Part


Paradigmas de Visualização

Fase 2 de 3

Esta fase é composta por **2 exercícios**.

Cada exercício será constituído por:

- uma introdução ao exercício (com ou sem uma imagem de apoio)
- uma tarefa para executar no **menor tempo possível**

Ao contrário da 1ª fase, nesta 2ª fase **apenas** se levará em conta **o tempo que demora a responder a cada pergunta**.

Antes de começar a responder, faça por favor 1 exercício exemplo para se ambientar a esta fase.

Fazer 1 exercício exemplo

A.1.17 2nd Part: Training Question #1

Paradigmas de Visualização

Fase 2 - Pergunta exemplo 1 de 1

Explicação -- Leia o enunciado até compreender bem qual é a sua tarefa:

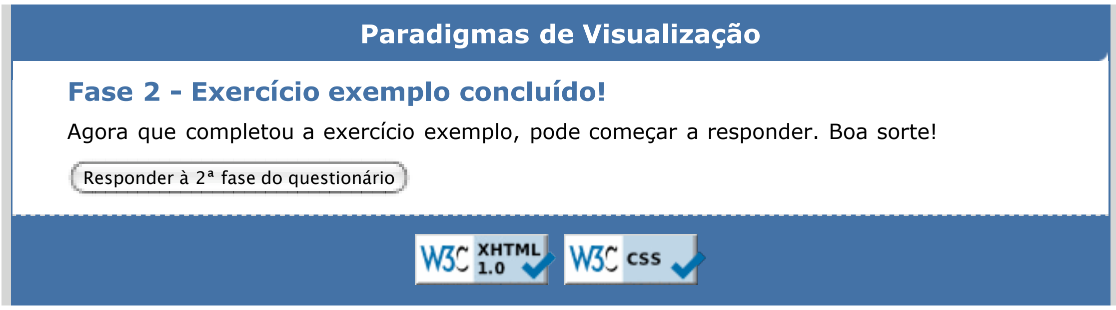
Imagine que o seu navegador GPS lhe mostra uma imagem com várias ruas de um mapa.

Sem "saltar" letras ou sílabas, leia por ordem crescente (de 1 a 9) as 9 ruas apresentadas no mapa! (Clique na imagem para terminar)

Informação apenas visível neste exemplo -- Tempo: 89 segundo(s)

Explicação -- O tempo da sua tarefa começou a contar. Tente completar a tarefa o mais rapidamente possível. Quando acabar clique na própria imagem.

A.1.18 2nd Part: Training Completed



A.1.19 2nd Part: Question #1

A.1.20 2nd Part: Question #2

A.1.21 3rd Part: Preference #1

Paradigmas de Visualização

Fase 3 de 3

Nesta última fase é interrogado sobre **as suas preferências**. Por isso, **não há respostas "correctas" nem é contabilizado o tempo** que demora a responder.

Preferência 1 de 2

No seguinte nível de zoom, em qual das seguintes imagens **consegue melhor identificar** a presença de uma igreja/catedral?

A.1.22 3rd Part: Preference #2

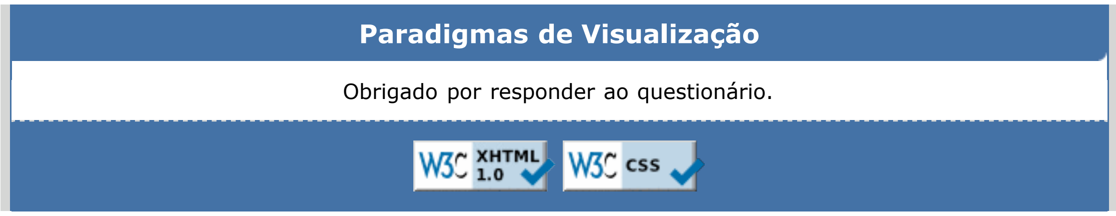
Paradigmas de Visualização

Fase 3 de 3

Preferência 2 de 2

No seguinte nível de zoom, em qual das seguintes imagens **consegue melhor identificar** a presença de uma igreja/catedral?

A.1.23 Questionnaire Completed



A.2 Results

A.2.1 Entry Form

Age

Data (ordered from the first to the last subject)
37, 24, 21, 21, 21, 20, 24, 21, 23, 31, 22, 20, 21, 20, 21, 23, 23, 20, 20, 19, 22, 19, 21, 22, 23, 22, 19, 22, 21, 22, 20, 23, 21, 19, 23, 22, 19, 19, 21, 25, 20, 19, 22, 25, 22, 23, 22, 22, 20, 51, 29, 20, 26, 22, 22, 21, 22, 37, 23, 21, 23, 21, 23, 22, 22, 46, 23, 20, 34, 22, 22, 23, 29, 24, 23, 32, 25, 19, 37, 29, 19, 21, 22, 19, 19, 22, 18, 27, 19, 28, 19, 24, 20, 24, 24, 27, 19, 33, 19, 20, 48, 20, 20, 18, 43, 23, 26, 24, 27, 25, 19, 20, 23, 19, 32, 18, 18, 32, 23, 20, 22, 23, 22, 23, 37, 19, 19, 21, 19, 23, 18, 18, 23, 22, 23, 23, 20, 19, 18, 19, 20, 29, 20, 21, 19, 25, 25, 43, 19

Gender

Data (ordered from the first to the last subject) – f = female, m = male
m, m, m, m, m, m, f, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, f, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, f, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, m, f, m, m, m, m, m, m, m, f, m, m, f, m, f, m, f, m, m, m, m, m, m, m, m, m, f, m, m, f, m, m, f, m, m, m, m, m, m, f, m, m, m, m, m, m, f, m, m, m, m, f, m, f, m, m, m, m, m, m, m, m, m, m, f, m, m, m, m, m, m, m

Occupation

Data (ordered from the first to the last subject)
Education (Higher), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Engineering, Student (Higher Education), Engineering, Student (Higher Education), Student (Higher Education), Education (Higher), Engineering, Student (Higher Education), Engineering, Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Education (Higher), IT / Computers, Student (Higher Education), Student (Higher Education), Student (Higher Education), Engineering, Student (Higher Education), Student (Higher Education), Education (Higher), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Engineering, Student (Higher Education), Engineering, Sales / Retail, Other, Student (Higher Education), Other, Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), IT / Computers, Student (Higher Education), Sciences, Student (Higher Education), Journalism, Student (Higher Education), Other, Student (Higher Education), Student (Higher Education), Student (Higher Education), Sciences, Student (Higher Education), Student (Higher Education), Education (Higher), Student (Higher Education), Student (Higher Education), Student (Higher Education), Education (Higher), Student (Higher Education), Education (Other), Student (Higher Education), IT / Computers, Journalism, Student (Higher Education), Student (Higher Education), Student (Higher Education), Engineering, Journalism, Student (Higher Education), Student (Higher Education), Education (Higher), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Engineering, Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Other, Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Student (Higher Education), Engineering, Other

Experience with maps

Data (ordered from the first to the last subject) – low experience = 1, medium experience = 2, high experience = 3
3, 2, 3, 2, 3, 2, 3, 2, 3, 3, 3, 2, 2, 3, 2, 3, 2, 2, 2, 2, 2, 2, 2, 2, 3, 3, 2, 2, 3, 3, 2, 2, 3, 3, 3, 2, 1, 2, 2, 2, 2, 3, 2, 3, 3, 3, 2, 3, 3, 3, 3, 2, 3, 2, 3, 2, 2, 3, 2, 2, 3, 2, 3, 2, 3, 3, 3, 2, 3, 2, 3, 2, 3, 3, 3, 3, 3, 3, 1, 3, 2, 3, 3, 2, 2, 2, 2, 2, 2, 2, 3, 2, 2, 3, 3, 2, 1, 3, 3, 2, 3, 3, 2, 2, 2, 2, 2, 2, 3, 3, 2, 2, 2, 2, 2, 2, 2, 2, 2, 3, 3, 3, 3, 3, 3, 1, 3, 2, 1, 2, 2, 2, 3, 2, 3, 3, 3, 3, 2, 2, 3, 3, 3, 2, 2, 2, 2, 3, 2

Experience with GPS navigators

Data (ordered from the first to the last subject) – low experience = 1, medium experience = 2, high experience = 3
3, 3, 2, 3, 3, 2, 3, 2, 3, 3, 3, 2, 1, 3, 3, 2, 2, 3, 2, 2, 3, 2, 2, 3, 3, 3, 3, 2, 2, 3, 2, 2, 2, 2, 2, 3, 2, 3, 2, 2, 2, 3, 2, 3, 3, 2, 2, 3, 3, 1, 2, 3, 2, 3, 2, 1, 2, 2, 2, 3, 2, 2, 3, 2, 3, 2, 2, 2, 3, 1, 2, 2, 3, 3, 2, 3, 3, 3, 2, 3, 2, 3, 3, 2, 3, 2, 3, 3, 3, 3, 2, 3, 3, 3, 2, 3, 3, 3, 3, 2, 3, 3, 2, 2, 3, 2, 3, 2, 3, 3, 3, 2, 2, 2, 2, 2, 2, 2, 2, 3, 2, 2, 3, 3, 3, 3, 3, 2, 2, 2, 3, 2, 3, 3, 3, 3, 2, 3, 2, 2, 3, 3, 3, 2, 3, 2, 2, 3, 3

Experience with Computer Graphics

Data (ordered from the first to the last subject) – low experience = 1, medium experience = 2, high experience = 3
3, 2, 3, 3, 3, 3, 2, 3, 3, 3, 3, 3, 2, 2, 3, 3, 3, 3, 3, 2, 3, 2, 3, 3, 3, 3, 2, 3, 2, 3, 2, 3, 3, 3, 3, 2, 1, 1, 2, 2, 1, 1, 3, 2, 3, 3, 3, 3, 3, 2, 3, 2, 3, 3, 3, 3, 3, 2, 3, 3, 3, 3, 3, 3, 3, 1, 3, 2, 3, 2, 3, 3, 3, 3, 3, 2, 2, 1, 1, 1, 3, 3, 3, 2, 2, 3, 2, 2, 1, 2, 2, 1, 1, 1, 2, 3, 1, 2, 2, 1, 2, 3, 3, 1, 2, 3, 1, 3, 2, 1, 2, 3, 3, 3, 1, 2, 1, 2, 2, 3, 3, 3, 1, 3, 3, 1, 2, 3, 2, 3, 1, 1, 3, 3, 2, 2, 1, 2, 2, 2, 2, 3, 1, 2, 1, 2, 3, 3, 2

A.2.2 1st Part: Question #1

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, w, w, w, w, w, w, w, w, w, r, r, w, w, w, w, r, w, w, w, w, r, r, w, r, w, w, w, w, r, r, r, w, w, w, w, r, w, w, r, w, w, w, r, w, w, w, w, w, r, w, r, w, w, w, w, w, w, w, w, w, r, r, w, w, w, w, w, w, w, w, w, w, r, w, w, w, w, w, w, w, r, w, w, r, w, w, w, r, w, r, w, r, r, r, w, r, w, w, r, w, r, w, r, w, w, w, r, r, w, w, w, r, w, w, w, w, w, w, r, r, w, w, w, w, r, r, w, r, w, r, r, w, r, w, w, r, r, r, w, w, w, w, w, w, r, r, w, w

Data (ordered from the first to the last subject) – times in milliseconds
4832, 16176, 8623, 8690, 24797, 18816, 8192, 9328, 10781, 9542, 18144, 9904, 5329, 12984, 75280, 9571, 12500, 32635, 35807, 12826, 12960, 9485, 6816, 7609, 10551, 26512, 37465, 20728, 4563, 31297, 24090, 12623, 11759, 12179, 79224, 18875, 19155, 19976, 10672, 10047, 18727, 28910, 8143, 9407, 15928, 15272, 1264, 11737, 8824, 19418, 27227, 17607, 10654, 23175, 14227, 7280, 28578, 20265, 14701, 18813, 7927, 39343, 15485, 15408, 7717, 16240, 11464, 21171, 6208, 4922, 13282, 15672, 7063, 17834, 16320, 21455, 3781, 16621, 31408, 1625, 17265, 24926, 14425, 8781, 17367, 17931, 27491, 25714, 3336, 8907, 5456, 69115, 23918, 57891, 9044, 19017, 14408, 22655, 55053, 8141, 50916, 17376, 19080, 2187, 24233, 16280, 7704, 89793, 27753, 9561, 5203, 14741, 16921, 9431, 11015, 11469, 36045, 7808, 14216, 9361, 39560, 13250, 28171, 7442, 44875, 14051, 4912, 16984, 13355, 14384, 12500, 7571, 19057, 4453, 20750, 13876, 3937, 5456, 11345, 37752, 10149, 5999, 12288, 16397, 20687, 13565, 33593, 10328, 3422

A.2.3 1st Part: Question #2

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, w, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, w, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, w, r, r, w, r, r, r, r, r, w, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, w, w

Data (ordered from the first to the last subject) – times in milliseconds
2688, 4424, 8212, 7378, 37315, 8576, 6199, 5532, 5295, 2944, 4999, 9120, 13219, 5182, 19052, 7719, 9031, 19709, 10585, 19692, 10848, 4328, 25513, 10625, 5159, 10824, 35058, 7934, 6703, 18625, 5267, 6513, 5131, 14212, 24615, 12114, 5649, 21141, 11281, 3734, 7121, 14839, 14416, 18328, 7216, 6934, 3559, 6576, 6256, 13310, 3202, 10511, 10097, 8320, 2288, 5494, 12125, 14953, 2888, 8922, 5600, 35500, 11606, 8181, 9104, 7380, 6624, 3797, 6270, 5719, 23973, 11276, 2968, 10043, 5232, 16719, 8109, 4565, 266, 2656, 16641, 5171, 20351, 12457, 12103, 2626, 4020, 6233, 5048, 6000, 11899, 25601, 6602, 28000, 22895, 11757, 7464, 7453, 28142, 31172, 20623, 15039, 14112, 13640, 11448, 13744, 8922, 20329, 23978, 13555, 2812, 15763, 5816, 8464, 10734, 5484, 21722, 8171, 10911, 8422, 27498, 10359, 6500, 5095, 15662, 10169, 6536, 5187, 14013, 13136, 6860, 3625, 5629, 5750, 14453, 9313, 10531, 7785, 8516, 14850, 3958, 5528, 17015, 7927, 10063, 7390, 21347, 18249, 2125

A.2.4 1st Part: Question #3

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, w, w, w, w, r, c, w, w, w, w, c, w, c, w, w, c, w, w, w, w, w, r, w, w, w, w, w, w, r, c, w, c, w, w, w, w, w, c, r, r, w, w, r, c, w, w, w, r, c, w, w, w, c, w, r, w, c, w, w, r, w, w, w, w, r, w, w, c, w, w, w, r, r, r, c, w, r, w, w, w, w, w, w, c, c, c, w, w, w, w, w, r, w, w, c, c, w, w, r, w, w, w, c, w, r, r, r, r, c, w, w, w, w, w, w, w, w, w, w, w, w, r, w, w, w, c, w, w, w, w, w, w, w, r, w, w, w, w, w, r, w, r, w, r, w, w, r

Data (ordered from the first to the last subject) – times in milliseconds
4976, 23160, 13089, 19684, 14270, 21728, 29212, 17047, 11222, 5631, 16031, 8528, 28797, 17434, 25698, 21157, 19984, 49849, 74242, 29090, 10545, 5125, 18042, 11953, 17848, 31119, 20804, 33881, 9609, 63797, 11533, 27606, 35307, 22208, 28141, 17975, 26071, 18184, 15703, 22297, 66436, 32294, 30520, 32843, 26894, 12729, 1216, 20877, 13020, 15132, 35058, 20335, 12722, 11522, 3769, 28661, 42719, 30219, 19529, 11953, 10429, 38016, 20316, 21656, 10904, 25555, 8203, 16406, 9298, 10063, 29982, 25276, 9757, 24362, 27991, 43759, 12625, 19131, 20933, 3390, 26672, 35063, 37825, 6584, 30371, 23476, 35544, 51555, 9080, 37078, 26088, 119106, 11970, 18985, 38044, 11706, 21432, 27108, 30529, 23703, 14807, 16068, 7320, 28079, 70282, 20921, 14220, 104303, 23969, 10501, 14328, 41330, 28600, 10356, 9656, 25093, 46701, 10770, 11128, 44453, 45554, 17219, 22079, 4994, 41790, 19436, 10289, 16547, 19427, 22074, 4109, 34530, 14261, 7812, 15407, 15860, 13438, 18964, 22564, 24635, 5187, 11737, 27610, 14043, 38141, 16397, 26900, 31506, 4812

A.2.5 1st Part: Question #4

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, w, r, r, w, r, r, r, r, r, w, c, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, w, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, w, r, r, w, w, r, r, r, r, r, r, w, r, r, w, r, w, w, r, r, r, r, w, r, w, r, r, r, r, r, w, r, r, w, w, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, w, r, r, r, r, r, w, r, w

Data (ordered from the first to the last subject) – times in milliseconds
3008, 10568, 9704, 20831, 23782, 5812, 14541, 9687, 8118, 3623, 8512, 18104, 17110, 6712, 33600, 14360, 4391, 7867, 26658, 11555, 9352, 2843, 6416, 8171, 17960, 14728, 10325, 32278, 4765, 15391, 14108, 9703, 9497, 7673, 38815, 49196, 36261, 7256, 13734, 11547, 33087, 25846, 10856, 13000, 18720, 11238, 1216, 7552, 2096, 12137, 19498, 7568, 2283, 11919, 21248, 9945, 15734, 6407, 8920, 5375, 5760, 13390, 7622, 16946, 11126, 6946, 8848, 15985, 5254, 7281, 8435, 6699, 6136, 18795, 6832, 11032, 6516, 10400, 22246, 2813, 9531, 14945, 15444, 7447, 31550, 16272, 13366, 29257, 3975, 16187, 17349, 82522, 9664, 1797, 18195, 14791, 21992, 43388, 7520, 8218, 31108, 10420, 840, 5938, 46631, 44527, 9282, 70237, 16313, 7831, 15297, 13299, 11960, 6068, 2922, 9484, 30865, 2716, 5976, 32641, 31415, 3859, 40922, 18302, 86074, 22654, 7168, 6266, 2723, 6727, 8953, 4146, 24125, 6829, 12328, 7251, 19860, 16096, 36204, 23736, 4048, 3325, 12327, 9328, 7781, 12589, 29078, 29201, 3859

A.2.6 1st Part: Question #5

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, c, r, r, r, r, r, r, r, r, r, r, c, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, c, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, c, r, w, r, r, c, c, r, r, r, r, r, w

Data (ordered from the first to the last subject) – times in milliseconds
7192, 6279, 5888, 5696, 11021, 6671, 9384, 7968, 6230, 5830, 12295, 5152, 7109, 6072, 25107, 8984, 8390, 9370, 12328, 7533, 4464, 8719, 21783, 12860, 5990, 9455, 7670, 13497, 5891, 15516, 14086, 11335, 6364, 12759, 12398, 7622, 6008, 9868, 6000, 9203, 26511, 13639, 5856, 20016, 15160, 12360, 15026, 13784, 12640, 7942, 7624, 5004, 38450, 14999, 5248, 9044, 15937, 13922, 8344, 8078, 5096, 13547, 7917, 16417, 7376, 14379, 5272, 12313, 16484, 6172, 28088, 6650, 7855, 9963, 31789, 8583, 7532, 18473, 7145, 4782, 7375, 12775, 15245, 13263, 26127, 5704, 14973, 31553, 8488, 11328, 14714, 41642, 8404, 3610, 28612, 7691, 12408, 22030, 6723, 7078, 7421, 8993, 776, 23485, 7992, 3800, 8672, 6458, 21601, 8713, 7641, 15442, 13207, 4484, 5812, 13625, 13595, 6613, 7248, 7687, 19720, 8297, 16719, 11131, 20199, 7627, 9393, 8578, 9094, 8953, 13438, 11166, 14962, 11063, 9687, 4781, 8047, 7472, 60080, 8815, 4761, 8923, 5909, 11324, 16890, 11982, 26670, 21680, 4453

A.2.7 1st Part: Question #6

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
w, r, r, w, w, r, r, r, r, w, r, r, r, r, w, r, r, r, r, r, r, r, w, r, r, r, r, r, r, w, r, w, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, w, w, w, w, r, r, r, r, w, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, w, w, w, r, w, r, r, r, r, w, r, w, r, w, r, w, r, r, w, r, r, r, r, r, r, w, r, r, r, r, r, r, w, r, w, r, r, w, r, r, w, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, w, r, r, w

Data (ordered from the first to the last subject) – times in milliseconds
9600, 2784, 2153, 18271, 13174, 13720, 7190, 9656, 2127, 5320, 6919, 4552, 14437, 6876, 38856, 17443, 4172, 6484, 7688, 10249, 7159, 7015, 25622, 8266, 6879, 20142, 27315, 43642, 11407, 21484, 8609, 6864, 13677, 11938, 14511, 8850, 21129, 23728, 16235, 15578, 12736, 37878, 12703, 24797, 11643, 4718, 1176, 27242, 6624, 22412, 43730, 9559, 10924, 9863, 3632, 5969, 8266, 8000, 16079, 7828, 12039, 17578, 37385, 17735, 5616, 11764, 4059, 9375, 13494, 6844, 11904, 39917, 4728, 12747, 17494, 22672, 3547, 18053, 40819, 3437, 20593, 26518, 6554, 5064, 28922, 12149, 23663, 34130, 4760, 6328, 12347, 99124, 10180, 2234, 38234, 13549, 17056, 6343, 6053, 19938, 19895, 16284, 712, 14735, 40128, 39687, 10360, 90106, 11368, 11937, 9500, 39306, 28599, 8056, 5171, 10078, 14177, 5546, 6840, 6109, 18671, 13250, 8313, 3769, 12397, 20877, 2085, 4313, 7184, 9896, 6063, 15272, 11556, 17438, 1828, 6937, 15328, 8268, 7906, 15200, 13439, 2103, 7611, 4510, 10953, 11965, 26198, 62979, 4031

A.2.8 1st Part: Question #7

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, w, r, r, r, w, r, w, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, w, r, r, r, r, r, r, w, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, w, w, r, r, r, r, w, w, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, w, r

Data (ordered from the first to the last subject) – times in milliseconds
2895, 3208, 2303, 5583, 18342, 4871, 5408, 8578, 2559, 4065, 6143, 17096, 6531, 5559, 43702, 7993, 9641, 3484, 6744, 7805, 5945, 9094, 8368, 6921, 12614, 10855, 18508, 3135, 9234, 22578, 7649, 9064, 2173, 3859, 2514, 8384, 9152, 5401, 14453, 14516, 13631, 4640, 6879, 5422, 11549, 8790, 1952, 8530, 6280, 8523, 8765, 2240, 3137, 6417, 4656, 4740, 11500, 8625, 9733, 7859, 8450, 13079, 12152, 6519, 12417, 7994, 11041, 2672, 5776, 5000, 2932, 8512, 7079, 16912, 5648, 20887, 6640, 5481, 9911, 1953, 5453, 4404, 13061, 7607, 3225, 4013, 12695, 20489, 3952, 27969, 6310, 41852, 2585, 2141, 6001, 17525, 11224, 7843, 10452, 13000, 11144, 8974, 840, 14110, 11719, 7968, 4766, 21717, 9640, 21381, 9172, 17705, 5415, 6173, 7843, 15281, 11729, 4395, 8384, 4140, 26337, 6375, 4140, 3601, 10194, 14689, 2392, 3062, 2314, 4097, 7500, 5248, 6259, 5125, 16765, 5751, 10875, 4323, 7265, 8408, 3910, 2133, 6810, 10181, 12359, 4670, 27703, 10240, 2610

A.2.9 1st Part: Question #8

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, w, w, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, c, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, w, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w

Data (ordered from the first to the last subject) – times in milliseconds
1761, 1840, 1933, 5351, 6752, 5743, 7731, 17859, 8158, 4479, 5840, 1560, 6734, 3547, 22196, 4922, 3531, 14500, 17672, 17072, 3848, 12594, 2191, 2766, 3005, 9584, 1920, 1998, 2157, 16360, 8102, 4545, 2352, 4058, 12808, 2125, 4118, 1859, 2125, 26078, 16727, 10880, 13640, 4187, 10592, 13138, 887, 2152, 1792, 17045, 3234, 8231, 3290, 2024, 5167, 2913, 13578, 14000, 11399, 14109, 5328, 15391, 6055, 13762, 6121, 5944, 3440, 14672, 10556, 6578, 3821, 4577, 3695, 5957, 5647, 16087, 14344, 2756, 6676, 2281, 5218, 2492, 11309, 3248, 2078, 4034, 15808, 9945, 3480, 18125, 4747, 219861, 4643, 1297, 7202, 7040, 9416, 5390, 10140, 11235, 2188, 7805, 728, 6313, 22183, 5816, 7735, 1804, 21929, 11617, 1750, 16164, 4616, 2162, 7516, 8578, 7766, 13923, 2840, 2875, 2686, 6579, 2609, 5550, 35290, 8953, 12208, 14625, 3542, 7545, 2469, 8212, 9484, 5203, 2235, 9797, 20516, 9206, 11032, 5631, 2968, 3315, 21070, 4055, 27547, 5832, 11206, 6049, 1734

A.2.10 1st Part: Question #9

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, w, r, w, r, r, r, w, r, r, r, r, r, r, r, w, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, w, w, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, w, r, r, w, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, w, r, r, w, r, r, r, r, r

Data (ordered from the first to the last subject) – times in milliseconds
3296, 6104, 6789, 5014, 20182, 7272, 2043, 8407, 5279, 3552, 5456, 4472, 10688, 2551, 10998, 8831, 4516, 4909, 6898, 9341, 5639, 18593, 6136, 5984, 4215, 9487, 6391, 6372, 6640, 6421, 7704, 6067, 3898, 8714, 11487, 6142, 10721, 10252, 3000, 6844, 10248, 7400, 5391, 8172, 2769, 8959, 1416, 5919, 4584, 9303, 8157, 12511, 9470, 12223, 5639, 6694, 17282, 17907, 5449, 3047, 2968, 12953, 4007, 7398, 2252, 14996, 6848, 5437, 4782, 7609, 4730, 3505, 2983, 9082, 10283, 5752, 3797, 2564, 3500, 1797, 7016, 4587, 7961, 1874, 7354, 5366, 3441, 17777, 4304, 13922, 14180, 24651, 4137, 1625, 3486, 4496, 1664, 8921, 12995, 11031, 6570, 13784, 737, 3718, 10920, 12039, 3438, 12293, 14240, 9513, 4047, 4256, 5336, 1870, 1781, 8672, 14729, 6433, 4248, 6531, 13624, 4594, 3125, 7322, 7230, 10871, 4004, 8718, 7565, 39455, 7516, 9103, 5227, 7109, 10406, 8109, 5828, 4909, 7031, 9481, 2628, 1402, 6079, 3439, 8406, 4939, 21209, 3784, 7547

A.2.11 1st Part: Question #10

Data (ordered from the first to the last subject) – r = right answer, w = wrong answer, c = clueless
r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, c, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, w, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, r, c, r, r, r, r, r, r, r, r, r, r, r, w

Data (ordered from the first to the last subject) – times in milliseconds
2344, 7040, 5848, 4023, 4704, 5799, 10685, 6781, 4815, 4752, 4263, 4568, 5203, 11139, 29970, 9782, 6375, 8110, 7623, 8377, 3567, 3968, 6264, 22937, 5505, 8440, 12294, 7254, 2797, 15938, 5461, 4904, 6366, 8676, 9294, 6895, 1096, 6552, 4687, 6687, 23384, 5383, 4191, 11844, 4333, 12045, 8176, 4847, 4976, 5808, 7969, 4240, 16420, 4326, 6663, 3425, 6719, 5000, 7792, 4953, 5576, 11641, 7320, 5775, 7913, 11054, 4029, 5953, 5047, 5563, 10312, 14130, 10318, 7310, 9885, 4511, 7984, 42091, 11939, 3547, 4172, 10264, 10987, 7541, 4372, 4162, 15501, 8520, 6320, 12657, 7335, 29736, 6016, 1531, 17822, 5008, 14552, 12187, 13245, 5437, 4854, 4994, 1064, 5734, 8904, 4896, 9219, 15121, 21171, 7191, 6062, 5969, 9160, 7283, 6812, 8313, 5048, 6026, 30808, 5110, 6664, 4391, 8062, 6741, 6600, 13412, 5305, 6782, 8130, 16209, 9547, 6300, 10696, 8656, 4641, 6016, 15015, 5477, 12532, 6872, 8387, 13409, 22342, 17420, 8750, 3699, 16740, 5296, 2766

A.2.12 2nd Part: Question #1

Data (ordered from the first to the last subject) – times in milliseconds
12303, 14510, 11066, 7863, 1864, 8533, 11937, 12922, 12772, 10994, 6038, 9198, 9906, 9706, 13798, 9701, 8859, 12966, 7750, 12559, 1870, 12937, 8600, 16000, 14223, 12116, 8574, 13440, 12422, 12297, 12341, 11709, 16448, 11646, 15312, 16107, 12286, 9955, 2906, 18703, 19137, 13855, 11379, 11547, 9971, 14380, 1222, 10901, 9446, 20600, 11064, 8311, 2865, 2555, 16615, 9035, 11688, 7844, 10930, 10047, 15108, 14984, 8571, 11984, 11888, 18520, 21497, 12344, 10653, 11844, 20210, 5088, 12758, 13047, 15249, 12556, 3031, 8884, 20159, 9329, 27094, 11359, 9767, 9396, 8245, 12565, 6293, 19185, 14183, 11515, 10060, 15659, 9544, 13391, 15322, 8482, 10179, 14265, 15272, 8266, 12159, 9274, 574, 19906, 16565, 9767, 11531, 19655, 11480, 8912, 16171, 9143, 8701, 8729, 8656, 12282, 6822, 5421, 8525, 8703, 47474, 9938, 19625, 12198, 9704, 12059, 10968, 4078, 3635, 10752, 11234, 12889, 8953, 14641, 7594, 12704, 14344, 10833, 18563, 12414, 7814, 9023, 11597, 14604, 12625, 19850, 13244, 12951, 9328

A.2.13 2nd Part: Question #2

Data (ordered from the first to the last subject) – times in milliseconds
15951, 6583, 13369, 12599, 7718, 6933, 21732, 15984, 14660, 15223, 7846, 13038, 12031, 23918, 15132, 10512, 12578, 16440, 10206, 16296, 1598, 24266, 9192, 17687, 17743, 22018, 7679, 17285, 16406, 19500, 23590, 14784, 26203, 2216, 15622, 25436, 14432, 16635, 13344, 26984, 22411, 12687, 16316, 15843, 16485, 16454, 926, 15567, 9926, 19568, 16673, 3784, 1713, 13957, 23631, 11319, 13469, 6703, 17759, 2547, 12021, 20656, 13085, 18302, 19583, 21210, 25390, 17343, 18346, 11594, 23220, 5888, 18222, 18164, 12585, 14982, 2484, 5569, 32348, 11313, 28157, 16422, 14862, 18526, 13037, 23219, 2923, 27777, 14295, 10968, 19289, 9572, 26338, 15750, 14215, 13679, 18260, 19296, 16660, 10453, 16415, 10828, 510, 11563, 21655, 17118, 8547, 21193, 14024, 10144, 24344, 12518, 14509, 13489, 14500, 12250, 17129, 12462, 13229, 11093, 21927, 10579, 19468, 18154, 22943, 19255, 14167, 14297, 2114, 11623, 13282, 15182, 10495, 24422, 10282, 8641, 18344, 19881, 21969, 17607, 11510, 6610, 14501, 6100, 11750, 18556, 29769, 24816, 1844

A.2.14 3rd Part: Preference #1

Data (ordered from the first to the last subject) – abstract landmark = 1, concrete landmark = 2
1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 1, 2, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 1, 1, 2, 2, 2, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 1

A.2.15 3rd Part: Preference #2

Data (ordered from the first to the last subject) – abstract landmark = 1, concrete landmark = 2
2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 1, 2, 2, 2, 2, 1, 2, 2, 2, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 1, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 2, 1, 2, 2, 2, 2, 2, 2, 2, 2, 1, 1, 2, 1, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 1, 2, 2, 2, 2, 2, 2, 1