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Editorial – GeoVisualization and the Digital City

ABSTRACT

We explore notions of the *Digital City* through four action types relating to complimentary levels of function and argue that GeoVisualization is a key component. An interdisciplinary and international workshop on *GeoVisualization and the Digital City* is reported upon and the process developed for supporting and stimulating cross-disciplinary research and publication in this area described. Discussion at the workshop drew attention to key trends and themes in this area and these are reported with an emphasis on those requiring additional research or cross community collaboration. The six papers subsequently selected for development and inclusion in this special issue are summarised and drawn together in relation to these themes and action types. The importance of research efforts that address more than one functional level and support analytical map use for effective contributions to the Digital City is emphasized.

1. GeoVisualization and the Digital City

More and more data about people and places are being generated on an operational basis at high spatial and temporal resolutions. This is not only due to the increasing availability of "conventional" sensors in space, in the air or on the ground, but also the contribution of buildings and communications infrastructures that collect and store data and citizens playing an increasingly active role as sensors. Cities are the focus of much of this information, as this is where most people are active and where masses of digital information is collected continuously by pervasive systems that record and contribute to the dynamics of urban environments. These data are incredibly useful. They are used to represent cities in games and for navigation, art installations, communication and planning. Ultimately they inform urban processes and development as digital traces left by people or devices or recorded by sensors or smart buildings feed back into the planning mechanisms. These data are often highly accessible and potentially valuable and so citizens with various interests and levels of expertise are using them as standard input for their needs. But they can be challenging to integrate, manipulate and utilise due to their multifarious nature, the complexity and resolution of the recorded characteristics and the volumes involved. All of this is particularly true in urban environments where the voluminous, dynamic and three dimensional nature of the data being generated result in new opportunities for studying the intricacies of cities.

The concept of *the Digital City* draws attention to these flows. The term was initially used in an early experiment in virtually networking citizens in Amsterdam's "*De Digitale Stad*" (Digital City Holdings BV, 2010). This project began in 1994 (Francissen & Brants, 1998) and whilst the portal still exists the subsequent waves of superior and advanced mobile networked opportunities for data collection, communication, access and usage have moved things on considerably (Rustema, 2001) – we are now at a point whereby digital communication seems to be the lifeblood of urban processes and the masses of digital information that citizens and sensors generate by the second are core to urban existence. Utilising this mass of information is a fantastic opportunity, but exploiting it successfully requires considerable work by the research community in developing methods that are effective, efficient and scalable along with tools that are usable. Grounding these techniques in use cases and embedding them in workflows is a related and not inconsiderable challenge. As yet processes for exploring and analyzing data associated with the Digital City are far from operational. The same is true of means for presenting new information and knowledge about the Digital City. The quantity, complexity and heterogeneity of the data and information pose a series of research challenges. *GeoVisualization* and *geovisual analytics* have the potential to play vital roles here as we strive to make sense of the data that are being collected. Approaches are being developed for acquiring information and establishing actionable knowledge in these rapidly developing disciplines, resulting in exciting opportunities for analysis and visualization (Vaccari, Calabrese, Liu, & Ratti, 2009).

As such, the International Cartographic Association (ICA) Commission on GeoVisualization coordinated an international workshop to focus on the Digital City. The meeting was held at HafenCity University, Hamburg – an institution specializing in architecture, civil engineering, geomatics and urban planning – in collaboration with the university's DigitalCity Research Group (HafenCity University, 2010a). In contrast to "*De Digitale Stadt*", the Hamburg view of the Digital City does not refer to a specific urban entity or formal communications mechanism. Instead a functional approach describes four interdependent action types that

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are highly reliant upon the kinds of digital information outlined above:

1. *supporting data and information* – through, for example advanced analytical interfaces that may emphasize the spatial and temporal nature of information;
2. *providing a communication infrastructure* – physical or virtual means for enabling information flows;
3. *delivering value added information and innovative services* – these are likely to synthesize data from a range of sources, be location based and may include analytical interfaces;
4. *using virtual environments in planning, decision-making and analysis* – when data collected by citizens are used in the process of modelling or digitally recorded citizen behaviour is influenced by formal planning an analysis a feedback loop is completed. Each of the previously listed action types may contribute here

These emphases reflect Aurgi's view that the focus of digital cities has moved from the technological and project based approach inherent in *De Digitale Stadt* towards a more holistic view of urban space enhanced by technology (Aurigi, 2006).

The key objectives of *GeoVisualization and the Digital City* were to present, discuss and develop approaches to using analytical cartography in supporting, exploring and enhancing this holistic notion of data-fuelled and information-rich cities.

2. The ICA Commission on GeoVisualization

The ICA Commission on GeoVisualization has broad aims that involve promoting and reporting upon the use and development of cartography in the context of the visual analysis of complex, voluminous and heterogeneous spatio-temporal information. This continues the work of the ICA Commission on Visualization and Virtual Environments, which was key in establishing the discipline of GeoVisualization and determining a series of research goals (MacEachren & Kraak, 2001). These aims are achieved through online and co-located activity. The former includes a website and e-mail list. These are used to report upon developments and examples of the latter, which include specialist themed workshops and annual meetings that are organised in conjunction with relevant academic conferences. A multi-disciplinary and international approach is key to these activities and also to the remit of the commission – with the *GeoViz Hamburg* meeting attracting 80 participants from 16 countries. The event itself coincided with the ICA's celebration of 50 years of promoting the discipline and profession of cartography in an international context. A full list of the commission's activities and publications is available on the commission web site (Andrienko & Dykes, 2010) and those with an interest in GeoVisualization are encouraged to visit the site and sign up for the e-mail list – both to keep abreast of recent activity and upcoming meetings and to make contributions to our collective ongoing research efforts.

3. GeoViz Hamburg: GeoVisualization and the Digital City

The *GeoViz Hamburg* workshop itself consisted of three days of structured activities. These were built around short plenary paper sessions and interspersed with a varied supporting programme of social activities and plenty of space in between times to breath, reflect and communicate. The workshop was designed to promote communication between participants from the outset, beginning with a strictly administered "*Fast Forward Session*" in which all 36 presenters introduced their research in a somewhat breathless half-hour of 1-minute tasters.

Participants subsequently presented their work through short lectures and active demonstrations in which research questions and use cases relating to GeoVisualization were addressed in the context of the Digital City. The 15-minute slots were structured into sessions of no longer than 1 hour and included time for questions. Sessions-were interspersed with long breaks, giving scope for intensive follow-up discussions, new introductions and lively information exchanges. All of this activity took place in the spectacular environs of a canvas circus tent erected in the HCU atrium. The structure and surroundings gave the meeting a unique character. This was very popular and the meticulous local organization undertaken by Jochen Schiewe and colleagues from the HCU Lab for Geoinformatics and GeoVisualization (*g2lab* – HafenCity University, 2010b) was greatly appreciated by participants.

The presentations covered a huge spectrum demonstrating the multifarious interactions between the concepts "Digital" and "City", the various interpretations of the term and the complex interrelationships between Digital City action types.

Some examples give a flavour of this variety and some of the more obvious themes. A review of WebGIS developments being used to provide official geo-data was presented by the State Enterprise Geoinformation and Surveying of the Free and Hanseatic City of Hamburg. Martin Over (University of Bonn) contrasted this with an alternative perspective, concentrating on employing user generated and freely available geo-data as basis for 3D city and terrain visualizations, and drawing attention to the way in which some previously proprietary city models were being donated to open data repositories.

The broad application of GeoVisualization in the context of digital cities varied from the use of spatially related visualizations for the analysis of decision-making processes in a city council (Rolf Hugoson and Fredrik Palm, Umeå University) to the realization of a historical model of the City of Solothurn as developed for a museum (Susanne Bleisch, FH Nordwestschweiz). Novel applications of 3D city models as analysis tools were presented by Jürgen Döllner and his group (HPI Potsdam) who demonstrated their application and development of approaches from Computer Graphics in the spatio-temporal domains. Wolf Dieter Rase's (BBR, Bonn) use of physical artifacts as cartographic representations of digital data and numeric models brought a contrasting and tangible, rather than virtual, angle to the 3D theme.

Adapted visualization techniques were emphasized by some participants, such as Anna-Lena Kornfeld (HCU Hamburg) who presented approaches for the visualization of acoustic phenomena in urban space.

In terms of developing methods for the interactive analysis of large data sets, Aidan Slingsby and colleagues (City University London) showed how morphing between alternative representations can help in exploratory analysis through a dynamic live demo focussing on spatial and temporal variations of real estate prices in London. André Skupin (San Diego State University) presented holistic high-resolution SOMs that reflect both physical and human attributes of geographic space and discussed navigation through them. Such highly abstract multivariate representations of the relationships between people, places and their characteristics provide opportunities for dealing with and visually exploring the masses of digital data that are generated through the Digital City.

Other presentations dealt with technical developments and their implications. Examples included Georg Gartner's (TU Vienna) use of mobile devices and location-based services for urban navigation and Volker Paelke's (Leibniz University of Hannover) demonstration of possibilities for using Augmented Reality interfaces for easing spatial interactions.

Methodological work on cartographic approaches and advances in Visual Analytics included Natalia and Gennady Andrienko's (Fraunhofer Institute IAIS) visual summary of multiple trajectories, the chorometic diagrams presented by Andreas Reimer and Doris

Dransch (Humboldt University Berlin/German Research Centre for Geosciences) and Larissa Pschetz and colleagues (University of Applied Sciences Potsdam) contributing a series of design patterns suitable for GeoVisualization.

Analysis and visualization of community-contributed data was an important theme with the Flickr collection proving a popular source. Ross Purves (University of Zürich) presented graphical approaches for exploring alternative descriptions of the place and space of digital cities and dealing with the bias in volunteered sources. Ayman Moghnieh and colleagues (MIT; Universitat Pompeu Fabra) derived digital footprints from Flickr geo-references and mobile phone records, using compelling visualization to show how flows of tourists and locals vary in Rome and Barcelona.

In addition to these and other stimulating presentations two well-attended panel sessions provided room for broad discussion on key themes and identification of research priorities. One of these reported upon and discussed the VisMaster EU Coordinated Action (VisMaster, 2010). The other focussed on themes emerging from the communal consideration of "*GeoVisualization and the Digital City*" that had taken place. These two plenary sessions provided scope for identifying and agreeing research opportunities and priorities in the context of the work presented at the meeting.

The rich supporting program was an essential component of *GeoViz Hamburg* and included visits to the State Enterprise Geoinformation and Surveying and the thought provoking "*Dialogue in the Dark*" exhibition in HafenCity that relied entirely upon senses other than sight.

In the spirit of collaboration and in line with the Commission's communication objectives full details of the meeting including abstracts, presentations and various demos and downloads are available online at the workshop homepage (HafenCity University, 2009). The most frequently occurring terms in the abstracts are shown in Fig. 1. This wordle (Feinberg, 2010) word cloud includes the 1000 most frequently occurring *non-common* terms sized by occurrence and laid out to maintain approximate alphabetical order. Some subjective but systematic pre-processing has removed plurals and aggregated terms with common stems. The cloud provides a nice summary of terms and an overview of the key themes addressed by participants. Considering the largest words draws attention to the heavy emphasis on **data** and the suggestion of a focus on **space** ahead of **time**. Whilst the term **model** is popular, the emphasis in the abstracts is on building digital cities rather than simulating urban processes – as suggested by the associated popularity of **3D**. **Web**, **network** and **Internet** are perhaps less evident than might be expected. It is also useful to consider the medium-sized words in clouds such as this. Doing so here reveals **energy** and **crime** as possible Digital City applications areas. Some Visual Analytics terminology is apparent with **change**, **time**, **pattern**, **process**, **large**, **complex understand** and **knowledge** occurring with some frequency. Terms such as **effective**, **standard**, **service**, **semantic**, and **webgis** are also relatively frequent in the corpus of abstracts, reminding us of the emphasis on **use**, **using**, **used**, and **user** – people are important participants in and contributors to the Digital City and its visualization.

In the spirit of a special issue on visualization these are initial reactions to a visual stimulus. Such patterns are subjectively selected and may be biased by single papers, the vagaries of language and terms that can be used in more than one way. But these frequencies give rise to potential trends and possible research questions that may warrant further analysis — and this kind of stimulating **graphic** for **exploration** in advance of subsequent **analysis** is a key element of visualization that finds favour in many of the approaches considered here.

4. Producing a special issue

As indicated above, our general call for participation resulted in 36 presentations and associated short abstracts. The workshop was intended to support ideas at an early stage of development and to provide opportunities and stimuli for scientists and practitioners in developing these with the aim of subsequent publication. To support this process, initial abstracts received feedback from two Commission colleagues and each presentation involved time for discussion chaired by a Commission member.

During the Hamburg meeting participants were asked to express interest in developing their work into original scientific papers for publication in this special issue. Responses were positive in most cases although the work of the Commission co-chairs and meeting organizers who would be involved in developing the special issue was not considered for inclusion.

Following the meeting six members of the Commission, including the organizers, reflected upon the abstracts, presentations and subsequent discussions and selected 16 contributions for possible inclusion. Decisions were based upon the strength of the work, its correspondence with the Digital City theme and journal mission statement and the potential for digital supplements to showcase the work. A process of discussion with lead authors resulted in 12 invitations to submit papers to the journal. Authors were encouraged to develop their ideas following feedback from organisers and at the meeting. The resultant papers were considered through the standard journal processes with Commission Co-Chair Jason Dykes acting as special issue Guest Editor. The review process involved at least three anonymous reviews. One of these was undertaken by a Commission member. Other reviewers were selected to ensure that perspectives from multiple disciplines were represented. The cross-disciplinary nature of the work presented here has resulted in significant changes to the original papers – with an average of three revisions required per manuscript following the initial submission. We are grateful to the reviewers for shaping the work, but also to the authors who made significant changes to their contributions to accommodate the wide range of views relating to the different audiences represented by our reviewers and shaped their research according to the advice offered by the community. We believe that the results are a robust set of high quality papers that do justice to a broadly applicable domain that is addressing a wide-ranging and important theme. The supportive developmental process has been key.

One way in which this is achieved is through the multimedia content that showcases some of the approaches described in the text. Editor in chief and guest-editor were keen that GeoVisualization be adequately represented in the journal and so authors were asked to develop their papers in close conjunction with digital materials that could be viewed as online supplements. These were considered as part of the regular review process and so each digital supplement included here has been peer reviewed and modified according to views expressed by the editors and our anonymous reviewers. As a result we are delighted to have produced some of the first multimedia articles to be published in Computers, Environment and Urban Systems – an important step forward in meeting the aims of both Commission and journal in promoting, developing and reporting upon advances in the use of digital cartography to analyse spatio-temporal data.

5. Introducing the papers

The papers themselves cover a range of subjects but all have a strong GeoVisualization theme and cut across the action types that define the HCU Digital City.

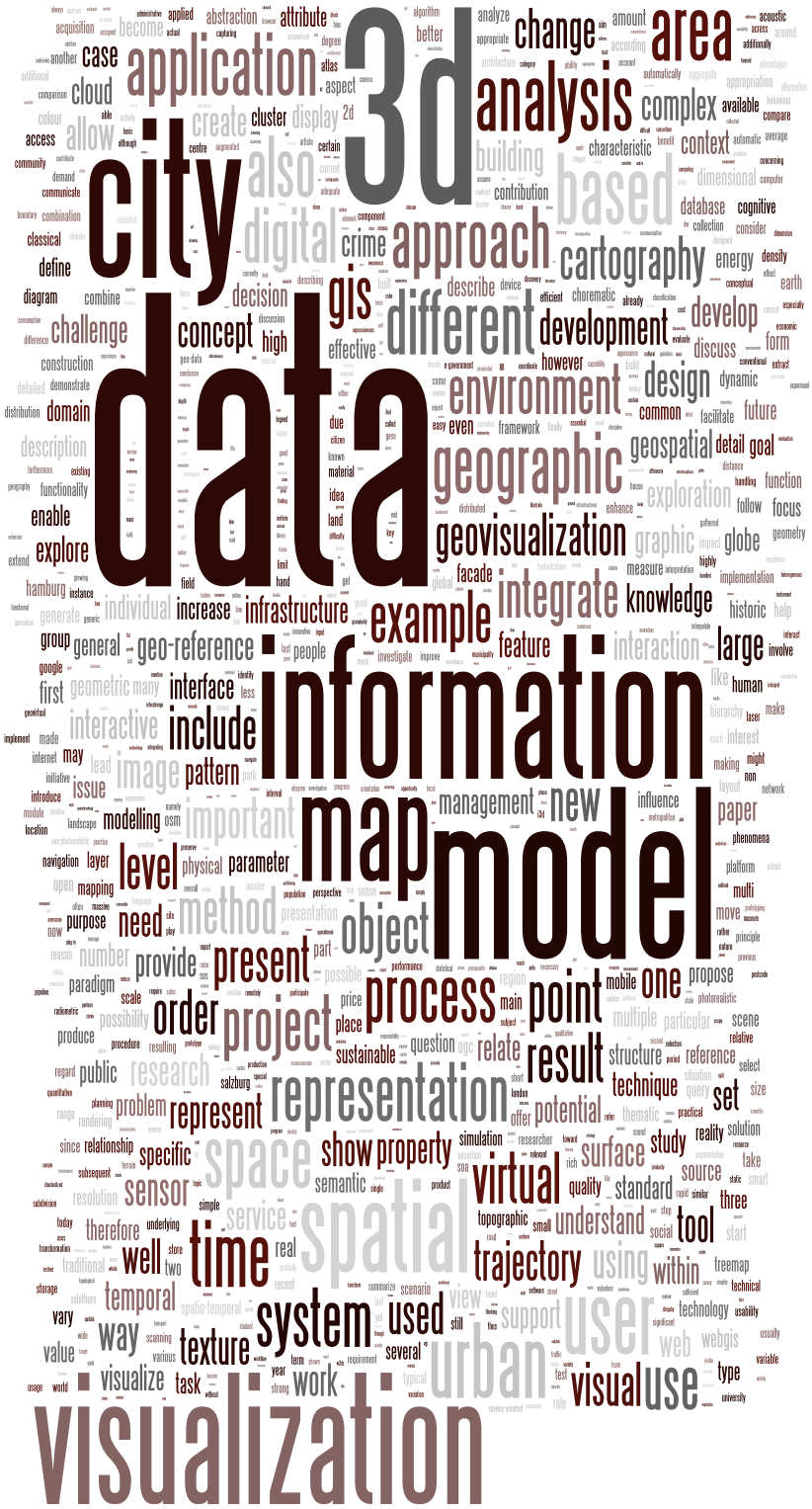

Fig. 1. GeoViz Hamburg abstract contents – word cloud showing 1000 most frequently occurring *non-common* terms in the 20,000 word abstract compendium.

5.1. Visualizing people and their interactions in urban spaces

First up is Frank Ostermann of the University of Zürich whose work focuses on using visualization to inform designers and managers of urban parks – public spaces that address important social and psychological needs of city dwellers.

Despite the various digital flows that occur in cities, Ostermann informs us that little detailed information about park use is available. He addresses this data need by developing a new observation methodology. Data on park usage are collected through an elegant digital solution in which activity is directly recorded in the field using portable GIS.

Graphics are then used to explore these data and communicate the key patterns identified to practitioners. Academic literature is used to select alternative candidate representations including dot maps and density surfaces, statistical summaries and symbolism depicting uncertainty. These are both enabled and constrained by a popular commercial off-the shelf solution. The methods selected

are then evaluated in terms of practitioner's needs by considering the level of abstraction and graphical complexity in the maps. This allows particular solutions to be selected over others for use with practitioners.

The figures presented in the article are indicative of the interactive online maps used in the study. These have been made available as a digital appendix to be used in conjunction with the paper (Ostermann, 2010 – see Fig. 2). We encourage readers to use this rich supplement of interactive cartography and evaluate the various representations as they consider Ostermann's work.

5.2. Understanding responses to alternative maps and graphics

Ron van Lammeren and colleagues at Wageningen University are also using visualization to present data to decision makers – in this case policy-makers dealing with land-use change in the Netherlands. Their experiments with representations of current and future land-use employ Google Earth as an alternative to traditional paper products that have a series of well-documented limitations. Here they assess affective responses to alternative symbolism in this interactive 3D cartography. Both the capacity for the maps to alter mood and their actual impact in so doing are considered in a series of user tests that help us understand how virtual environments may be used in planning, decision-making and analysis.

The studies uncover significant effects. 3D icons elicit higher affective responses than alternative graphical representations of the same data and have a positive influence on reported perceptions of environmental quality. This knowledge that representation form has an effect indicates that relatively subtle design choices influence a viewer's affective appraisal of the digital representation of the environment.

The Wageningen group show that visualization technique has an influence on the perceived quality of visualized environments and contend that this quality includes features of the environment that cannot be inferred directly from the graphics. This influence on a viewer's affective appraisal is likely to impact upon judgment and decision-making. The authors note that the findings fuel the debates on aesthetics and ethics and call for further experiments with well-defined target groups in environmental, urban and landscape planning.

Once again the authors provide access to the application – GESO in this instance – that is the focus of the article as a digital supplement to the paper. Readers are therefore able to (informally) evaluate their own affective response to the alternative representations. We encourage you to do so.

5.3. Populating building surfaces with data graphics in 3D models

Whilst the first two papers emphasize and evaluate representational alternatives, Haik Lorenz of the Univerity of Potsdam is interested in new data sources and developing means of accommodating them in interactive graphics for use in analysis. Work undertaken with Jürgen Döllner of the Hasso-Plattner Institute enables continuous spatial data occurring on the surfaces of 3D geometric features to be displayed and interacted with. This "*generic, multi-functional data category for Digital City applications and systems*" links levels 1 and 4 of the HCU action types and is explored through two scenarios – the analysis of photovoltaic potential and the assessment of residential quality. A movie showing a prototype implementation in the context of these scenarios is used to supplement the paper and should be consulted as you read the article.

Oblique remote sensing, simulation models and spatial analysis may be the source of this kind of information and the work reported here allows some surface properties to be calculated. Data captured and served by intelligent buildings can also be used through these techniques. The methods presented here provide opportunities for such data to be considered in visualization of the Digital City.

Lorenz and Döllner conclude that "*surface properties have the potential for increasing expressiveness and detail in simulations and analyses as well as for capturing real-world phenomena using digital city models*". They are positive about the potential for incorporating surface properties into geographic information systems indicating that doing so requires orthogonal functional components to be added without the need for major changes to system architecture. However a series of challenges are detailed that must be addressed by the research community to make surface properties more widely accessible in GeoVisualization - thereby adding an exciting analytical element to 3D representations.

5.4. Mobile 3D Geovisualization through a service-oriented approach

More of Jürgen Döllner's ground-breaking work at the Hasso-Plattner Institute is reported in the next paper where he and Dieter Hildebrandt assess service-oriented architectures and open standards in the context of 3D virtual environments and 3D Digital City models. Their approach aims to "*provide geospatial information to everyone, everywhere, in appropriate and useful ways*" – enabling them to undertake GeoVisualization through an integrated network of shared resources. Once again the paper shows the potential of GeoVisualization for contributing to the Digital City and that GeoVisualization research needs to cut across and link the four functional levels.

The paper has a strong theoretical and technical framework and introduces an example SOA in which open standards are used to support the dynamic exploration of massive, 3D city models over the Internet. This approach is developed in light of a series of requirements for 3D GeoVisualization. SOA standards are discussed in terms of whether they have the potential for meeting these requirements or pose significant challenges.

The implementation is hugely impressive – the movies that support the paper show high levels of interaction with digital cities produced using cube maps on mobile devices. The potential for navigating within a physical city using these mobile Digital City models is evident, as is the scope for individuals using such devices in cities to contribute to the digital models.

Hildebrandt and Döllner see SOAs as extremely promising, and prove this to be the case, but consider the highly interactive nature of GeoVisualization in the context of massive data sets to be a significant challenge.

5.5. Using community contributed data for 3D city models

Martin Over and colleagues are also using open standards to generate 3D Digital City models, but deal specifically with community-contributed information. They build digital cities and make them available to the citizens who create them by collecting and contributing digital data.

The potential of this data source for visualizing traffic infrastructure, buildings and points of interest in 3D is evaluated by looking at a series of application areas and their accuracy requirements in light of the data available for a number of German cities. Web services are developed to meet many of these needs with data sourced from OpenStreetMap and the Shuttle Radar Topography Mission. The architecture and process used in generating a 3D Web service through which city and landscape models can be explored are described. This service models all of Germany in more than 6 million VRML files. It is available online as a digital supplement to the paper and we encourage readers to use it in conjunction with the paper by visiting OpenStreetMap-3D (University of Heidelberg, 2010).

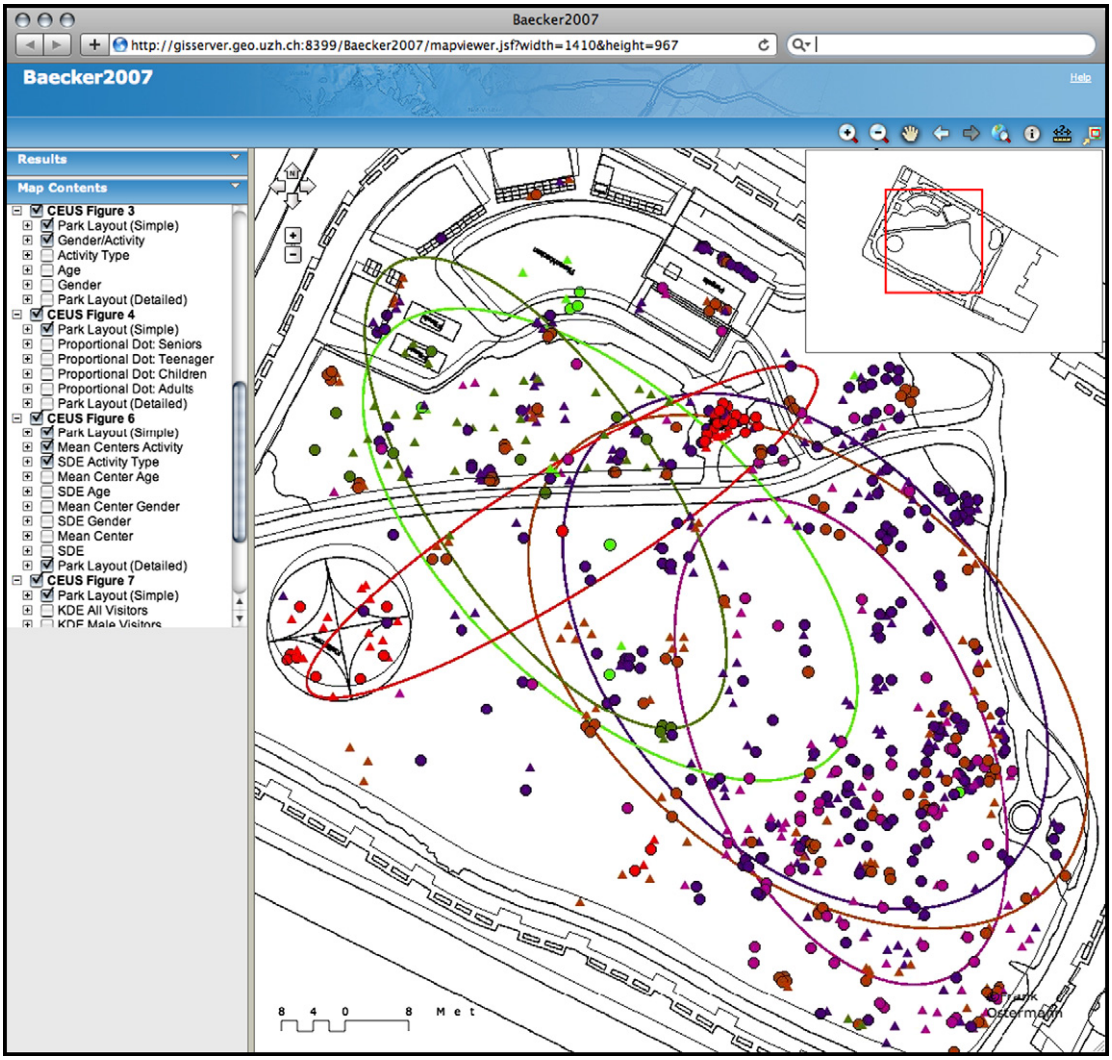

Fig. 2. Online visualization of park use data – point symbols show activity type by gender. Oval symbols show summaries of activity by type. Explore the data through a series of interactive maps available online as a digital supplement to the paper (Ostermann, 2010).

The authors surmise that at the time of writing the OSM dataset did not as yet meet the completeness and absolute accuracy needs of the applications areas considered. They also report that geographic variations are considerable. They postulate that as development continues and the data that describe the structure of digital cities improves, community contributed data sets such as OSM and services such as OpenStreetMap-3D will be increasingly utilised in many of the application areas considered in this special issue. Once again the paper cuts across key Digital City themes in developing services in which virtual environments provide scope for analytical work. Cartography is important here too as depiction of these spatially variable quality measures is likely to be important in representations utilizing community-contributed sources at any of the levels of the HCU Digital City model.

5.6. Better, faster, cheaper 3D city models with mobile terrestrial laser scanners

Stephan Nebiker and colleagues from the University of Applied Sciences Northwestern Switzerland (FH Nordwestschweiz) combine the 3D and new data source themes in comparing geometric 3D city models such as those developed by Over et al. with alternatives derived using a dense and semantically rich new data source – the 3D point cloud. Nebiker et al. document the explosion of interest in digital representations of cities and note that many city authorities "*consider their 3D city models as attractive and important communication and information platforms for citizens, politicians and tourists alike*". They also draw attention to the increasing needs and expectations in term of coverage, detail and currency. Their work uses 3D point clouds to create Digital City models in a proof of concept prototype. Like van Lammeren and colleagues the group from FHNW use a virtual globe to visually explore data – their i3D browser in this case. Attention is drawn to the interactive manipulation of the cloud in the desktop software. Once again the article contains a digital supplement – in this case a series of movies showing navigation through the prototype. This test environment is used to evaluate 3D point clouds in comparison to existing geometry and image-based alternatives. Data capture, enhancement and visualization are considered as the alternative approaches are compared.

The authors conclude that 3D point clouds offer the potential for producing better, faster and cheaper 'smart' city models than existing methods. Whilst there is enormous potential for using mobile terrestrial laser scanners as a rich source of information about the urban environment that offers the opportunity for a new means of modelling and analysis the authors make it clear that a number of important challenges lie ahead. A stimulating set of research issues are discussed in light of these arguments.

6. Other themes and other fora

These six papers explore a range of advanced topics that relate closely to our Digital City theme in the context of the kind of interactive, exploratory map use that is so crucial to GeoVisualization. In terms of Digital City action types the papers cut across the HafenCity levels - showing how they are connected and how research in GeoVisualization addresses each. The early papers focus on applications, knowledge and design at the 4th level – *using*. The later papers include examples of *services* and show how *virtual environments* can be enhanced to *support data and information* through *advanced analytical interfaces*. An emphasis on 3D models and their representation and software implementations is evident in the papers presented here and whilst data sources, forms of representation and usage vary in many cases considerable research effort is going in to facilitating real-time interaction and analysis of the type that is so fundamental both to GeoVisualization and making effective use of these data. Efforts to bring together the action types are core to advancing GeoVisualization.

The 3D emphasis is somewhat indicative of the focus of the workshop, as Fig. 1 suggests. However other aspects of the Digital City were also considered in Hamburg. The "*GeoVisualization and the Digital City*" panel enabled participants to identify key themes in the area and aspects of the Digital City that were omitted from the workshop programme and that may require additional research effort. Key themes that were identified and discussed include:

1. *New data* – precise and continuous streams of digital information are providing enormous scope for visual analysis as described in the workshop call for papers and demonstrated by the range of work presented.
2. *New methods of representation and interaction* – a '*creativity boom*' was described in which novel types of graphic, symbolism, model, technology and interaction were being applied to new data and new scenarios. The range of representation types was noted – some of representations presented are extremely abstract, others very realistic. The former of these are less well represented in this special issue than the latter. Highly interactive means of linking and morphing between alternative representations helps relate the less familiar to additional information through which they may be grounded. But research is required to take advantage of this creativity and to use and develop the techniques that are being proposed effectively.
3. *New means of sharing resources* – are contributing by relating and connecting data, people and functionality. Using these possibilities to share resources through which visualization and analysis can be undertaken will be essential in making the most of the data that are becoming available. As will developing graphical and analytical methods and means of reporting that exploit such possibilities. A number of papers showed real progress here, but changing practices to accommodate these possibilities may be more difficult than demonstrating that they are feasible.
4. *New angles on analysis* – With time varying data, moving entities and dynamic updates increasingly important and real time distributed analysis possible it is essential that we model and manage this information effectively in a manner that supports its exploitation. Multi-scale analysis seems to be key in terms of time, space and attribute: do relationships and patterns hold as scale varies? Sensitivity analysis has a role here. Importantly we need to use visualization to help us undertake multi-scale analysis, accommodate sensitivities and uncertainties and communicate relationships, patterns and answers that are scale-dependent and uncertain.
5. *Informed practice* – In the context of so much change and creativity, how do we deal with various options for graphical representation and interaction made available by the gamut of impressive technologies available to visually represent and analyse the glut of data? Work that offers frameworks for design was deemed important, and the need for a design semiology for interactive 2D and 3D graphics was discussed along with a desire for more usable information about people's likely reactions and responses to some of the possibilities (see below and van Lammeren et al., this issue) as well as their needs. Some of this work should be long-term and the idea of establishing a repository of design patterns (see Pschetz, Deiml-Seibt, Behrens, & Heidmann, 2009) was deemed a viable and extensible solution by some.
6. *Applied practice* – Grounding visualization work in applied scenarios was regarded as a trend in the Hamburg presentations and an ongoing need. Much of the research delivered at the meeting used applications to validate the approaches taken and applied studies were appreciated and encouraged. Whilst many nice examples show creative uses of newly available data through novel technology-inspired representations and interfaces a focus on *how can we use it* can be an important ally of *what we can do*.

Workshop participants also identified a series of GeoVisualization/Digital City themes that might have been expected but that were not evident in the contributions. Such omissions could be the basis for future research effort including collaboration across communities. An open discussion amongst the participants suggested that these include:

i. Dealing with the illusion of accuracy – its likely effects and how this might be handled or accommodated.
ii. Undertaking formal evaluations of effectiveness and impact.
iii. Studies that deal with temporal aspects of the Digital City in a sophisticated manner.
iv. Developing semantic services to support the smooth integration of data and resources.
v. Applications featuring full workflows – involving sense-making and the generation of knowledge through synthesis as well as exploration, as advocated by the Visual Analytics approach.
vi. An emphasis on analytical work in the context of 3D representations, in addition to the task of 3D model building.
vii. Using GeoVisualization in steering, testing and parameterizing dynamic models and communicating their uncertainties and results.
viii. Learning – what exactly is GeoVisualization education? Is there a need for it, and if so how do we do it?

The papers presented here, developed subsequent to the meeting, begin to address some of these issues. For example, van Lammeren et al. (this volume) consider affective responses to alternative graphical representations of a data set in an applied context. Equally, Over et al. (this volume) focus on building models using standards and Lorenz and Döllner (this volume) and Hildebrandt and Döllner (this volume) add interactive analytical capabilities to 3D representations – using a service-based approach in the later case.

Visual Analytics, in which interactive visualization is combined with efficient computation and database processing for effective human-led problem solving, was the focus of a panel and core to many of the presentations but is another topic that is not particularly well represented in this special issue (see item 5. above). This may in part be due to the ICA Commission's subsequent workshop on *Geospatial Visual Analytics* where the temporal aspects of spatial information and their use in analytic approaches were the focus. This work drew upon the Hamburg meeting and in "*Space, Time and Visual Analytics*" (Andrienko et al., 2010), a paper resulting from this subsequent workshop, a series of usage scenarios are developed that describe Visual

Analytics approaches – several of which apply to urban context and the Digital City theme. Indeed Visual Analytics research may contribute directly to items ii, iii, v, vi and vii from the above list of omissions. The paper concludes with a series of research challenges that must be addressed for visual approaches to be deployed effectively and these are applicable to our consideration of *GeoVisualization and the Digital City*:

1. integrating and using diverse spatio-temporal data
2. dealing with the effects of scale in the consideration of patterns and relationships
3. supporting diverse users with effective methods and light-weight flexible tools

Much of the work presented in Hamburg, and at the subsequent *Geospatial Visual Analytics* workshop, aims to address these challenges.

We have emphasized the developmental nature of the Hamburg workshop. Happily, some of the preliminary work presented at the meeting has subsequently been published elsewhere. In addition to the papers presented in this themed special issue, a number of contributors have developed their research following presentation, feedback and discussion at the meeting for publication in other fora. These include Andrienko and Andrienko (in press), Gartner and Hiller (2010), Hollenstein and Purves (2010), Pereira, Vaccari, Girardin, Chiu, and Ratti (2011), Reimer (2010) and Slingsby et al. (2009).

7. Contributing to and participating in the Digital City

GeoViz Hamburg was designed to support researchers from different countries in related disciplines in developing their work and was thus intended to be something of a springboard that provided participants with ideas and the opportunity to test these out before developing them further. The kinds of medium term results listed

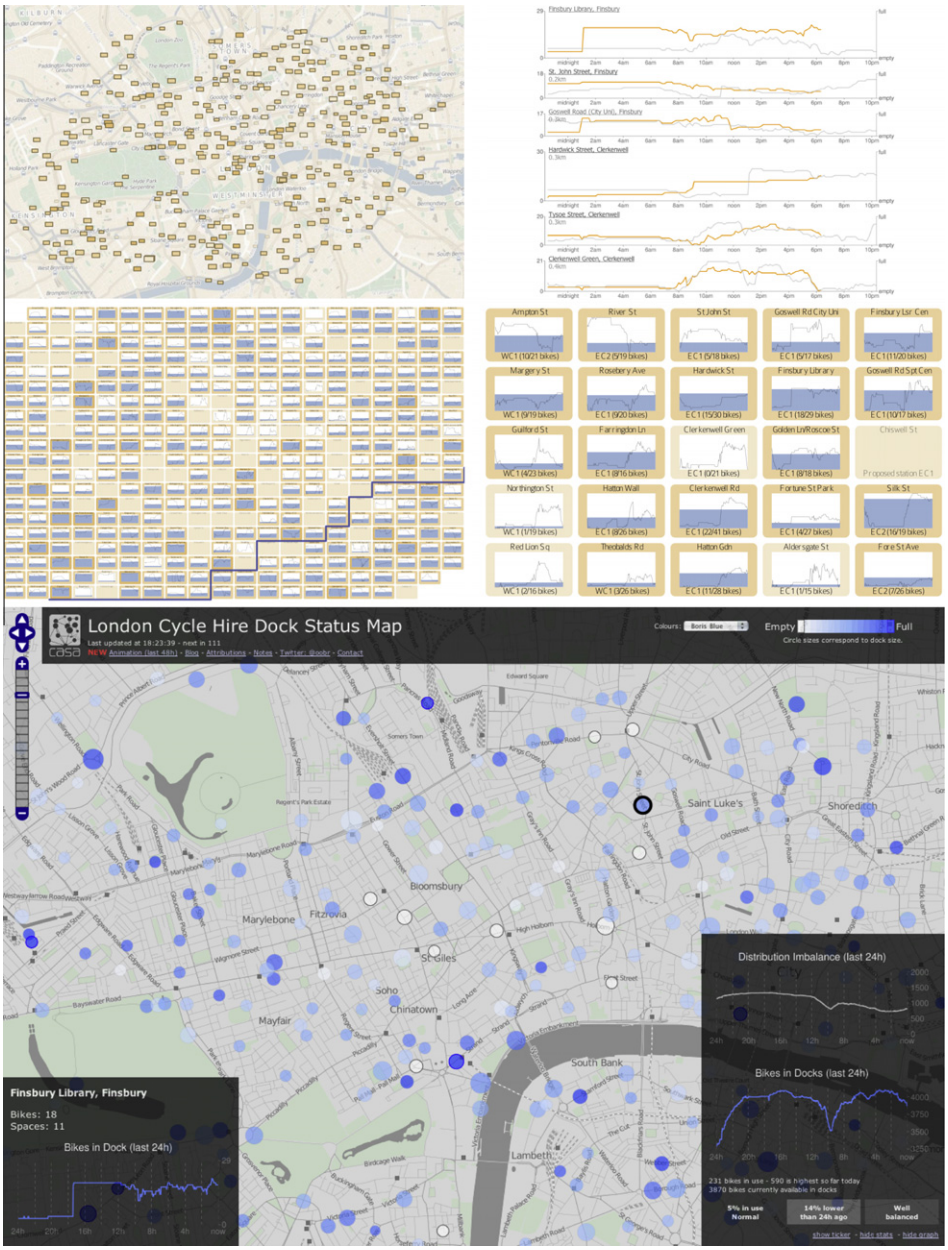

Fig. 3. Online visualization of real-time cycle availability data in London – a number of mash-ups provide access to current information about availability of bikes and docks in the TFL Cycle Hire scheme by scraping digital information from sensors in bike docks that is published online and comparing this with the historical record (Wood, 2010; Slingsby, 2010; O'Brien, 2010).

above, demonstrating that work has been developed subsequently and published in a variety of places, are therefore particularly pleasing. As is the collection of papers and digital supplements presented here, which documents the current contribution of GeoVisualization to the Digital City and identifies areas in which additional contributions are required. The ideas have been significantly developed since the meeting – revised, improved and shaped by the community through the processes of discussion, feedback and anonymous external review. We would like to thank all those who have participated in this process. We hope you enjoy considering these ideas as you learn about and contribute to the development of the Digital City through GeoVisualization.

This will be important as the flows of information continue apace and increasing volumes of real-time information become accessible. These may themselves represent flows of people in digital cities and may result in further flows of information and people as a consequence.

For example, as principal author of this introduction I sit here at my computer finalising this document to finish the special issue – but also doing some spatial thinking that is prompted by and supported through visualization. I'm consulting open spatio-temporal data that have been pushed into open visualization APIs to generate accessible graphics that help me make decisions. These interactive real-time maps show the number of bicycles available at the cycle docking stations closest to my office by space and time (Slingsby, 2010; O'Brien, 2010; Wood, 2010). I realize it is probably time to wrap up this introduction, cycle to the station and join the flow of commuters out of London... and both know where to go so that I can do so (Fig. 3) and that the actions I take will be digitally recorded and subsequently visualized to influence future decisions.

Acknowledgments

We are grateful to colleagues who volunteered to help review submissions at all stages and with the organisation of the Hamburg meeting. The former include Commission members Menno-Jan Kraak, Georg Gartner and Lorenz Hurni who provided feedback in advance of the meeting as well as the anonymous reviewers who participated in the subsequent development of the papers for the journal. The latter include Carlos Acevedo, Christoph Kinkeldey, Anna-Lena Kornfeld, Jörg Münchow, Kristin Schreyer and Silke Töllner. Thanks indeed to all those who participated in a lively and valuable workshop. We would like to thank the Editor in Chief for his patience and prompt action in helping us collate this special issue. The Hamburg workshop was organized by the ICA Commission on GeoVisualization and supported by the Commission on Geoinformation and Visualization of the German Cartographic Society and the State Enterprise Geoinformation and Surveying of the Free and Hanseatic City of Hamburg. ESRI Germany and the German GI network GiN e.V. kindly sponsored the meeting.

As a founding father of Visual Analytics, Jim Thomas made key contributions to the *Geovisual Spatial Analytics* meeting and the VisMaster efforts mentioned here. We learned of Jim's untimely death whilst writing this editorial and would like to express our sadness, appreciation of Jim's contributions to the field and acknowledgment of the significant impact of his considerable efforts in this area.

Appendix A. Addendum

The 2009 Hamburg meeting was so successful that we will be returning in 2011 for a further GeoViz symposium (HafenCity University, 2010c). Organised collaboratively by the ICA Commissions on GeoVisualization and Geospatial Analysis and Modeling, in conjunction once again with the *g2lab* at HCU, the focus will be on linking GeoVisualization with an important aspect of the Digital City that was under-represented in 2009 – Spatial Analysis and Modeling. You can find out more at the commission website (Andrienko & Dykes, 2010) and we encourage you to participate.

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