

# Geodata for the urban environment

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**Abstract:** Since the development of the first 2D urban geological map of Bath by William Smith in 1799, the production and representation of geological information has changed little until relatively recently. In the last 20 years, information technology and increased computing capacities have transformed the way in which geoscientists work. In particular, the development and use of geographic information systems (GISs) and modelling packages have meant that there is now a far greater opportunity to develop engineering geological products that show more effectively the third dimension in the urban environment. Because the information is captured and manipulated digitally, the outputs can be tailored to various end-user needs and more readily updated as new data become available. To illustrate these developments a brief overview of the 30 papers that were submitted to the Theme 'Geodata for the Urban Environment' of the 10th International Congress of the International Association for Engineering Geology and the Environment (IAEG) are presented and discussed.

Three-dimensional geological modelling is revolutionizing geological interpretation in the urban environment. It is a tool that, for the first time, is allowing geologists and engineering geologists to create and communicate, interactively, 3D geological and engineering geological models, which were previously developed as 2D images (maps and cross-sections) by combining ground investigation information and geological knowledge. For engineering applications in the urban environment, the modelling has provided a 3D framework for the spatial presentation and interpretation of geotechnical data (Culshaw 2005). From these spatial data, engineering geological classifications can be formulated and the engineering geological ground conditions visualized. Engineers and geologists can use these in urban environments to assist in the recognition and identification of problematic ground conditions (Reeves *et al.* 2005), as a tool to aid in the planning and location of ground investigations, and to ensure that the most economical and valuable information is obtained from ground surveys. By using examples from the 30 papers that were submitted to the Theme 'Geodata for the Urban Environment' of the 10th International Congress of the International Association for Engineering Geology and the Environment (IAEG) these concepts and ideas will be presented to demonstrate how engineering geological products can show the third dimension, allow the spatial attribution of geotechnical data and, hence, allow the effective communication of engineering geological information to audiences of specialist and non-specialist backgrounds.

## Summary of papers submitted to the Theme 'Geodata for the Urban Environment'

In the 30 papers that were submitted to the Theme, five key Q1 topics that were covered: (1) the development of spatial databases for borehole and geotechnical information; (2) the development of GISs, for geoscientific purposes; (3) the development of dynamic 3D geoscientific computer models, which hold and manipulate large spatial datasets (such as borehole and geotechnical data); (4) the development of sophisticated knowledge-based and decision-making tools for a variety of specialist and non-specialist users; (5) examples and case studies of specific types of geodata used in the urban environment.

Of these topics, the first four will form the basis of the discussion in this paper. A brief summary of the highlights of each topic and some examples from the papers submitted to the Theme are discussed below. These summaries aim to indicate how engineering geological products can show the third dimension, allow the spatial attribution of geotechnical data, and hence allow the effective communication of engineering geological information to a wide range of users.

### Development of spatial databases

Four papers were submitted on the topic of the 'Development of spatial databases'. These varied from papers that

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58 presented the detailed design and specification of geotechnical  
59 databases (Ngan-Tillard *et al.* 2009; Oliveira *et al.* 2009)  
60 to more complex and integrated geoscientific database  
61 management systems as described by Kiehle *et al.* (2009)  
62 and Giles (2009).

63 Ngan-Tillard *et al.* (2009) discussed a large geotechnical  
64 database of cone penetration test (CPT) data that was devel-  
65 oped by municipalities, scientific institutes and geotechnical  
66 engineering consultants in The Netherlands. Ngan-Tillard  
67 *et al.* (2009) demonstrated a specialist clustering tool's  
68 ability to analyse and effectively interpret the shallow sub-  
69 surface from these data. In comparison, Oliveira *et al.*  
70 (2009) described a similar database (GEODATA) that has  
71 been compiled for the Portuguese city of Oporto. This data-  
72 base formed an integral part to a larger engineering geologi-  
73 cal mapping programme of work in the city (see below in the  
74 section on 'Development of GISs for geoscientific pur-  
75 poses'). The GEODATA database consisted of three main  
76 modules that hold geophysical investigation information,  
77 mechanical investigation information and *in situ* test results.

78 The more complex and integrated geoscientific database  
79 management systems that have been produced as a result  
80 of recent developments in Geoinformatics have allowed  
81 systems as described by Kiehle *et al.* (2009) to be developed.  
82 This system is called the Spatial Data Infrastructure (SDI). It  
83 manages huge amounts of spatially related data and fosters  
84 the reuse of existing data inventories for future uses that  
85 are not yet known. The main building block of the hypothesis  
86 is that spatially related data are available in several places.  
87 The data storage and preparation is located with the data pro-  
88 viders. The task of data preparation, manipulation and retrieval  
89 is carried out using Web services and, hence, is available  
90 to a multitude of users. In comparison, Giles (2009)  
91 described a similar system that the British Geological  
92 Survey (BGS) is developing (the BGS Geodata index).

93 All the papers discussed above highlight the important  
94 role that data and databases have in large geotechnical and  
95 engineering geological projects in the urban environment.  
96 With more information being available through well-  
97 managed systems, better results are produced. To supply  
98 the relevant information, all data have to be collected and  
99 stored in one place, which is an extensive task. Therefore,  
100 it is vital to have the correct infrastructure in place to  
101 acquire, manage and distribute the geoscientific information  
102 from these systems in a way that gives potential users  
103 confidence and the information that they want. Without the  
104 development of these well-designed and managed systems,  
105 valuable ground investigation data and information can be  
106 lost and, hence, not incorporated into current, as well as  
107 future, studies and investigations.

#### 109 **Development of GISs for geoscientific purposes**

110  
111 Eleven papers were submitted that covered the topic 'Devel-  
112 opment of Geographical Information Systems (GISs) for  
113 geoscientific purposes'. Collectively, the submitted papers  
114 highlighted various ways that a GIS can be used to aid

geoscientific data visualization and investigations in urban  
environments. Papers submitted generally fell into two  
categories: (1) cartographic production and data holding of  
maps; (2) interrogation of spatial datasets using specialist  
tools and functionality. Many of the papers have demon-  
strated how a GIS can produce and manage information  
from geological, engineering geological and environmental  
mapping projects within the urban environment. For  
example, Mironov (2009) presented a project that described  
how a GIS was used to manage a geological mapping project  
that investigated ancient buried erosion valleys in Moscow.  
Similarly, Oliveira *et al.* (2009) produced a comprehensive  
engineering geological map of the city of Oporto. One  
output was a Geotechnical Zoning Map. The GIS and maps  
produced for this project are now used as an important tool  
for land-use planning and management in Oporto. A similar  
engineering geological GIS to manage an engineering geo-  
logical mapping project proposed for the southeastern part  
of Brazil was discussed by Bastos & Zuquette (2009).

In addition to the production and management of geologi-  
cal, engineering geological and environmental maps, a GIS  
also can be used to produce more complex maps with  
additional functionality. Four papers gave examples of this  
(Calijuror *et al.* 2009; Harrison & Forster 2009; Mellon & Q2  
Frize 2009; Zhou & Yao 2009). Mellon & Frize (2009) pre-  
sented a GIS-based system that centrally held spatial and  
tabular datasets. The key feature of this system was the  
seamless link from the GIS to a digital archive of scanned  
reports and borehole logs held in an electronic document  
management system. In comparison, Calijura *et al.* (2009), Q2  
Harrison & Forster (2009) and Zhou & Yao (2009) demon-  
strated a slightly different application of a GIS, whereby a  
geo-referenced database was manipulated in a GIS environ-  
ment. Calijura *et al.* (2009) discussed a risk map in an urban Q2  
environment that was produced using this technique. The  
Chinese Geological Hazard Information System was  
described by Zhou & Yao (2009), and they demonstrated  
how the stored geohazard information for China on land-  
slides, land subsidence, debris flows, ground fissuring and  
other geohazards is managed. Harrison & Forster (2009)  
described a similar project called GeoHazarD. This is  
described further below under the topic 'Knowledge-based  
and decision-making tools'.

One of the most powerful attributes of a GIS is the ability  
to interrogate spatial datasets using specialist tools and func-  
tionality. A number of papers gave examples of a GIS being  
used in this manner. Apolinário-Francisco *et al.* (2009), for  
example, described a GIS-based research project in the  
city of Brasilia, Brazil. This project made use of spatial  
analytical tools to investigate, estimate and model the loss  
of soil in this region. This study supported the socio-  
economic and environmental planning in the short and  
medium term, as well as being able to model future scenarios  
of this geodynamic phenomenon. In comparison, Moreda-  
Mendes & Lorandi (2009) and Choi & Park (2009) demon-  
strated the use of geostatistical methods within a GIS  
environment to spatially analyse data. Moreda-Mendes

& Lorandi (2009) discussed how geostatistics (with indicator geostatistical resources) are used to create probabilistic maps, which show where the most favourable areas for constructing foundations at specific depths can be found in the São José do Rio Preto urban area (Brazil). Choi & Park (2009), in comparison, demonstrated how, within a GIS environment, interrogation of data and 3D geostatistical methods can be used to predict variation of soil properties, such as hydraulic conductivity.

The key observation from all of the papers under this topic is how GISs, are now common tools of practice for geotechnical engineers and engineering geologists. They form a fundamental platform for data collection, visualization and communication of geotechnical and engineering geological information to a wide range of end-users (e.g. geologists, engineers, planners, the general public).

### Dynamic 3D computer models

Dynamic 3D computer models are the most rapidly expanding research area within geoscience; this is mainly due to the increase in computing capacities and capabilities. Eight papers were submitted on this topic. Some papers looked at aspects of 3D geological modelling (Bourguine *et al.* 2009; Develeschouwer & Pouriel 2009; Neber *et al.* 2009; Q3 Palmu *et al.* 2009) ranging from case studies to wider applications and the attribution of 3D geological models with geotechnical, engineering geological and other data. Breyse *et al.* (2009) and Bouguine *et al.* (2009) presented a case study of geotechnical modelling undertaken at a town scale, which focused on the southern part of Bordeaux, France. The purpose of this work was to reinterpret the near-surface geological model to develop information that was more useful for urban planning. In comparison, Neumann *et al.* (2009) depicted a project that was undertaken by the State Geological Survey of Saxony-Anhalt, Germany, where engineering geological maps of the city of Magdeburg with seven thematic map sheets were produced. From this, innovative interactive computer modelling techniques were applied using a 3D spatial modelling package with an interactive 3D modeller to create a 3D engineering geological model of the subsurface. A similar case study by Merritt *et al.* (2009) has been undertaken in Glasgow, UK, in collaboration with Glasgow City Council, which is discussed further below under the topic 'Knowledge-based and decision-making tools'.

The models discussed above are all generally based on urban centres but there were a few examples from the papers submitted that also dealt with more site-specific engineering geological modelling. Van Knapen & Slob (2009) discussed an automated identification method for 3D engineering geological rock mass characterization of discontinuity sets, using the results from a terrestrial laser scanner survey. From this survey a dense point cloud was generated that represented the geometry of the scanned rock face. Through 3D surface reconstruction techniques the original rock face could be rebuilt and, hence,

identification of the discontinuity sets and characterization of the rock mass could be undertaken. Using similar scanning technology, Rahman *et al.* (2009) were also able to quantify the surface roughness of discontinuities within a rock mass.

From the papers submitted under this topic, it is apparent that 3D computer modelling is starting to be used in a wide spectrum of applications, from regional 3D urban geological modelling to specialist site-scale projects. In addition, it is also being undertaken using a variety of tools and methods.

### Knowledge-based and decision-making tools

The development of 'Knowledge-based and decision-making tools' cannot be undertaken without the development of information technology systems such as spatial databases, GISs for geoscientific purposes and dynamic 3D computer models. Knowledge-based and decision-making tools form the 'front end' or 'final end-product' of the information technology systems that are developed. As a result, they can take a multitude of forms and can portray data and information to a multitude of end-users, not just those with geological training and expertise. In the papers submitted under this topic, this approach was presented by Gocmez *et al.* (2009), Harrison & Forster (2009), Li *et al.* (2009), Martin & Toll (2009) and Merritt *et al.* (2009).

Merritt *et al.* (2009) presented a fully integrated geological model, where INSIGHT Geologische Softwaresysteme GmbH have developed, in collaboration with the BGS, a linked 3D geological and attributed property model for part of Glasgow, UK, which deals with several geoscientific issues (hydrogeological, geotechnical, engineering geological, geohazards and uncertainty). In contrast, Gocmez *et al.* (2009), Harrison & Forster (2009), Li *et al.* (2009) and Martin & Toll (2009) presented systems that are designed to deal with more specific problems.

For example, Harrison & Forster (2009) described a rule-based system using ArcGIS that combines digital vector geological data. This system (GeoHazarD) integrated expert knowledge, national databases, multi-criterion analysis and a flexible rule-based approach to model the geohazard datasets of the UK (collapsible deposits, compressible ground, slope instability, running sand, shrink–swell (subsidence and heave) and dissolution). The major advantage of this system is that it produces a fully auditable trail leading to the final geohazard risk classification. This allows the assessment to be updated automatically following a revision of the primary datasets (e.g. by geological mapping). This system has allowed geohazard susceptibility maps of the UK to be produced, which contribute to a number of products that portray geohazard risk information to a number of end-users (e.g. insurers the general public, local authorities, engineering consultants).

In contrast, Li *et al.* (2009) described a very detailed highway tunnel decision-making system that has been applied to the Zhegu Mount highway tunnel, in the west of China. This system aimed to develop and improve the

172 methods and techniques that are used when building a  
 173 highway tunnel. The system synthesizes theory analysis  
 174 and expert judgement and monitors measurements in a  
 175 tunnel to allow the 'intelligent' classification of the wall  
 176 rock, analysis and forecasting of wall rock stress, and analy-  
 177 sis and forecasting of wall rock deformation. This process  
 178 then allows the security of rock wall supporting structures  
 179 to be assessed. Martin & Toll (2009) have developed a  
 180 similar system to that of Li *et al.* (2009), which is designed  
 181 to address and manage the complex parameters and infor-  
 182 mation required when undertaking a risk assessment exer-  
 183 cise for a contaminated site. To assist with this process, at  
 184 the preliminary stage of a ground investigation, a prototype  
 185 knowledge-based system (ATTIC: Assessment Tool for The  
 186 Investigation of Contaminated Land) and database have  
 187 been developed to capture the wealth of scientific knowledge  
 188 required and ensure that a structured approach to the inves-  
 189 tigation is undertaken.

190 The papers submitted to this topic have shown how the use  
 191 of knowledge-based and decision-making tools is expand-  
 192 ing. Such tools are now forming one of the principal  
 193 techniques to communicate technical and complex geoscientific  
 194 data and information to end-users who may or may not  
 195 have a geoscientific background. These systems are helping  
 196 to increase the effective use of geotechnical and engineering  
 197 geological information in the urban environment.

### 198 Concluding remarks

201 A total of 30 papers were represented within the Theme  
 202 'Geodata for the Urban Environment' at the IAEG 10th  
 203 International Congress. This paper provides a review of  
 204 many of the papers submitted to this theme. The main con-  
 205 clusions from the papers that were submitted are that, as  
 206 geoscientists, we can now: develop GIS and 3D computer  
 207 models to hold, manipulate and query large databases (bore-  
 208 hole, geotechnical) on a relatively standard desktop compu-  
 209 ter; produce dynamic upgradeable models that can be rapidly  
 210 changed and developed to suit different purposes and  
 211 requirements; attribute models with geotechnical to hydro-  
 212 geological to geophysical property data; visualize and  
 213 present geoscientific data and information to a wide range  
 214 of end-users (geologists, engineering geologists, geotechni-  
 215 cal engineers, civil engineers, planners and the general  
 216 public).

217 From the discussion in the session, it was noted that when  
 218 using GISs and developing 3D models it must not be forgot-  
 219 ten that there are standards and procedures that are followed  
 220 in engineering practice (e.g. Eurocodes, ASTM guidelines).  
 221 Therefore, it is vital that the standards and procedures now  
 222 start to take account of the new methods and techniques  
 223 that geotechnical engineers and engineering geologists can  
 224 use to manage and visualize geoscientific data. It is crucial  
 225 that these standards and procedures are kept up to date and  
 226 take account of new developments in information  
 227  
 228

technology, so that practising geoscientists can ensure that  
 they are following good practice.

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