# Vision for the next decade of GIS technology

**A research agenda for the TU Delft, the Netherlands**

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**Summary:**
*In this document a vision for the research in the area of GIS technology is presented. Based on this research program, the section GIS technology of the TU Delft expects to reach its ambition level to become one of the top five universities in the world in the field of GIS technology in general and become the number one university in the field of geo-DBMS research.*

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# CONTENTS

**LIST OF FIGURES**

# 1. INTRODUCTION

GIS technology or Geo-Information and Communication Technology (Geo-ICT) can be considered a part of the more general discipline of geo-information science. Geo-information science is based on several related disciplines or scientific themes. Geo-information is being and has been applied throughout the world for many centuries or even millenniums, so why bother doing scientific research in this area?

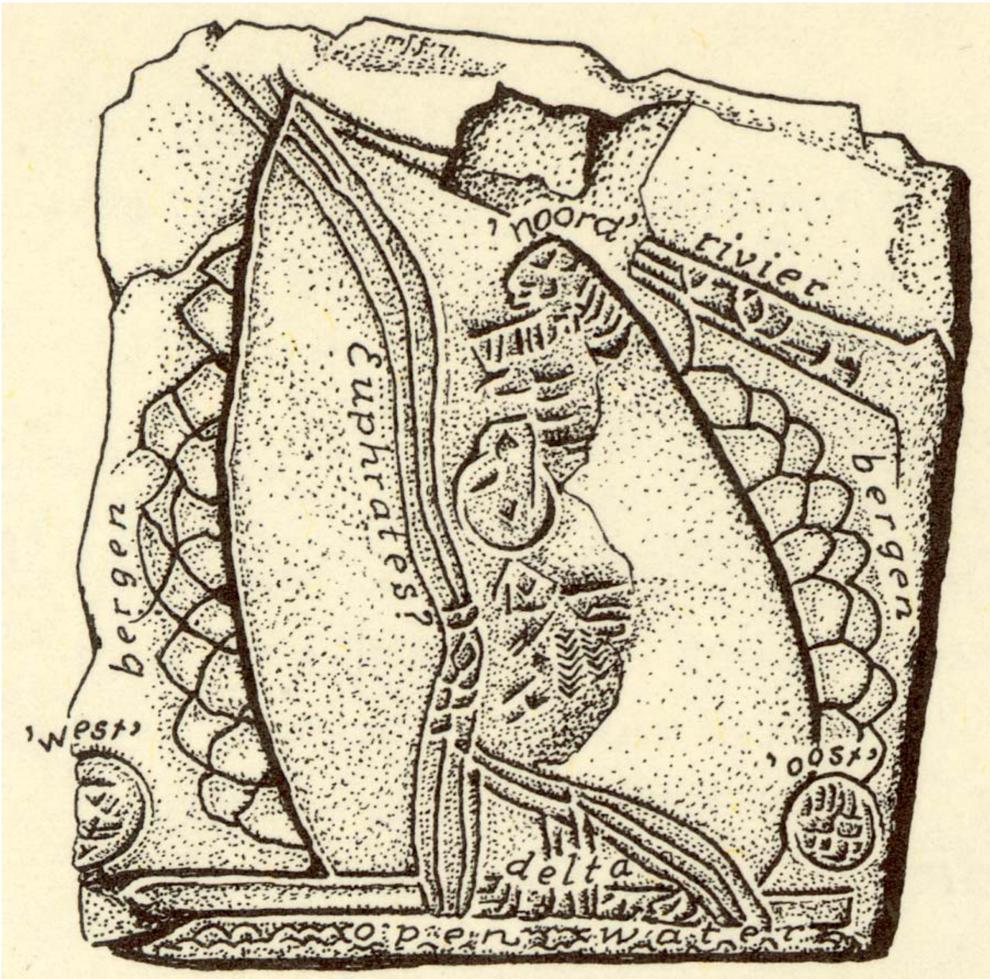


*Figure 1: A clay tablet originating from Mesopotamis (± 1700 BC).*

The answer is that we want to improve our way of handling geographic information. The overall goal of the research of the section GIS technology is to provide/develop the technology, including the knowledge behind it, to stimulate the realization of the geo-information infrastructure (GII) [1]. This in a global context but with specific attention for the Netherlands: this could be called 'the *Virtual Netherlands'*. Our current society is heading towards an information society; the impact of this may be varying for the different parts of our economy. However, in the geo-information business the impact and the potential advantages are enormous as our main product, geo-information and services, can be transported very well via (wireless) networks. The engine(s) of the GII nodes throughout the world will be the geo-DBMSs (DataBase Management Systems) filled with geographic data. The presented TU Delft, GIS technology research agenda is not isolated, but fits within the overall geo-information science research agenda, which has recently been developed in the

Netherlands in the Bsik[1] knowledge project proposal 'Space for geo-information' (RvG) [3].

The specific issues in or requirements from the geo-information application sector are presented in Section 2 organized according to a number of major changes (expected transitions) taking place in geo-information handling during the next couple of years. Sections 3 and 4 will give an overview of respectively the related international and national geo-information research agendas. Both are described in more detail in the appendices of this document. The main organization principle for the different research themes is the place of the research theme in the well-known geo-information process chain [2]:

1. geo-information reference systems,
2. geo-information collection,
3. geo-information modelling and storage,
4. geo-information analysis and handling,
5. geo-information presentation and interaction,
6. geo-information exchange, and
7. geo-information use in applications (the primary 'business', which is supported by the geo-information process).

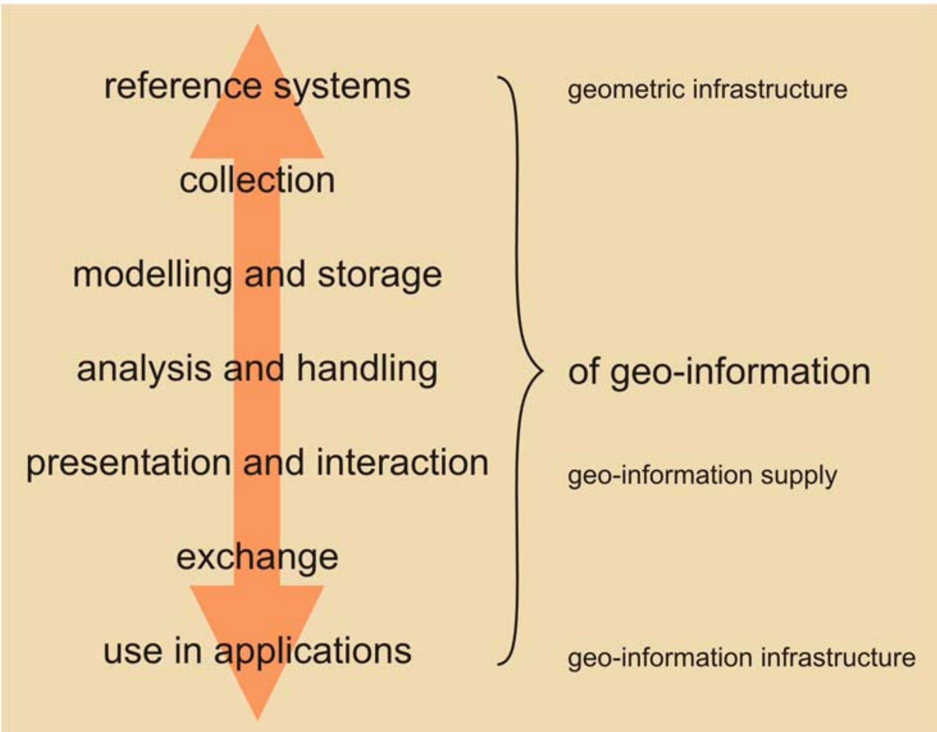


*Figure 2: The geodetic disciplines.*

Knowing what is happening and what is planned to happen elsewhere, helps to avoid duplications in research, but also gives indications of potential research partners. With the expected transition in geo-information handling and the related (inter)national research agenda as our context, the main scientific and technological innovations targeted by the GIS technology research are discussed in Section 5. In

[1]Bsik is an acronym of the Dutch 'Besluit subsidies investeringen kennisinfrastructuur', in English 'Decision State aided investments knowledge infrastructure'.

Section 6 it is indicated how the scientific aspect of the GIS technology research should be organized in order to obtain the envisioned quality and results: the scientific approach and methodology are described and it is explained why this approach is to be preferred over alternatives. An important aspect of the scientific approach is the collaboration with the leading Geo-ICT industry within the Geo-Database Management Center (GDMC) as described in more detail in Section 7. The ties with other national, European and international research activities are given in Section 8. Finally, some last remarks and conclusions can be found in Section 9.

## 2. EXPECTED TRANSITIONS IN GEO-INFORMATION PROCESSING

Analysing the changes of the geo-information applications requirements, a number of different transitions can be observed, which are currently taking place or are expected to take place in the near future. These geo-information application transitions need to be supported by scientific/technological and societal innovations. The four main transitions are; also see [3]:

1. *From ad hoc (project) geo-information to GII; from ad hoc demand to structural demand:* the demand is becoming more structural within the different user groups: government (policy makers), citizens (the Netherlands is a country with a lot of 'spatial' plans, rules, and regulations), and organizations (cultural, recreation, commercial, etc.). Research efforts have to focus on how to use geo-information in sustainable development, analyse how users (policy makers, citizens, organizations) make their decisions and use geo-information, what geo-information is needed in what context, how can the geo-information provision be organized to these different groups of users. Currently, there is no operational national GII, due to technological and societal factors. Research efforts are needed on issues such as: linking our national model to an international (European) GII, solving the societal (legal, financial, organizational) problems, finding (information) technical solutions for realization the GII related to international standards developments; OpenGIS, ISO.
2. *From static 'maps' to 'dynamic' models of space:* the traditional way of working with 2D static spatial information (maps) has been augmented by methods for 3D, 3D+time data/processes, Multimedia and Virtual/Augmented Reality tools. This has been driven by both the technological developments and the scientific and societal needs. Research efforts are needed to obtain knowledge related to (3D/4D) spatio-temporal modelling, how the user perceives the spatial information presentation/interaction methods and how to further develop new man-machine interaction in the context of geo-information.
3. *From traditional map production to dynamic data collection and positioning on the fly*: more and more geo-information applications dynamically require geo-information to be obtained or at least to obtain the current position of the user; e.g. via Global Navigation Satellite Systems (GNSS), such as the American GPS or the future European Galileo System. This offers new possibilities as services can be dynamically chained via wireless communication networks and the geo-information process chain is traversed 'real-time'. Research efforts are on issues such as: how to integrate the new data acquisition (dynamic positioning) with the data collection processes of the large data providers, and how to connect the different knowledge domains to make this operational successful.
4. *From implicit semantics of geo-information to explicit knowledge*: within a certain domain it was perhaps not necessary to make the semantics explicit as the limited number of users had (more of less) the same interpretation of the basic geo-information within their domain. However, the GII will expand the user community of basic geo-data sets to persons not familiar with the meaning of this information. Therefore the explicit semantics of different geo-data sets have to be captured explicitly (in the form of ontologies).

The research objective of the Section GIS technology is to support the realisation of the Geo-Information Infrastructure (GII) in a technological sense. Internationally the GII is sometimes also called the SDI (Spatial Data Infrastructure). In this respect the GIS tools are considered to be the principle research objectives and not - like with other universities and research institutions - using GIS tools within the different types of spatial applications. The GII provides a better access of geo-information and facilitates the use by more organizations/individuals, who deal with spatial problems in one way or the other:

- What is the quickest route to go from A to B taking into account this morning's heavy traffic on the highway?
- What is the best method for a municipality to open up its zoning plans internally and externally (citizens, private companies)?
- What is the nearest restaurant, service station, etc. taking into account my current location?
- Which owners have to be notified by the Telecom Company about the construction of a new cable connection?
- How looks the landscape after the realisation of a new railway?
- Which cables and pipes should be taken into account during the excavation at this location?


*Figure 3: Map fragments: a) cadastral map and line Large Scale Base Map of the Netherlands (GBKN), b) polygon/object GBKN (1:1000 topography) and c) NAM pipelines projected on the cadastral map.*

All these questions have in common that they need one or more geo-information sources to give the right answer. Often it is not realistic to collect the data for each question (application) by oneself or to buy these data covering the whole area at a geo-information source. However, shared use on the basis of a shared infrastructure, makes it realistic to make use of geo-information. Groups of users making use of the same information and exchanging information are called information communities.

GISs are used within (local, regional, central) governments, utility and other companies to support their core business, which often depends heavily on spatially referenced data. Due to more and more exchange of geo-information within and between organizations, the need for a GII is also growing. The GII consists of four, rather different basic components: geo-data sets, geo-data processing services (geo-DBMS), interoperability standards, and (wireless) networks. More in detail:

1. Basic or authentic *geo-data sets* in different domains: topography, elevation, cadastre, geology, companies, persons, etc. These data sets should be defined in an unambiguous way with respect to their data model, geometric and thematic contents, quality, accuracy, actuality and access (management, maintenance).
2. Geo-data processing services in general and the *geo-DBMS* specifically. The geo-data sets are maintained in these geo-DBMSs and are served to users from these geo-DBMSs via networks and/or traditional means. For these purposes, the DBMS has to support spatial data types and operators (simple analysis and selection oriented queries), spatial indexing and clustering (for large data sets), and if possible support for advanced analysis (topology based analysis). Also, temporal support is required in the form of some kind of future standard TSQL.
3. *Interoperability standards* are required to enable the integration of the different data sets and to combine the geo-data processing services. In fact, different organizations and individuals using each others geo-data sets in a digital environment can be regarded as parts of one distributed computing environment. One of the most obvious examples of this is an Internet GIS retrieving and combing *on-the-fly* data from different sources on the Internet. In order to be able to work in such a heterogeneous world (different types of hardware, networks, operating systems, geo-DBMSs, geo-data sets) interoperability standards at many levels are required.
4. *(Wireless) networks* are obviously needed to transfer data and functionality (or 'services') between the involved parties. More and more often this also includes a mobile communication partner, which often posses the possibility to determine its own position via GNSS.

Each of these components of the GII holds many aspects: organizational, financial, technical, etc. Nowadays Internet is being using intensively all over the world. The success of the Internet has shown the power and superiority of an open infrastructure. The open (public) standards and the decentralised architecture are responsible for the many free and non-free services. One of the most time-consuming tasks when implementing a GIS is obtaining geo-data. First, relevant data sets and sources have to be located and then these data sets have to be copied and converted into the local system/format. Some reasons why this process is so time-consuming are that it may be difficult to find the data, the data model of the source may be very different from the model implemented by the local system and the supported exchange formats of source and destination are different. The GII is trying to improve this situation by providing:

1. consensus on the geometric parts of the data model, both raster and vector data have to be supported (including different spatial reference systems);

2. how to formally describe the geo data sets (and geo processes), that is a meta data standard covering both the spatial and non-spatial aspects;
3. how to access and query the meta data and how the result of such a query is returned, this is called catalogue services;
4. how to query the geo-data itself;
5. how to format (and transfer) the resulting geo-data set.


*Figure 4: Internet GIS.*

By developing systems based on the above standards, a new model for implementing GIS applications becomes feasible. Instead of always copying and converting geo-data, it becomes possible to access the geo-data directly at the source. This model has a number of advantages. At the client side no data management (of copies) is needed anymore. Moreover the data can become available all over the word via Internet. However, the most important advantage is the fact that users have the guarantee that they have always the most actual and complete geo-data set directly from the source at their disposal. Furthermore this model allows fair pricing of geo-data as every time data from the source is used (possibly through a local cache) the user can be charged for this. Currently, in the *full data set* copy model the user has to pay for the whole data set, even if certain data (regions) are not used at all (in a certain period). The new *data at the source* model allows fairer pricing, both viewed from the vendors and buyers point of view.

## 3. WORLDWIDE GEO-INFORMATION RESEARCH AGENDAS

This paragraph discusses some of the major geo-information research agendas worldwide (not including specific Dutch agendas, see Section 4) in order to have a global picture of the geo-information science. This section is based on the analysis of the recent research agendas from the following organizations: United States (US) University Consortium for Geographic Information Science (UCGIS), Association of Geographic Information Laboratories for Europe (AGILE), US National Center for Geographic Information and Analysis (NCGIA)/Varenius, European Spatial Data Research (EuroSDR, formerly the OEEPE), the Australian Cooperative Research Centre (CRC) for Spatial Information (SI), and the Canadian Geomatics for Informed Decisions (GEOIDE). In Appendix A (with details of all these research agendas) it becomes clear how the different elements in the geo-information process chain are supported by worldwide research. Looking at the international research agendas of the different consortia/organizations, a number of things become clear:

- Many different topics belong to geo-information science and based on the overlap of the different research agendas, it can be concluded that there is international agreement on this.
- Geo-information science is multidisciplinary: all kinds of geo-sciences, information sciences, and many different application domains are involved.
- Geo-information science is a very active discipline within science, with many research institutes worldwide involved and many new research themes being added to the agenda all the time.

*Figure 5: Worldwide geo-information organizations.*

All research agendas are quite broad and cover a large part of the geo-information processing chain, which is not strange if one considers that these research agendas service the interest of many participants within these organizations. There is a difference between the research agendas of the organizations with their roots in the 'pure' scientific (university) world, such as UCGIS, AGILE and NCGIA/Varenius and the research agenda's of organizations with mixed roots (industry, government, university), such as EuroSDR, CRC-SI, and Geoide. Both have a long and broad list of scientific research topics with challenges for the short- and long-term. However, the group with 'mixed' roots also identifies a list of applications (user categries, demontrator projects). The relationship between the research themes and the application (domains) is often presented in a matrix structure.

The Canadian GEOIDE and the Australian CRC-SI are very relevant as the context is very similar to the situation in the Netherlands. These research programs are originating from two (also) leading geo-information countries, with a similar sized funding from the central government, having a similar population, and there are more striking resemblances. For example, the Australian seven-year mission plan has analysed other CRCs and concludes that 25 other CRCs (knowledge projects) make use of spatial information[2] products and services. These 25 CRCs do not conduct research themselves in spatial information; their success depends heavily on the availability of spatial information products and services, i.e. research. The same can be concluded for the Netherlands when we analyse the call for knowledge projects, the Bsik knowledge themes[3].

All research agenda's include a solid portion of GIS technology, indicating that it is a shared opinion from all over the world that there are important and interesting challenges ahead in this field. Also modelling, including the semantics aspect, and data management get a good share of attention in most research agenda's. However, only the research agenda of EuroSDR specifically mentions the topic of geo-DBMS.

[2] Though the Australians call it spatial information, they actually mean geo-information as their research program does not cover more than geo-information (information related to a location on the earth). The more general term spatial information should be used in case also non-geographic information is intended, such as in medical images, CAD-design, computer vision, etc.

[3] It can be claimed that more than one-third of the Bsik themes make heavy use of geo-information (and their success will depend on the availability of these products and services): 'system innovation in use of space', 'water and space', 'climate and space', 'sustainable use of the subsurface', 'linked networks', 'transition towards sustainable mobility', and 'transition towards sustainable architecture'.

# 4. The situation in the Netherlands

After this short overview of geo-information research programs all over the world, now an overview of the geo-information R&D agendas in the Netherlands will be given. These may be different from the worldwide agendas because the Dutch needs for geo-information (services) and our expertise may be different. Three recent initiatives are very useful in order to analyse this: first, the NCG-GIM research agenda, second the Geo-ICT study of TNO for RWS-MD, and third the Bsik knowledge proposal 'Space for Geo-information' (in Dutch: 'Ruimte voor Geo-informatie', RvG).

*Figure 6: Organizations involved in the Dutch geo-information R&D agendas.*

Within the Netherlands, the subcommittee Geo-Information Models (GIM) of the Netherlands Geodetic Committee (NCG, an institute of the Royal Netherlands Academy of Arts and Sciences, KNAW) has produced their research agenda in 2000. For more information of the NCG and details of the research agenda see: http://www.ncg.knaw.nl/. This could be considered a first direction for the selection of the different research themes relevant for the Netherlands (consult Appendix B.1 for more details). Several aspects of data and process modelling get quite a bit of attention in this research plan: modelling the temporal aspect (both raster and vector approaches), modelling the semantics (that is developing ontologies), multi-scale modelling (and generalization), modelling uncertainty (related to quality), and consistently maintaining the data and process information in a digital environment (databases). Other important NCG-GIM research themes are related to the use, distribution (via a GII) and visualization of geo-information.

The more recent TNO 'Geo-ICT trend analysis' of December 2002 [2], conducted as an assignment for RWS/MD, is based on meetings and information from the main geo-information players in the Netherlands: government agencies, geo-ICT industry, research institutes and universities. It is therefore a well-balanced overview and gives an impression of the main players related to the future of Geo-ICT in the Netherlands. Besides the topics also mentioned by the NCG-GIM (modelling, distributed use, …), the Geo-ICT trend analysis reveals a few additional (sub) themes, which are considered important for the Netherlands: data collection, geo-information analysis, location based services, and interoperability standards (meta data). For more details see Appendix B.2. The NCG-GIM decided not to include data collection and geo-information analysis in their research agenda, not because these topics were not important, but in order to focus. Moreover it was expected that other countries would take care of the needed R&D. In a world of networks it is clear that interoperability standards are needed (and the Netherlands should play an active role in areas were these standards are being developed; e.g. OpenGIS/ISO).

Very recently, February 2003, a large consortium consisting of over 120 parties, including the TU Delft, submitted the Bsik (Dutch 'Besluit subsidies investeringen kennisinfrastructuur', or in English 'Decision State aided investments knowledge infrastructure') knowledge proposal 'Space for Geo-information' (Dutch 'Ruimte voor Geo-informatie', RvG) [3]. RvG selected two starting points when deciding on scientific innovations of vital importance. First, RvG gives preference to innovations that are specific for the Dutch situation and relevant for Dutch society. Second, RvG focuses on innovations with the potential to put the Netherlands among the world's leaders in ten years time. For more details on the RvG research agenda see Appendix B.3. Based on this the main innovations (spearheads related to the geo-information process chain, see Section 1) of this project are:

a. *Geo-infrastructure concepts* for handling geo-information (related to the whole process chain);
b. Spatio-temporal modelling aspects (related to link number 3);
c. Geographic man-machine interaction (related to link number 5);
d. Geo-information & society: institutional related legal, financial, organizational, management, cultural and awareness aspects in the development of the National Geo-Information Infrastructure (related to link number 7).

## 5. THE MAIN SCIENTIFIC/TECHNOLOGICAL GOAL

After describing the research needs resulting from the expected transitions in geo-information handling and the (inter)national research agendas, this section describes the specific research goal for the section GIS technology. The main innovations are related to thinking in *infrastructure concepts* for handling geo-information, which requires *technological innovations* making optimal use of geo-data and services possible, focussing on *modelling* aspects and the geographic man-machine *interaction.* The foundation of the GII consists of geo-DBMSs filled with geographic data. A consistent GIS technology research programme has been formulated concentrating on the central theme of geo-DBMS. All research projects will have geo-DBMS roots and from this angle cover topics such as: Quality/semantics of geo-information, 3D GIS and Virtual/Augmented Reality (VR/AR), Distributed geo-information handling via (wireless) networks and Spatio-temporal modelling.

*Figure 7: Logo of the Geo-Database Management Center (see Section 7).*

The establishment of GII will be associated with a tremendous growth in numbers of non-professional users. Proper metadata is necessary to ensure that these users know *where* they can find *what* type of geo-information. It is the general experience that many of these users are often unaware of the importance of the quality issue in relation to geo-information. Quality is related to geometric, temporal, as well as to thematic aspects of spatial features. Research topics include metadata, identification of proper quality indicators and their propagation behaviour under GIS operations; querying, analysis and visualisation of the quality indicators, and their incorporation in current spatial (data transfer) standards. In addition to modelling 2D and 3D spatial aspects of features, the modelling of changes in features over time becomes increasingly important. The modelling of these features depends on the nature of the changes, which may be discrete (e.g. ownership of a parcel) or continuous (e.g. movement of dunes). The integration of this 4th dimension in existing data-structures, such as raster, TINs and DEMs, represents a major research topic involving a wide range of issues, from translating logical and conceptual models described in the Unified Modelling Language (UML) to implementing the associated physical model in a DBMS.

Until recently the spatial data management has been handled by GIS software outside the DBMS. As DBMSs are being spatially enabled more and more, also GISs are or will soon migrate towards an integrated architecture: all data (spatial and thematic) are stored and managed in one DBMS. This marks an important step forward that took many years of awareness creation and subsequent system development. Many organizations are currently in the process of migrating towards this new architecture. This is a lot of work and will still take many years. As indicated in Section 2, the next step will be the creation of a shared GII for related organizations; the so-called information communities. By direct, controlled access of geo-date at the source, the exchange of copies of data sets between organizations will become superfluous in the long run. It requires good protocols, standardization such as the OpenGIS interoperability standards in general and the feature geometry models, the meta data and catalogue services, and the web mapping server specifications specifically. The OpenGIS consortium has basically two levels of standards: abstract (comparable to 'official' CEN and ISO standards describing a certain domain) and implementation standards. In case there are other good standards available, the OpenGIS consortium adopts these standards. The implementation standards are an important added value of the OpenGIS consortium, describing the exact interfaces (protocols) of (a part of) an abstract standard in the context of a specific distributed computing platform. A good overview of the OpenGIS domain can be found in the OpenGIS Guide (via http://www.opengis.org). The section GIS technology (via the Department of Geodesy) of the Delft University of Technology is an OpenGIS member.

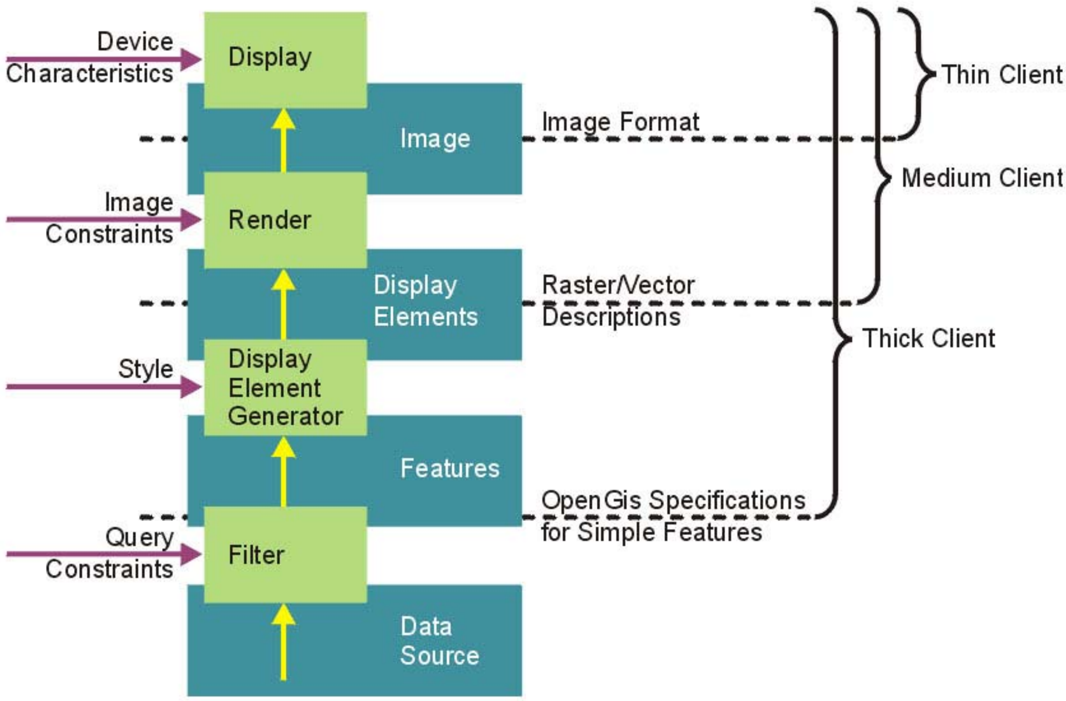


*Figure 8: The OpenGIS overview of the different types of Internet GIS options.*

The importance of the geo-DBMS is increasing at the transition to the GII, because not only one organization depends on it, but the (geo-)information community as a whole. The main use will be query oriented and less update oriented. Only one organization will be responsible for updating a specific type of data, all others query and use these data. As the query aspect is dominant and the cost of memory chips reduces, VLM (Very Large Memory) DBMSs might offer a very suitable technical solution. They are powerful enough to serve large numbers of users via the Internet. An important component to get the data in time at the (mobile) users is the development in the field of network infrastructure (bandwidth) itself. This is covered by the Internet2 developments and in the Netherlands by the Gigaport project. Both developments in hardware and software and in database technology will contribute to the future shape of the Geo-Information Infrastructure. Current extensible DBMSs are very well capable of storing 2D spatial data. Also simple queries like zooming in and zooming out can be handled efficiently by making use of spatial indexing and clustering. However, more complex operations, like map overlay, on the fly generalization, enforcing correct topology during updates, 3D analysis, etc. are still not within reach of these systems. New developments in DBMS technology, like Extensible (Object Relational) DBMSs, Object Oriented DBMSs, and Very Large Memory (VLM) Databases, will underlie the new generation of DBMSs. The University of Amsterdam has developed the VLM database Monet. In co-operation with this University it will be investigated in which way this Main Memory Database can be used for geo-data storage.

The first OpenGIS implementation standard was related to the feature geometry abstract specification. It was called Simple Feature Specification (SFS) and takes care of the standardization of basic spatial types and functions. The implementation specification for the SFS are described for three different platforms: SQL, Corba, and OLE/COM. Currently, OpenGIS is revising/changing the feature geometry abstract specification in order to be consistent with the excellent standard ISO TC 211. This new abstract standard covers also 3D types, more geometric primitives (curve and surface types), and complex features (topology). What is still missing is the implementation specification of topology for specific platforms. However, it is questionable if this can be realized for pure relational DBMSs. What the feature geometry abstract specification and simple feature implementation specifications are for the vector model, are the earth imagery abstract specification and the implementation grid coverage implementation specification for the raster data model.

The described GII is based on interoperability standards and advanced geo-DBMS technology, can be used to re-implement existing GIS applications in a more efficient and effective manner. The GII will integrate sectors (areas), which have until now been separated. Besides re-using general geo-information knowledge (perhaps first discovered in one domain and then applied in other domains), the GII will also give an impulse to the use of geo-information and services from other domains. A prerequisite is that these different domains understand each other (share a common ontology). It was already difficult in the past to share the concepts within one geo-information domain (transportation, topography, geology, (ground) water, cadastre, elevation, land use, utilities, and so on), so one can image the difficult task ahead when concepts have to be shared between different domains. Finally, the GII can be used to build new, sophisticated applications, e.g. mobile location dependent applications and VR (Virtual Reality) and AR (Augmented Reality) applications. As stated before we are in the middle of a number of fundamental developments. However, there are still many open problems. The section GIS technology will contribute in solving these problems by carrying out research in the field of the standardization of complex features; inclusion of quality in the DBMS (perhaps on data type level), 3D modelling and visualisation and the usability of VLM databases for GIS applications.

*Figure 9: Karma: an integrated 3D-GIS and VR-environment.*

## 6. SCIENTIFIC APPROACH AND METHODOLOGY

The most important characteristic of the chosen scientific approach for the GIS technology research is the strong focus on the main research goal: a geo-DBMS for the GII. The section GIS technology has the ambition to be one of the *leading technology partners in a network of R&D* centers from (private and public) organizations and from the universities in the domain of geographic science. Two alternative R&D organizational models could have been:

1. Isolated research center, with strong focus on the research program described in Section 5 (geo-DBMS). This would not fit to the current geo-information knowledge culture in the Netherlands and would also not take benefit of the strong capabilities of (industry) partners.
2. Loosely directed research center, with or without participation in the geo-information knowledge network. This would not be effective, as the lack of focus would scatter the GIS technology resources over too many topics (and therefore will not excel in any of them). Therefore, this would cause a sub optimal use of resources.

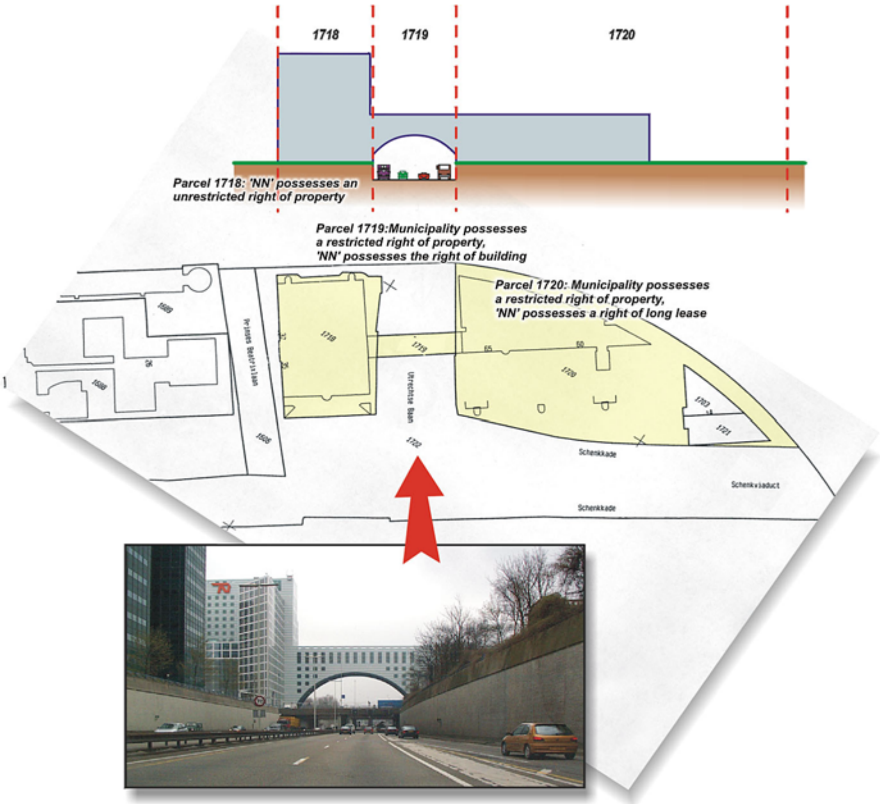


*Figure 10: 3D Cadastre:*
*an example of the intensive cooperation with the Dutch Cadastre.*

Having selected the relevant geo-information research theme (targeted innovations with respect to the geo-DBMS and the related topics) for the GIS technology research, the following choices further characterize the scientific approach and methodology:

- Mission driven: a common, shared GII (instead of everyone for her/himself);
- Individual scientific/technological research projects (instead of one big research project);

- Participation in and initiation of (inter)national research networks and projects (instead of only working within the TU Delft);
- Demonstrator projects to show the integration of scientific research from the different themes. They are application driven, so they may show further knowledge gaps (pure scientific/technological research will not show the integration of technologies and will not have the application drive);
- Scientific research focussed on the main theme geo-DBMS (instead of trying to investigate the whole geo-information process chain);
- Education and knowledge dissemination being explicitly part of the research program, close coupling with the MSc Geo-information (and Land Management) (instead of pure focus on knowledge development and application of knowledge in domains);

*Figure 11: Educating young people is the real challenge of our profession.*

- Links to the Bsik knowledge project RvG (via active participation in several research projects) and other geo-information related Bsik knowledge projects is important (instead of letting these other Bsik knowledge projects discover and solve generic geo-information themes themselves);
- Active in the organization of (inter)national symposia, workshops or conferences, which should result in formal publications: books or edited proceedings. (The alternative of not initiating any serious scientific event and no scientific book publications might reduce the scientific impact of the GIS technology research);
- Evaluation of individual research projects, both internally and externally at different phases in the project. (No evaluation will make 'half-way' adjustments impossible and it will also be difficult to assess the overall impact of the research of the section GIS technology);
- Networks (such as the GII) require standards and at this moment these are created at an international level: link to OpenGIS (and ISO TC/211).
- Cooperation with the international leading Geo-ICT industry, will provide a level of basic technology (which is advancing rapidly) on which research initiatives can be developed/tested and afterwards delivered to the society (instead of working on an academic island and developing everything ourselves and only producing scientific papers, which may take very long before being used by industry and applied in society).

# 7. Geo-Database Management Center (GDMC)

As described in the previous section an important characteristic of the research approach of the section GIS technology is through cooperation with the leading international Geo-ICT industry. Therefore, the section GIS technology created the open research center, called Geo-Database Management Center (GDMC), which was officially opened on 15 November 2000. This section gives some more background information related to the GDMC. The developments in the field of GIS technology are going very fast. The basis for this can be found in the ICT developments regarding DBMSs, (mobile) communication/Internet, computer graphics (Virtual/ Augmented Reality), development of object-oriented software (e.g. based on the Java platform) in general and specifically in the geographic area. For a university it is impossible to keep track of all these developments by its own and to anticipate on new developments as well. In order to become one of the five top universities in the world in the field of GIS technology, it has been decided to follow the research model of the GDMC including participation of industry. The GDMC is a research and development center for all activities related to modelling, storage, retrieval, analysis, presentation and distribution of geo-information.

The GDMC has six participants at the moment: Sun, Oracle, CA, PGS, Bentley, and ESRI. The GDMC is the only 'Oracle R&D Center of Excellence' in Europe.

*Figure 12: The partners of the GDMC.*

The Oracle DBMS offers at each version more functionality for supporting spatial data. Supported by consultants of Oracle the GDMC builds up expertise of Oracle spatial by using it in its research and by participating in beta testing programmes. The GDMC takes part in the 'Academic Partner Programme' of Computer Associates (CA). Through this the GDMC has the relational DBMS Ingres (first commercial DBMS which supports spatial data and used by the Dutch Cadastre at the moment) and the object DBMS Jasmine (very promising as far as the storage of complex objects and the execution of complex operations are concerned) at its disposal. Sun

Microsystems has provided a 'hardware grant' and participates in the GDMC because of its - also for GIS - very suitable Java-platform and its stabile and powerful server hardware. Thanks to the co-operation with Professional Geo Systems (PGS) the GDMC can make use of the data model driven GIS front-end GEO++ (originally developed by TNO) and the Internet GIS software Magma/Lava. The 3D capabilities, the model creation capabilities and the spatial connection to Oracle of MicroStation GeoGraphics are the main reasons for the partnership with Bentley. Finally, the products (ArcIMS, ArcGIS) and the R&D activities of ESRI with respect to Internet GIS, Mobile GIS, topology, 3D modelling, and several other geo-ICT area's form the motivation behind the partnership with ESRI. Although the structure of the GDMC is an open one, it is not sensible to let the number of participants grow in an unlimited way. For this the capacity is not sufficient. Moreover the added value would be too low.

The GDMC includes the research activities of the Section GIS technology. Therefore the staff members and graduate students of the Section GIS technology are the 'main occupants' of the GDMC. But also staff members of the participants from the industry find an ad hoc workplace within the GDMC. The GDMC is located at the second floor of the TU Delft building at the Thijsseweg 11 in Delft and consists of a number of laboratories. First there is the '3D GIS and VR' lab existing of a large projection wall and sophisticated computer graphics hardware for experimenting with new 3D geographic user interfaces. Next there is the 'geo-DBMS' lab. Finally there is a large students' computer room with graphic terminals. An important aspect of the GDMC is the web site, which can be found on http://www.gdmc.nl. This web site forms a vital link in internal and external communication. Like many other web sites it holds general descriptions of the organization and of the (research) products as well as specific project documentation. Moreover a part of the research itself is carried out via this web site, e.g. research in the field of 'distribution of geo-information via Internet'. Actual research projects of the GDMC (section GIS technology) can be found on the website http://www.geo.tudelft.nl/GISt under 'Projects'. Types of geo-DBMS research at the GDMC include:

1. Testing performance and functionality (spatial indexing and clustering)
2. Research and development of DBMS extensions for geo-data, e.g. 3D types and operators
3. Research of complex spatial features (topology)
4. Support of temporal aspects (spatio-temporal models)
5. Generalization within the geo-DBMS
6. Fundamental support of the quality of geo-data (based on specific data types)
7. Investigating the use of VLM databases for GIS applications
8. Realization of distributed (Internet) GIS applications based on geo-DBMS
9. Linking of VR/AR applications (based on a limited scene size in a VR/AR environment)
10. Providing services to mobile terminals (with positioning capabilities)

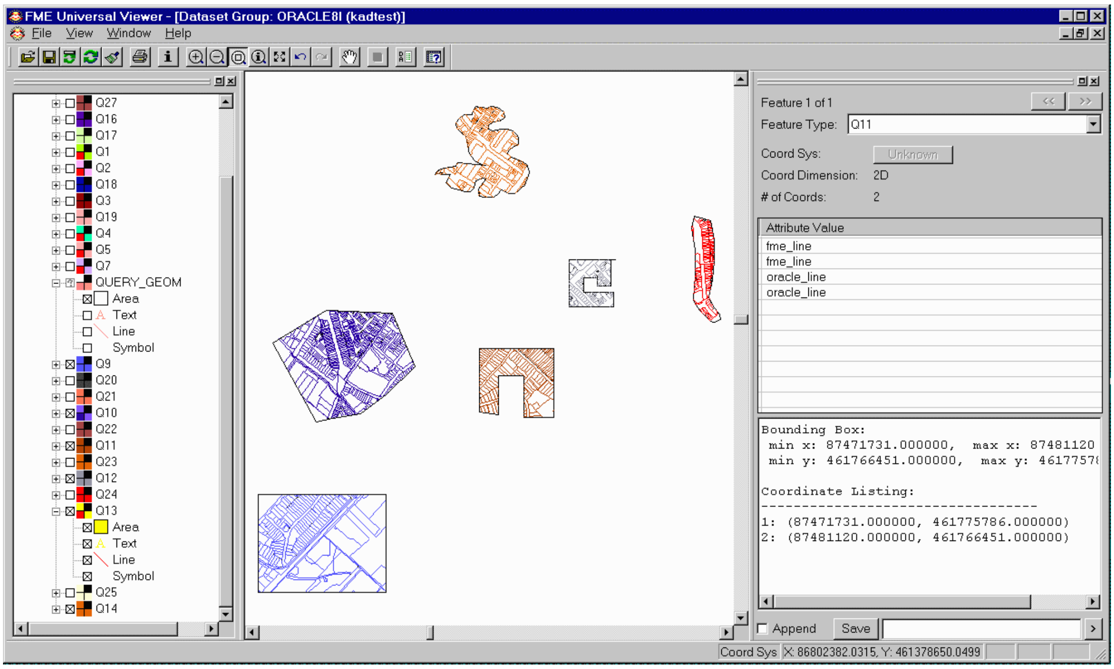


*Figure 13: One of the tests used in geo-DBMS benchmarking: clipping the data in a DBMS with different types of objects.*

# 8. SCIENTIFIC PROGRAMS IN WHICH THE SECTION GIS TECHNOLOGY PARTICIPATES

The section GIS technology is and has been very active in the organization of several international symposia; e.g. SDH and UDMS; see Subsection 8.1. These activities stimulate the GIS technology researchers to present and publish their results and attributes to the international reputation of the TU Delft in general and the section GIS technology in specific. Further, the section GIS technology (often via the department of Geodesy of the TU Delft) is an active member of several professional organizations, both national and international (OpenGIS, FIG, AGILE, GIN); see Subsection 8.2. Finally, the section GIS technology is involved in the proposal or execution of research projects, again both at the national and international level (Bsik, EU FP6); see Subsection 8.3.

## 8.1 Organization of international events

The International Symposium on Spatial Data Handling (SDH) is one of most important forums in the field of geographical information science (GISc). This bi-annual conference has been organized as one of the main activities of the International Geographical Union (IGU). Since 1984, the SDH symposium has been organized every two years in respectively Zurich, Seattle, Sydney, Zurich, Charleston, Edinburgh, Delft, Vancouver, Beijing, and Ottawa. The SDH symposia have become the bi-annual focal point for advances in GIS research. SDH has been established to bring together in an intimate setting an international group of interdisciplinary researchers who are working at the cutting edge of new approaches of handling geographic data. It offers a unique opportunity to exchange ideas, and to present research progress and results. The presentations at SDH are generally considered to represent the state of the art in this field.

UDMS*, the Urban Data Management Society* has been active in organizing international symposia at various locations in Europe since 1972 in order to promote the development of information systems in local government. An important aim of UDMS has been to provide a forum for people to discuss new approaches, to consider new technologies and to share practical experiences in the field of urban data management. Traditionally, the focus has been on urban applications. However, regional and rural issues have always been well represented at UDMS. From an economic point of view land becomes more and more scarce and therefore more and more valuable. From the countries in Central Europe we learn how important it is to solve the land market problems in order to establish a free market economy. Since 1996 UDMS has also paid attention to developments in Central Europe.
(See also www.udms.net)

## 8.2 Membership of professional organizations

The OpenGIS Consortium is (quote taken from http://www.opengis.org): 'an international consortium of more than 230 companies, government agencies and universities participating in a consensus process to develop publicly available geoprocessing specifications. Open interfaces and protocols defined by OpenGIS specifications support interoperable solutions that geo-enable the web, wireless and location-based services, and mainstream IT'.

AGILE, the *Association of Geographical Information Laboratories in Europe* has active participation from university research and training groups from all over Europe: there is active participation in AGILE by the members of the section GIS technology. The AGILE research programme covers an exhaustive list of research topics in GIS that is shared with other major GIS organizations in the USA, Canada, Australia and other world leaders (see appendix A.2).

FIG, the International Organization of Surveyors, was founded in 1878 in Paris. It is a federation of national associations and is the only international body that represents all surveying disciplines. It is an UN-recognised non-government organization (NGO) and its aim is to ensure that the disciplines of surveying and all who practise them meet the needs of the markets and communities that they serve. It realises its aim by promoting the practice of the profession and encouraging the development of professional standards. Traditionally the Department of Geodesy of the Delft University of Technology has been involved in the activities of FIG. As far as the section GIS technology is concerned the cooperation concentrates on the Commission 3 ´Spatial Information Management´ and Commission 7 ´Cadastre and Land Management´ (See also: http://www.ddl.org/figtree/indexmain.htm).

Within the Netherlands, there are many geo-information organizations (with out trying to translate their full names): VVL (Vereniging van Landmeetkundigen), VGVI (Vereniging voor Geografische- en Vastgoedinformatie), NVK (Nederlandse Vereniging voor Kartografie), NVG (Nederlandse Vereniging voor Geodesie), KvAG (Nederlandse Kring voor Aardobservatie en Geo-Informatica), Geo-VenW (voor Rijkswaterstaatpersoneel), Bond voor Kadasterpersoneel, Stichting Geodesia, en de Stichting GITA (Netherlands branch of the Geospatial Information Technology Association). In several of these organizations, the members of the section GIS technology play and have played an active role; e.g. being a board member or being an organizer of an event, such as a national seminar. After several years of preparations, these organizations will all merge during the year 2003 into the new organization called 'Geo-Informatie Nederland' (GIN, in English 'Geo-information Netherlands'). The term 'geo-information' is defined by GIN to include Geo-information sciences, geo-information technology, and the applications of both. The section GIS technology is very pleased with GIN and will support this organization in the future by active participation.

## 8.3 Research project proposals

The section GIS technology is involved in several project proposals for the Bsik (formerly ICES/KIS3) *'Ruimte voor geo-informatie' RvG* programme. Within the TU Delft, the section GIS technology is responsible for the coordination of the RvG project proposals. Other groups participating in RvG project proposals from the TU Delft are: Informatics (ITS), OTB and the other Geodesy sections (FMR, MGP, FRS, GiGb). The section GIS technology participates in the following RvG project proposals (nearly all scientific research, so these proposals will have to be evaluated by NWO):

- 'Location-Based Services' (GIS technology project leader)
- 'MONEY-SPOT: GIS-based monitoring of the value of real estate as an indicator of the vitality of neighbourhoods' (together with OTB/GiGb)
- 'Formele methoden & Best practice voor Ontwerp, Implementatie en Onderhoud van Grote Geo-datasets', or in English: 'Formal methods & Best practice for Design, Implementation and Maintenance of Large Geo-data sets'

- 'Vraaggerichte webportalen - Bouwstenen voor een e-governance software architectuur' or in English: 'Demand driven web portals – building blocks for an e-governance software architecture'
- 'Geo-Informatie Management voor grote Civieltechnische Infrastructurele Werken' or in English: 'Geo-Information Management for large civil engineering infrastructural works'
- '3D Topografie' or in English '3D Topography' (GITt project leader)
- 'Geo-informatie op afstand' or in English 'Geo-information at a distance' (together with GiGb in the context of the MSc GIMA)


*Figure 14: The RvG knowledge project.*

Besides the RvG knowledge project, the sections GiGb and GIS technology have together proposed three projects for the Bsik programme *DelftCluster* (again scientific research): '3D Cadastre', 'Pipelines and cables registration', and 'Multiple use of space'.

FP6: The European Commission Sixth Framework Programme, Work Programme "Information Society Technologies" (see http://www.cordis.lu/fp6/) lists many opportunities for research initiatives, which though not specifically linked to GIS, are unmistakably overlapping with the GIS technology research proposals. To paraphrase the FP6 document "Information Society Technologies", the focus of IST in FP6 is on the future generation of technologies for integrating computers and networks in the every day environment, providing a multitude of services through easy-to-use human interfaces. In particular, the eEurope 2005 programme aims at an even wider deployment of IST including modernizing government services and services for business and leisure. This certainly includes GIS technology. The section GIS technology is involved in several expressions of interest (EoI) for a network of Excellence (NoE) submitted to the European Union in June 2002. Among them is 'Modelling Real Property Institutions' (together with the section GiGb), which connects well to the current EU COST G9 action 'Modelling Real Property Transactions'.

Further, the section GIS technology is also involved in defining a large FP6 project proposal in the area of 3D geo-information combined with location-based services. Currently, there is a core team of 5 organizations, University College London (England), University of Aalborg (Denmark), Fraunhofer research Institute (Germany), Sintef research institute (Norway) and TU Delft (Netherlands), preparing the project proposal. The FP6 projects require at least 15 organizations to be involved, so after the initial preparations each of the partners will look for participating organizations.

## 9. CONCLUSION

In this document a vision of the future GIS technology research has been presented. The research agenda is based on the expected transitions in geo-information handling due to changes in science, technology and society. The GIS technology research at the TU Delft has chosen one main focus area: the Geo-DBMS. The Geo-DBMSs will form the fundament of the (future) Geo-Information Infrastructure. This research theme and the role of the section GIS technology fit well in both the international and national research agendas.

The chosen scientific approach is based on cooperation with leading organizations and the Geo-ICT industry. This is among others materialized in the Geo-Database Management Center (GDMC), in which GIS technology research is performed in cooperation with a selected number of participants from the Geo-ICT industry: Oracle, ESRI, Bentley, Sun, CA, and PGS. The described research goal and the scientific approach must enable the section GIS technology of the TU Delft to become one of the top five universities in the world in the field of GIS technology (and the *number one university* in the specific field of geo-DBMS research).

A research agenda with a reasonable long-term scope, such a this one, will have to be adjusted regularly due to further changes in the University, surrounding science and technology and society. Therefore an updated version of this document can be expected in three years.

**References**

[1] Oosterom, P.J.M. van, 2001, De geo-database als spin in het web, intreerede, TU Delft, 6 juni 2001.
[2] TNO, 2002. Geo-ICT trend analysis, December 2002.
[3] RvG Consortium (Ravi), 2003. Space for Geo-information, Bsik knowledge project poposal, February 2003.

# APPENDIX A. RELATED (INTER)NATIONAL GEO-INFORMATION SCIENCE RESEARCH AGENDAS

In this appendix an overview is given of the major other geo-information research agendas worldwide (not including specific Netherlands agendas; see Appendix B) in order to have a global picture of the geo-information science. To be more specific, this includes the recent research agenda's from the following organizations:

- Appendix A.1: UCGIS, http://www.ucgis.org
- Appendix A.2: AGILE, http://www.agile-online.org/
- Appendix A.3: NCGIA/Varenius,
- http://www.ncgia.ucsb.edu/varenius/varenius.html
- Appendix A.4: EuroSDR (OEEPE), Rolling research plan 2001-2003, http://www.eurogi.org/peaf/OEEPE_rolling_research_plan_2001-2003.doc
- Appendix A.5: Australian Cooperative Research Centre (CRC) Spatial Information (SI 2002-2010), http://www.sli.unimelb.edu.au/events/crc.html
- Appendix A.6: Canadian GEOIDE (phase I: 1999-2002, phase II: 2003-2005), http://www.geoide.ulaval.ca/

It should be noted that the UCGIS, AGILE, Austrian CRC-SI, and the Canadian GEOIDE research agenda's are very up to date (their last version is not older that half a year) and that the NCGIA/Varenius is related to an older, but probably the most successful research program in the history of geo-information science, program (last version at least a couple of years old).

## Appendix A.1 UCGIS

The United States (US) University Consortium for Geographic Information Science (UCGIS, information taken from http://www.ucgis.org) is a non-profit organization of universities and other research institutions dedicated to advancing our understanding of geographic processes and spatial relationships through improved theory, methods, technology, and data. The goals of UCGIS are:

- to advance theories and methods in geographic information science;
- to assess the current and potential contributions of GIS to national scientific and public policy issues; and
- to expand and strengthen geographic information science education at all levels;
- to promote the ethical use of and access to geographic information;
- to foster collaborative interdisciplinary research in geographic information science; and
- to support such national needs as:
  - advancing the nation's geographic information infrastructure;
  - addressing global environmental quality and change;
  - improving international economic competitiveness;
  - increasing efficiency, effectiveness, and equity in all levels of government;
  - advancing democratic participation; and
  - maintaining world leadership in basic science, mathematics, and engineering.

Their most recent research agenda (July 2002):

1. Long-term Research Challenges
   a. Spatial Ontologies
   b. Geographic Representation
   c. Spatial Data Acquisition and Integration
   d. Scale
   e. Spatial Cognition
   f. Space and Space/Time Analysis and Modelling
   g. Uncertainty in Geographic Information
   h. Visualization
   i. GIS and Society
   j. Geographic Information Engineering

2. Short-term Research Priorities
   a. GIS and Decision Making
   b. Location-based Services
   c. Social Implications of LBS
   d. Identification of Spatial Clusters
   e. Geospatial Semantic Web
   f. Incorporating Remotely Sensed Data and Information in GIS
   g. Geographic Information Resource Management
   h. Emergency Data Acquisition and Analysis
   i. Gradation and Indeterminate Boundaries
   j. Geographic Information Security
   k. Geospatial Data Fusion
   l. Institutional Aspects of SDIs
   m. Geographic Information Partnering
   n. Geocomputation
   o. Global Representation and Modelling

p. Spatialization
q. Pervasive Computing
r. Geographic Data Mining and Knowledge Discovery
s. Dynamic Modelling

## Appendix A.2 AGILE

The mission of the Association of Geographic Information Laboratories for Europe (AGILE) is to promote academic teaching and research on Geographic Information Science by representing the interests of those involved in GI-teaching and research at the national and the European level, and the continuation and extension of existing networking activities. The following **five challenges** are put forward as priorities to develop a research programme:

1. GI Policy and Society
   The exploitation of digital information poses challenges and opportunities as yet not fully understood or tested. Hence this stream will focus on the economics of digital information, ad GI in particular; the role of government in the information society, including issues of access to information and information infrastructures; the spatial impacts of such agency on economic and social development; the transfer of innovation and organizational change.

2. Theory of spatio-temporal information systems
   The construction of databases for spatio-temporal information requires nontrivial extension to current database theory. The questions posed are directly linked to the structuring of spatiotemporal information, the methods to describe and manipulate it and also to present it. It seems possible today, to construct a comprehensive theory of spatio-temporal information management and presentation.

3. Dynamic Modelling of environmental and social processes
   The construction of explanatory models and the use of models for the assessment of the outcome of different policies is a large area of connected research questions. We must proceed from single resolution, rasterized (gridded) space or economic-ecologic non-spatial models to integrated dynamic spatial and temporal models, where the influences at different resolution levels integrate socio-economic and natural science contributions.

4. Semantic interoperability of spatial data and services
   The use of the existing large data collections for many applications, many novel, is a crucial step in promoting economic and social development in the information age. Space related information systems are in a unique position, in that the meaning of their terminology can be connected to physical objects and operations on them (so called 'semantic grounding') and become therefore independent of national natural languages. This is the stepping-stone to build metadata, which not only supports data discovery, but can be accessed by applications and visualization tools ('intelligent' data know when they are relevant and how to 'behave' when being accessed by particular spatial services).

5. Integration of social and physical sciences in their contribution to space
   Methodological approaches and ontological assumptions for the physical and social sciences and the humanities are very different. For example legal procedures, engineering and planning are vastly different in their thinking – but all affect geographic space. Bridging the conceptual gaps of how space and time are viewed from different disciplines is crucial for the eventual integration of their results, and for the interoperability of models across domains.

The AGILE list of themes is based on the UCGIS Research Themes. This list has now been modified and adapted to the AGILE research topics.

- 3D / 4D Modelling
- Administrative use of GIS
- Aspects of Data Quality
- Cartography and Visualization
- Change Detection/ Modelling
- Conflation and Data Integration
- Databases
- Dynamic Processes
- Environmental management/ modelling
- Environmental Hazards
- GIS and Institutions
- GIS and Multimedia
- GIS and Society
- GIS as a Planning -Tool
- GIS Design Methods
- GIS Foundations
- GIS in Decision-Making
- Miscellaneous Applications
- Miscellaneous Data Modelling
- Model - GIS Interoperability
- Participatory GIS
- Remote Sensing / Data Capture
- Scale
- Spatial Cognition
- Spatial Data Analysis
- Spatial Data Infrastructures
- Spatio-Temporal Models
- Usability

Much ore detailed lists of themes and topics can be found on (http://agile.isegi.unl.pt/agenda).

## Appendix A.3 NCGIA/Varenius

The National Science Foundation (NSF) established the US National Center for Geographic Information and Analysis (NCGIA) in the late 1980s (http://www.ncgia.ucsb.edu/varenius/jec.html). The NCGIA's original mandate was to reduce impediments to the widespread use of the GISystems. The NCGIA has now chosen to realign its research, education and outreach agendas focusing on more fundamental issues in geographic information science while at the same time maintaining the original three site consortium (with sites at University of California Santa Barbara (UCSB), State University of New York at Buffalo and University of Maine). The objective of NCGIA's new research plan, entitled Project Varenius, is to advance geographic information science through basic research, education, and outreach. The research is motivated by scientific, technical, and societal concerns:

1. Cognitive Models of Geographic Space
   The research serves science and scientists in two ways, focusing on areas in which our knowledge of formalizable geographic concepts is currently incomplete, and contributing to the development and refinement of tools and methods that, scientists can use to study geographically distributed phenomena. High priority will be given to the initiation of research on scale (i.e. level of geographic detail). There is an urgent need to study scale from a cognitive perspective and scale is a poorly understood but fundamental concept geographic concept that presents very substantial problems in digital geographic worlds.

2. Computational Implementations of Geographic Concepts
   The research provides basic understanding of geographic concepts, which is required for the production of new technologies. An initiative on the Ontology of Fields is proposed. Geographers and other geographic information scientists have long recognized a fundamental duality in conceptualizations and models of geographically distributed phenomena, between spatially continuous fields on the one hand, and discrete objects on the other. The proposed initiative will examine the concepts of fields, their formalization in computer implementations and the effects of this process on geographic understanding

3. Geographies of the Information Society
   The research examines the impacts that these technologies have on individuals, organizations, and society, and that other digital technologies have in the context provided by geographic space. The range of research topics falling within this theme is related to information law, information economics, communications, geography, sociology, public policy, political science, planning and spatial data policy.

## Appendix A.4 OEEPE (EuroSDR)

The EuroSDR's original name, OEEPE (European Organization for Experimental Photogrammetric Research) already indicates the main focus of their research. However, the research scope is broadened and this is also reflected in the new name of the organization: EuroSDR (Spatial Data Research), but of course the roots remain. To be the European research platform for National Mapping Agencies (NMA's), Academic Institutes, Private Sector, Industry and User's Groups, on issues related to the implementation of technology developments in view of optimising the provision (collection, processing, storage, maintenance, visualisation, dissemination and use) of core data (data serving as a spatial framework for organizations involved in monitoring, management and development) in a Geo-Information Infrastructure (GII) context.

Key OEEPE (EuroSDR) research targets, for the period 2001-2003, are:
1. Sensor systems (including calibration aspects)
2. Geometric data acquisition issues (geo-referencing, DEM)
3. Semantic data acquisition issues (information extraction, contents, automation)
4. 3-D core data; emphasis on spatial modelling, information extraction and tools for 3-D
5. Integrated problem solution from industry (systems manufacturers should become more database centric)
6. Process modelling and interfaces (product diversity/servicing)
7. Core geospatial databases (data modelling, currency/maintenance, unique ID, metadata, changes only)
8. Data integration (integrating core data with other data)
9. Generalisation in terms of up-scaling/down-scaling
10. Harmonisation requirements on core data (cross-border issues; e.g. river basins, transportation networks)
11. Delivery mechanisms and access to data (internet and standards)
12. Geospatial data quality

The OEEPE is organized in 5 commissions and a matrix indicates which commission has primary or secondary interest in which research target.

## Appendix A.5 Australian CRC for SI

The mission of the CRC for Spatial Information (CRC-SI) is to develop the concept of a Virtual Australia, uniting research and commercial innovation in spatial information. The Centre is funded by the central government (Commonwealth) by AUS$ 13.3 million, and the public and private research partners provide AUS$ 10.1 million (cash) and AUS$ 35 million (in-kind). The Centre will harness Australia's recognized research and commercialization strengths in spatial information technologies to create new opportunities and increased prosperity for all Australians. To the technology end-user, spatial information is often defined in terms of how it is presented. Examples are digital topographic maps, land titles, thematic maps from satellite imagery, 3D landform models, computer visualizations, or outputs from a Geographic Information System (GIS). Behind the presentation of spatial information lies the necessary components of data acquisition, analysis and processing required to both integrate multi-source spatial data and convert this data into usable information products. Associated with these operational themes are the issues of local, state and national spatial data infrastructures, quality and standards, and access and public policy. The Centre will have five research programs (each including several research projects), which will be highly integrated and linked by common threads ranging from application systems, including demonstrator projects, to quality and standards. First, an overview of the five research programs:

1. Integrated Positioning and Mapping Systems
   - Reference station networks and their utility
   - Positioning technologies for precise applications
   - Mobile and automated mapping systems
   - Geopositioning for consumer applications

2. Metric Imagery
   - Landform and built-environment analysis from high-resolution satellite imagery
   - Automated feature extraction and mapping from space, aerial and terrestrial imaging sensors
   - Heritage recording and real-world modelling via metric imagery
   - Fundamental modelling, analysis and systems development for integrated imaging and positioning sensors

3. Spatial Information System Design and Spatial Data Infrastructures
   - Design concepts for Virtual Australia
   - Data integration, modelling and standards
   - Access to spatial data
   - Quantitative risk management processes for error propagation modelling

4. Earth Observation for Renewable Natural Resource Management
   - Near-real time satellite image processing and distribution
   - Multi-scale, multi-spectral and multi-temporal image analysis for environmental and natural resource monitoring
   - Agricultural Assessment
   - Land cover classification, and the monitoring and assessment of land-use change (with an initial focus on biomass estimation and carbon cycling, and on bushfire applications

5. Modelling and Visualization for Spatial Decision Support
    - Extraction and integration of expert knowledge in SDSS
    - Development of generic, scale-independent spatial modelling toolkits
    - Visualization systems with full GIS integration
    - Software tools/techniques for visualizing and communicating data uncertainty

Industry-driven *Demonstrator* projects will form a major R&D focus for the CRC-SI. These Demonstrator projects highlight the strong interaction between the individual research projects within the five research programs. Research activities undertaken as industry/university, or as fundamental supporting university research, will also be actively pursued, with the main aims being improved industry education and training, technology transfer, and ultimate commercialization to promote industry development. Besides the research programs with their projects, the following seven initial multi-year 'Demonstrator' projects have been selected:

1. An SI system for bushfire management;
2. Design & maintenance of national georeferenced address databases;
3. Portable, on-line mobile mapping systems for urban planning and resource management;
4. Urban planning and management via the Virtual City;
5. Multi-scale, web-based SI delivery and case study evaluation involving Virtual Victoria;
6. Integrated remote sensing technologies for agricultural assessment; and
7. The design and building of a multi-resolution national DEM for landform analysis and modelling.

A matrix describes the relationship between the research projects and the demonstrator projects.

## Appendix A.6 Canadian GEOIDE

GEOIDE – Geomatics for Informed Decisions – is a $30 million (1999-2002) R&D investment program currently consolidating Canadian expertise in geomatics. The GEOIDE investment portfolio has 2 phases (until now): for the phase I (1998-2002) see http://www.geoide.ulaval.ca/en/research/matrix.html and for the phase II (2002-2005) see http://www.geoide.ulaval.ca/en/research/matrix2.html. As a federally supported Network of Centres of Excellence GEOIDE brings together many of the country's leading experts from 24 universities, 27 companies and 17 agencies and departments.

GEOIDE selects and manages opportunity-driven R&D projects through our collaborative R&D investment program. It is an "institute without walls" – GEOIDE itself does not perform R&D, instead it funds projects with strong potential for fostering economic and social development in a networking environment. GEOIDE is a strategic link to research funding and a critical mass of world-class expertise in the important arena of geomatics.

GEOIDE is not-for-profit and is open to Canadian organizations whose own R&D and business efforts could be enhanced through the development and exploitation of geomatics technologies. The R&D program is organized in a matrix structure based on thrusts and themes. The thrusts are the application domains (users) and the themes are the fundamental R&D areas.

GEOIDE List of Technologies and Research Areas (= Themes, from http://www.geoide.ulaval.ca/Public/an/programmesRD/technologies.html):

1. Data Acquisition
   1.1 Geodesy
      - geoid mapping
      - Canadian Spatial Reference System
      - positioning techniques
      - in situ sensors
   1.2 Cartography
      - topographic base mapping (NTS scales)
      - revision mapping
      - digital elevation model generation
      - thematic (geographic) mapping (NTS, planning/engineering scales)
      - real time mapping
      - cadastral surveying, property mapping
      - boundary mapping and maintenance
      - digital map production and distribution
   1.3 Remote Sensing
      - satellite and air photo imaging
      - high resolution optical imaging
      - hyper spectral satellite and airborne imaging
      - satellite and airborne radar imaging
      - total station data gathering (engineering scales)

2. Data Management
      - Geographic Information Systems (GIS)
      - database design and management

- generalization and standards for cartographic and geospatial data
- data fusion (multiple data bases)
- interoperability (distributed data bases, e.g. forestry)
- raster and vector computation and representation
- social environments

3. Decision Support and Information Dissemination
   - decision support tools
   - decision process modelling and enhancement
   - artificial intelligence, computational geometry, cognitive science
   - use of the internet for disseminating geomatics data
   - user interface improvement

GEOIDE List of User Categories (=Thrust, from http://www.geoide.ulaval.ca/Public/an/programmesRD/users.html)

1. Natural Resources
   1.1 Renewable resources
   - agriculture sector
   - forestry sector
   - fisheries sector

   1.2 Non-renewable resources
   - oil and gas servicing sector
   - geology/mining sector, exploration and planning
   - water resource management

2. Environment
   2.1 Pollution Monitoring and Assessment
   - air (e.g. air quality measurement, lidar mapping, smog warning)
   - water (e.g. oil spill and red tide mapping, ocean dumping detection)
   - land (e.g. tailings pond monitoring, tips and landfill monitoring)

   2.2 Global Change
   - physical, chemical and biological measurements and assessment
   - climate change and monitoring

   2.3 Disaster Management
   - damage assessment
   - damage recovery
   - river crest forecasting and flood assessment
   - drought measurement and forecasting
   - earthquake and tsunami warning, volcano monitoring
   - hurricane and tornado warning and alerts
   - forest fire tracking and forecasting
   - dust and hail storm warning
   - ice storm monitoring and forecasting
   - flooding and mudslide monitoring and forecasting
   - avalanche warning
   - man made disasters (e.g. spill mapping and cleanup)

   2.4 Ecosystem Management
   - forest
   - coastal
   - northlands

- first nations
- special places (egg. archeological sites, parks, etc.)

3. Transportation
   3.1 Water
   - ice, ice reconnaissance and forecasting, arctic navigation/regulation
   - hydrographic chart maintenance and revision
   - wind and current now casting and forecasting
   - navigation, pilotage, buoys support and maintenance
   - harbours, jetties, piers: planning and protection
   - vessel traffic management
   - water level management (inland and international)
   - locks and canals management

   3.2 Air
   - charts
   - approaches
   - air traffic control
   - weather forecasting

   3.3 Land
   - roads, bridges and rail planning and maintenance
   - road map creation and maintenance
   - public transportation
   - trucking industry
   - intelligent transportation systems (ITS)
   - intelligent vehicle and highway systems (IVHS)

4. Services
   - commerce, retail
   - land use planning
     - urban, suburban and rural conflicts of interest in land and land protection
     - environmental assessment
   - telecommunications: intervisibility assessment and route planning
   - infrastructure planning and maintenance (hydro and gas transmission and distribution, water, cable TV, telephone and fibre)
   - population health, health care delivery, epidemiological studies
   - social services, demographic studies
   - property surveying and mapping, registration, title searching
   - real estate transactions
   - recreation, trail and wilderness maps, boating, bathymetric maps
   - coastal and littoral zone management
   - parks management
   - positioning (GPS and DGPS)
   - learning travel and travel planning
   - consumer information vendors

## APPENDIX B RELATED NATIONAL GEO-INFORMATION SCIENCE RESEARCH AGENDAS

After the overview of geo-information research programs all over the world (Appendix A), now an overview of the geo-information R&D agendas in the Netherlands will be given. These may be different from the worldwide agenda because the Netherlands needs for geo-information (services) and our expertise may be different. Three recent initiatives are very useful in order to analyze this:

- Appendix B.1: the NCG-GIM research agenda,
- Appendix B.2: the Geo-ICT study of TNO for RWS-MD, and
- Appendix B.3: the Bsik knowledge proposal 'Space for Geo-information' (in Dutch: 'Ruimte voor Geo-informatie', RvG).

## Appendix B.1 NCG-GIM research agenda

Within the Netherlands, the subcommittee Geo-Information Models (GIM) of the Netherlands Geodetic Committee (NCG, an institute of the Royal Netherlands Academy of Arts and Sciences, KNAW) has produced their research agenda in 2000. For more information of the NCG see: http://www.ncg.knaw.nl/. Within the programme of RvG, it has been decided to use the research agenda of the NCG-GIM as a starting point. This could be considered a first direction for the selection of the different research themes. Therefore a short overview of this research program is now described:

1. Modelling of the spatial-temporal reality
   a. Classification, modelling, and representing dynamic systems
   b. Representations of spatial-temporal reality (4D raster/vector)
   c. Context specific classifications (domain ontologies)
   d. Algorithm specific classifications

2. Spatio-temporal algorithms
   a. Algorithms for storage and access of spatio-temporal data
   b. Algorithms for manipulation spatio-temporal data
   c. Algorithms for efficient system recognition computation
   d. Algorithms for efficient system simulation

3. Updating databases and database consistency
   a. Creating history by registration of mutations/changes
   b. Edit actions composed of several elementary edit primitives
   c. Multi-user environments for editing: locking and/or versioning

4. Multi-scale spatio-temporal data
   a. Generalization of spatio(-temporal) data, e.g. GBKN and Top10
   b. Consistent multi-scale representations based on explicit relationships
   c. Multi-scale spatial analysis

5. Quality of spatio-temporal data and modelling uncertainty
   a. Quality information captured in the meta data: context, scale, actors, process flow and resources
   b. Quality captured in representation uncertainties of spatio-temporal data
   c. Quality in multi-scale representations

6. Visualization and use of geo-information
   a. Analysis of interactive use of geo-information
   b. Cartographic aspects
   c. Presentation of quality (fuzzy objects)
   d. 3D-visualization, Virtual Reality (VR) and multimedia

7. Geo-information infrastructure and interoperability
   a. OpenGIS architecture and standards
   b. Geo-information infrastructure
   c. Integrated use of geo-information from multiple sources

## Appendix B.2 TNO (RWS/MD) Geo-ICT trends

The TNO Geo-ICT trend analysis, December 2002, conducted as an assignment for RWS/MD is based on meetings and information from the main geo-information players in the Netherlands: government agencies, geo-ICT industry, research institutes and Universities. It is therefore a well-balanced overview and gives the impression of the main payers related the future of geo-ICT in the Netherlands. After an iterative selection process with the involved parties, 14 main trends are selected and described in more detail in fact sheets. These main trends are grouped according the in geo-information process:

- Geo-information reference systems:
  (not explicit in TNO report)

- Geo-information collection:
  1. Requirements for data: more often, more accurate, faster and more reliable
  2. Remote sending and laser altimetry
  3. Technology for digital map production

- Geo-information modelling and storage:
  4. Data base management systems (geo-DBMS)
  5. From 2D to 3D (and 4d/temporal) data models
  6. Balance between centralized and distributed databases

- Geo-information analysis and handling:
  7. Complex analysis and simple user interfaces
  8. Risk management and decision support systems (DSS)

- Geo-information presentation and interaction:
  9. Location based (wireless) services
  10. Animation, Virtual Reality and Augmented Reality

- Geo-information exchange, and geo-information use:
  11. Standards for data and operations
  12. Meta databases and portals
  13. Technology and standards for quality and reliability

## Appendix B.3 Bsik 'Space for Geo-information' (RvG)

The Bsik knowledge proposal 'Space for Geo-information' (in Dutch: 'Ruimte voor Geo-informatie', RvG) has selected four spearheads for scientific/technological innovations.

The first main scientific/technological research theme is *spatial modelling*. The foundation of geo-information processing is spatial data and process modelling. Within the Bsik knowledge project RvG a number of spatial modelling topics will be treated:
- Integrated spatial data and process modelling,
- Modelling the temporal aspect (both raster and vector approaches),
- Modelling the semantics (that is developing ontologies),
- Multi-scale modelling (and generalization),
- Modelling uncertainty (related to quality), and
- Consistently maintaining the data and process information in a digital environment (databases).

The second main scientific/technological research theme is *visualization and using* geo-information. Again several topics are investigated under this theme:
- Analysis of interactive use of geo-information
- Cartographic aspects
- Presentation of quality (fuzzy objects)
- Explorative interaction with spatial-temporal (process) models
- Advanced man-machine interfaces for designing 3D/4D plans
- 3D-visualization, Virtual/Augmented Reality (VR/AR) and multimedia

The third main scientific/technological research theme is *distribution* of geo-information and services as one of the important enabling technologies for realizing the Dutch GII in a European (global) context:
- OpenGIS/ISO architecture and standards
- Geo-information infrastructure (networks, metadata, catalogue services, data, organization)
- Integrated use of geo-information from multiple sources
- Using positioning and wireless network connection to create location based services (LBS)

Finally, the fourth main research theme, which deals with the *societal* aspect of the GII, covers the following topics, which have to be investigated within the context of RvG:
- Legal aspects (ownership, use rights, privacy, responsibility, accessibility)
- Financing (payment models, realization of banking, security)
- Organization (definition of basic data sets, coupling of basis data sets)
- Management and maintenance of data and processes within the GII
- Cultural aspects and competences (integrated approach instead of domain specific approach of problems)
- Awareness, cooperation and the acknowledgement of GII

Reports published before in this series:

- GISt Report No. 1, Oosterom, P.J. van, Research issues in integrated querying of geometric and thematic cadastral information (1), Delft University of Technology, Rapport aan Concernstaf Kadaster, Delft 2000, 29 p.p.
- GISt Report No. 2, Stoter, J.E., Considerations for a 3D Cadastre, Delft University of Technology, Rapport aan Concernstaf Kadaster, Delft 2000, 30.p.
- GISt Report No. 3, Fendel, E.M. en A.B. Smits (eds.), Java GIS Seminar, Opening GDMC, Delft, 15 November 2000, Delft University of Technology, GISt. No. 3, 25 p.p.
- GISt Report No. 4, Oosterom, P.J.M. van, Research issues in integrated querying of geometric and thematic cadastral information (2), Delft University of Technology, Rapport aan Concernstaf Kadaster, Delft 2000, 29 p.p.
- GISt Report No. 5, Oosterom, P.J.M. van, C.W. Quak, J.E. Stoter, T.P.M. Tijssen en M.E. de Vries, Objectgerichtheid TOP10vector: Achtergrond en commentaar op de gebruikersspecificaties en het conceptuele gegevensmodel, Rapport aan Topografische Dienst Nederland, E.M. Fendel (eds.), Delft University of Technology, Delft 2000, 18 p.p.
- GISt Report No. 6, Quak, C.W., An implementation of a classification algorithm for houses, Rapport aan Concernstaf Kadaster, Delft 2001, 13.p.
- GISt Report No. 7, Tijssen, T.P.M., C.W. Quak and P.J.M. van Oosterom, Spatial DBMS testing with data from the Cadastre and TNO NITG, Delft 2001, 119 p.
- GISt Report No. 8, Vries, M.E. de en E. Verbree, Internet GIS met ArcIMS, Delft 2001, 38 p.
- GISt Report No. 9, Vries, M.E. de, T.P.M. Tijssen, J.E. Stoter, C.W. Quak and P.J.M. van Oosterom, The GML prototype of the new TOP10vector object model, Report for the Topographic Service, Delft 2001, 132 p.
- GISt Report No. 10, Stoter, J.E., Nauwkeurig bepalen van grondverzet op basis van CAD ontgravingsprofielen en GIS, een haalbaarheidsstudie, Rapport aan de Bouwdienst van Rijkswaterstaat, Delft, 2001, 23 p.
- GISt Report No. 11, Geo DBMS, De basis van GIS-toepassingen, KvAG/AGGN Themamiddag, 14 november 2001, J. Flim (eds.), Delft 2001, 37 p.
- GISt Report No. 12, Vries, M.E. de, T.P.M. Tijssen, J.E. Stoter, C.W. Quak and P.J.M. van Oosterom, The second GML prototype of the new TOP10NL object model, Delft, 2002, 68 p.
- GISt Report No. 13, Vries, M.E. de, T.P.M. Tijssen en P.J.M. van Oosterom, Comparing the storage of Shell data in Oracle spatial and in Oracle/ArcSDE compressed binary format, Delft, 2002, .72 p. (Confidential)
- GISt Report No. 14, Stoter, J.E., 3D Cadastre, Progress Report, Report to Concernstaf Kadaster, Delft 2002, 16 p.
- GISt Report No. 15, Zlatanova, S., Research Project on the Usability of Oracle Spatial within the RWS Organisation, Detailed Project Plan (MD-NR. 3215), Report to Meetkundige Dienst – Rijkswaterstaat, Delft 2002, 13 p.
- GISt Report No. 16, Verbree, E., Driedimensionale Topografische Terreinmodellering op basis van Tetraëder Netwerken: Top10-3D, Report aan Topografische Dienst Nederland, Delft 2002, 15 p.
- GISt Report No. 17, Zlatanova, S. Augmented Reality Technology, Report to SURFnet bv, Delft 2002, 72 p
- GISt Report No. 18, Vries, M.E. de, Ontsluiting van Geo-informatie via netwerken, Plan van aanpak, Delft, 2002, 17 p.
- GISt Report No. 19, Tijssen, T.P.M., Testing Informix DBMS with spatial data from the cadastre, Delft 2002, 62 p.