Information Systems and Models for Territorial and Cultural Heritage

Original
Information Systems and Models for Territorial and Cultural Heritage / Bocconcino, MAURIZIO MARCO - In: Digital Strategies for Endangered Cultural Heritage (forthcoming INTERSPECIES) - Handbook of Research on Strategies and Creative Interdisciplinarity for the Digitization and Safeguard of Endangered Heritage / Sandro Parrinello, Raffaella De Marco. - STAMPA. - Pavia : Pavia university Press, 2023. - ISBN 978-88-6952-166-9. - pp. 52-63

Availability:
This version is available at: 11583/2976753 since: 2023-03-10T09:22:48Z

Publisher:
Pavia university Press

Published
DOI:

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Abstract
The contribution considers in an introductory way synthetic frameworks relating to aspects of the organisation of the information heritage, the nature and format of data with respect to different thematic areas of the Cultural Heritage, the spatial processing of data in order to build digital information models, finally data management and processing environments, today's evolution of information systems.
The topics will concern: data formats and coherence of interchange flows (some definitions for the design and implementation of interdisciplinary and multiscalar information systems and models); a brief review of methods and tools for the management and representation of data and information in the field of Cultural Heritage; methods and tools for the representation of models and interpretative conceptual schemes related to complex geodatabases; use of graphic information for technical and non-technical communication.

Keywords
Information systems and models, Graphic information, Territorial and cultural heritage.

Information Systems and Models for Territorial and Cultural Heritage

"We build our image of the world with data from our senses. By presenting these data in novel patterns, artistic inventions alter our sensibilities – change what we see and therefore how we conceive the world and again how we look at it."

Kevin Lynch, *What Time Is This Place?*, 1976

Urban survey as an information system of knowledge

Information and communication technologies are changing the way we understand Cultural Heritage (CH). Technologies allow researchers, public administration, professionals, to think about the non-digital aspect of heritage in a digital way, using computer simulation and modelling - Geographic Information System (GIS), Building Information Modelling (BIM), Database Management Systems (DBMS) - to manage, visualise, model, design and operate the physical environment from the large scale (building and architecture), to the medium scale (urban), to the small scale (land). The elements of cultural value are now more valuable than ever thanks to our ability to digitise, analyse, design, manipulate and predict trends over time and the evolution of building and infrastructure systems.

Of course, social objectives, political mechanisms and economic development continue to be the main driving forces behind urban forms and their transformation, as well as Cultural Heritage. Investigation and urban design see illustrious references in the research. We observe perceptual, visual approaches, linked to the reading of urban space, scenes collected apparently as a quick sketch, but dense with layers of interpretation, as well as analytical approaches, which break down the image of the city and operate syntheses at different levels of interpretation. However, our attention must also be drawn to the graphic language that conveys interpretations, to the codes of representation that give access to knowledge and allow the conception and implementation of conscious protection and conservation projects.

In recent years, considerable efforts have been made by institutions to digitise Cultural Heritage sites, artefacts, historical documentation, for digital preservation and online sharing. On the other hand, extensive research projects and studies have been published demonstrating the great capabilities of web-geographic information systems (web-GIS) for the dissemination and online representation of Cultural Heritage data. However, the Cultural Heritage data and associated metadata produced by many Cultural Heritage institutions are heterogeneous. To make this heterogeneous data interoperable and structured, an increasing number of public actors are adopting the principles of linked open data[1]. Although the cultural heritage sector has already started to implement linked open data concepts for heritage data to be preserved and passed on (Bizer et al., 2009; McKenna, 2013), there are not many references in the literature presenting an easy to implement, free and open-source web-GIS architecture that integrates 3D digital models of Cultural Heritage with cloud computing and linked open data.

Fig. 1 Analogical-perceptual and analytical approaches to urban surveying (Author's elaboration on sources: Lynch, 1960; Cullen, 1961; Cavallari Murat, 1968).

The integration of web-GIS technologies with web-based 3D visualisation and linked open data can offer new dimensions of interaction and exploration of digital Cultural Heritage. To demonstrate the high integration potential of these technologies, new cloud architectures are enhancing digital Cultural Heritage exploration by integrating digital cultural heritage information models with linked open data from DBpedia and GeoNames platforms using web-GIS technologies[2]. More specifically, an interactive digital map, 3D digital models of Cultural Heritage, open data linked from DBpedia and GeoNames platforms are frequently integrated into a cloud-based web-GIS architecture. Thus, users of the digital platform can easily interact with the digital map, visualise 3D digital models of Cultural Heritage and explore linked open data from GeoNames and DBpedia platforms, which provide additional information and context related to the selected CH site and external web resources.
Research on Cultural Heritage preservation has shifted from emphasising digital information with the advantages of 'accuracy' and 'amplified visualisation' at an early stage, to focus on the development of 'realistic' and 'highly experiential' gamified interactive environments. Just as game technology provides a highly interactive experience, effective communication and a virtual environment provide new application opportunities for the future development of the reconstruction of physical places and cultural spaces (Batty, 2005).
The meeting point of these complementary approaches is the discipline of drawing, graphic representation and the codes that in this language constitute the alphabet and dictionary of storytelling. In the last decade we could say that the approach to urban information modelling for protection and conservation has changed its focus from land use analysis and the balance of transport infrastructure to more complex and dynamic systems incorporating social and economic components. This is to a large extent made possible by the diffusion of analyses based on large amounts of data and the possibility of exercising artificial intelligence to propose alternative

project scenarios. In the following paragraph some definitions of a specific category of data and information, those of a geospatial and geostatistical nature.

Geospatial data and geostatistical information

Spatial geostatistics is a system of analysis that considers different types of data and produces different types of information. The compound term ‘geospatial data’ can be defined as data representing the position of a specific point or area in a geographical space (including relevant temporal data) and any associated parameters. Spatial data can be classified as follows (Cressie, 1993, p. 32)[3]:

- geostatistical data;
- data networks (lattice data, observations of a random process observed over a numerable set of spatial regions and supplemented by a linear neighbourhood structure; it is discrete data residing on an irregular lattice);
- point patterns (distribution of points in space).

From a strictly technological point of view related to geographic information systems, it is necessary to highlight the paradigm shift from a two or three dimensional vector management to a raster data processing in space, i.e. a matrix of ordered cells where each cell corresponds to a qualitative or quantitative value representative of the entire area covered by the cell (whose dimension defines the resolution of the analysis, i.e. the minimum readable and representable area, below which the variation of values cannot be collected). The need to map the survey in three-dimensional terms is fundamental for the development of a CH governance strategy based on climate, ecology, geology, physiography, hydrology, as well as anthropogenic influences. Compared to extensive fieldwork, the use of remotely sensed data provides remarkably convenient means of collecting data over large land masses. Remote sensing provides high-resolution data with which to structure land representation. For example, the Landsat programme that was launched in 1972 by the United

Fig. 2 Brief overview of open source and free web-gis environments and main functionalities.

Fig. 3 Data-information-knowledge (source: McCandless, 2014, p. 14).

States Geological Survey (USGS) and NASA provides the most continuous record of data used for over 30 years to study the environment, resources, and natural and man-made changes occurring on the Earth’s surface. Turning to data processing, statistical surfaces are numerical-graphic representations of the distribution of values of a given phenomenon defined, for each triplet of coordinates, by measured or calculated values as associated parameters (Robinson et al., 1995; DeMers, 2008). The easiest statistical surfaces to understand are those referring to terrestrial topography[4]: geographical entities that change in space: the elevation, the piezometric height of an aquifer or the deep sliding surface of a landslide. There are other examples of statistical surfaces: the representation of temperatures or precipitation over an area, the diffusion of pollutants, socio-demographic and economic parameters, the cultural value of an asset, its history. The important aspect of these surfaces is the adjective that qualifies them: statistical. The term statistical, associated with the concept of surface area, derives from the fact that this type of representation is obtained by estimating the value of a variable where no measurement has been made. Statistical estimation techniques are used when a variable is calculated at every point on a surface from data measured only at certain positions. Interpolation or extrapolation processes are used to calculate unknown points.

In the McCandless diagram, unstructured information means relationships, i.e. the external world with its complexity. Any phenomenon that can be perceived or measured can be described as information. McCandless finds a metaphor between organisms and interconnected knowledge, looking at atoms as data, going through molecules DNA chromosomes cells, then structured data information, connected information, knowledge and finally interconnected knowledge. Looking at the infographic you will get a glimpse of the whole process.

The range of data types and the development of a landscape strategy from these types is complex, as is the choice of representation tools for these activities. Understanding the principles of the various data acquisition processes enables an understanding of the appropriate tools to achieve results. An example of data

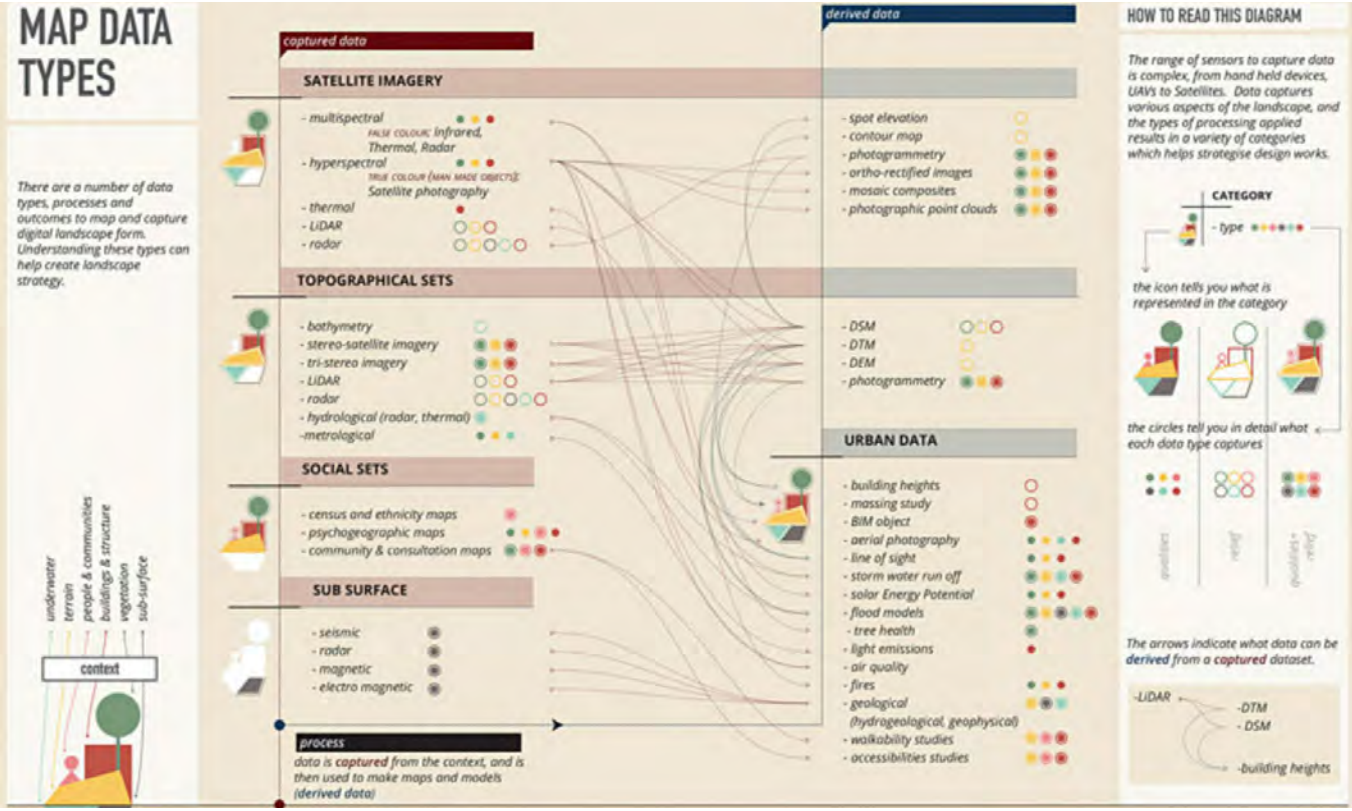

Fig. 4 Serena Pollastri, Imagination Lancaster, Lancaster University, mapping data typology, 2016 (source: Cureton, 2017, p. 39).

and workflow types has been rendered infographically by Serena Pollastri. The translation of the scheme into a sankey diagram helps to make evident some relationships and how the single type of data can contribute to defining more parameters and more indicators of territorial quality and cultural value.
The effectiveness of representation is reflected in more effective and efficient processes of territorial and city government. The brief notes expressed highlight the need to articulate the frameworks according to the necessary geostatistical skills, each for its own disciplinary field of analysis: demographic development, social characterisation, urban development and transformation, cultural value. The point of view that must not be overlooked is that relating to the opportunities to analyse phenomena graphically in order to provide a glance, a synthetic and immediate reading with the specific aim of sharing them with vast and heterogeneous publics. In the following paragraph we will observe the interpretative models that can be applied to the data and some useful references in the literature.

Active protection of the built and social heritage

The senses of the urban environment can be defined as the clarity with which spaces can be perceived and identified by linking experiences, activities and places in a coherent mental representation of time and space, as well as being linked with concepts and values that are not only geometric. Interpretative models and informative elaborations must be assumed for the conservation and care of the built heritage and the social value of communities and places. In literature we can trace four possible models, excellently described by Yamagata & Yang (2020)[5] and here summarised, integrated and adapted to the CH theme.

Urban detection systems as a human interactive model

There is a common ground between the geometric and functional form of the city and the human processes of perception and cognition, the urban senses, which has been termed identity, or sense of place (Lynch, 1984). People tend to identify with the urban places that they appropriate, that they experience, that impose an experience on them (McCullough, 2004). The question of confidentiality and the issue of who controls the data, what are the mechanisms for classifying and analysing the data for applications, and how decision-making is managed collaboratively with communities, define the most central role in the processes of building cities and preserving their heritages. Urban sensing systems define the first dimension of design in terms of attention to socially interactive processes. Systems capture data through sensing infrastructures without compromising privacy, individual choice and participatory processes through community involvement. Human senses are extended to wider urban environments with the help of electronic sensors by engaging human activities in cities through receiving, responding to and interacting with users in near real time: data is captured, analysed and represented for smart city planning (Batty, 2013a).

Data-driven heritage protection as a normative model

Data-driven protection links values and the creation of urban forms that imagine future cities and societies; these are driven by visions, goals and proposals, also based on data and performance criteria that drive system changes. Urban planners now collaborate with systems scientists to develop a dynamic digital city model, or urban cyber-physical systems that constantly renew their data and information with inputs from both inside and outside the system boundaries of the smart city project. Inspired by the performance-based model of city design (Lynch, 1961), data-driven advocacy offers additional dimensions, emphasising the connection of data analysis with design to transform cities and urban spaces. It is driven by normative questions, focusing on the values of urban form. The ability to raise questions such as 'what urban systems should be implemented and how cities are transformed by them' is crucial. In other words, the utopian vision of the future will define what analytical data is selected and how design scenarios

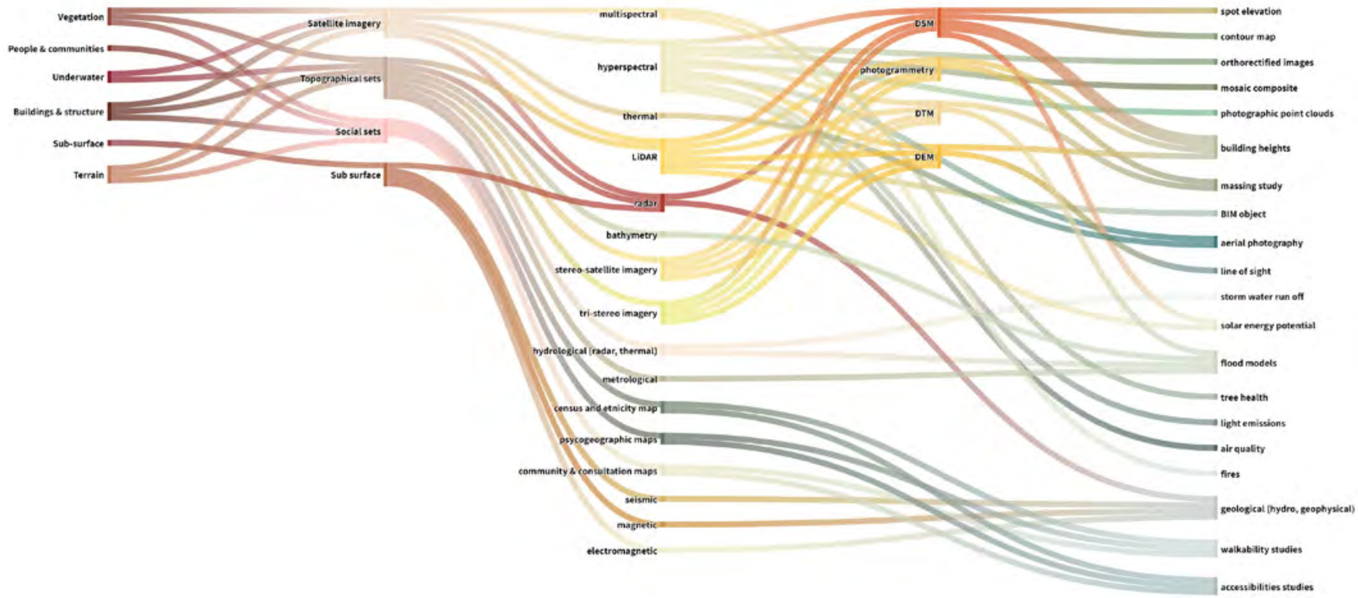

Fig. 5 Types of data, aggregation into sets and processing contexts (source: Author's elaboration on Pollastri infographic, 2016).

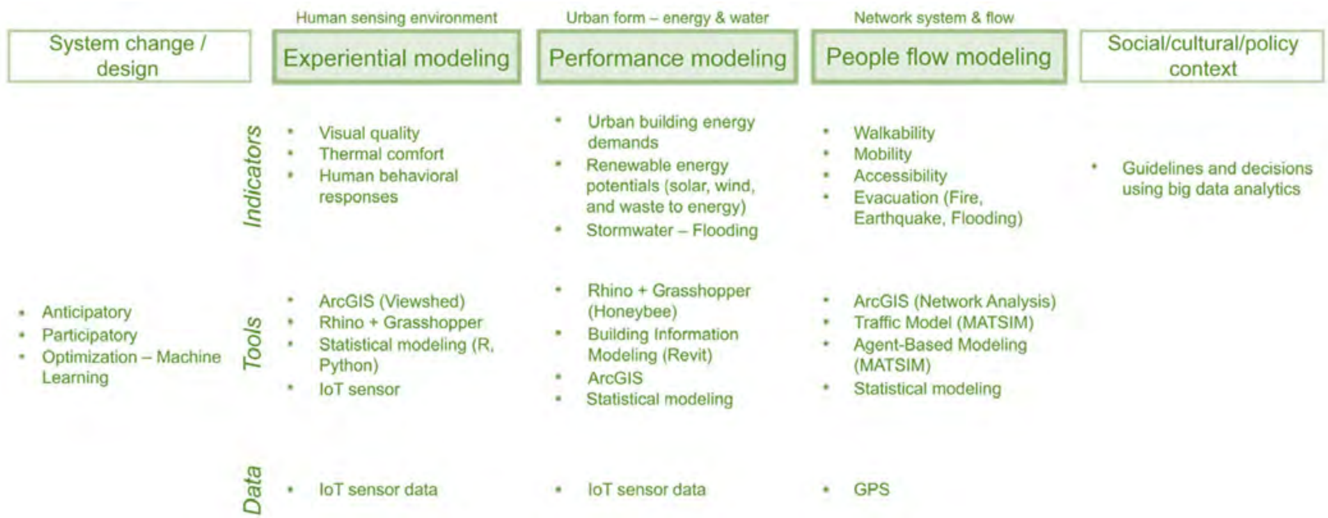

Fig. 6 Summary of modeling approached in urban systems (source: Yamagata & Yang, 2020, p. 25).

are derived. Conservation design is driven by human values and people's desire for their future. It is therefore a participatory model, as opposed to the previous analytical model based on surveying. Both models are based on the observation of present and future urban form.

Urban metabolism as a functional model

The third model is a theory of complex systems and urban metabolism. Urban metabolism refers to system functions. The method sees cities as complex systems containing processes and flows of energy, material, water, human movement and information that transcend different sectors and operate on different spatial and temporal scales. A city does not operate like a machine. It is more like a metabolism. We should conduct a comprehensive urban metabolic study of energy, material and water flows to and from urban areas or cities to explore issues of efficiency, intensity, distribution and recycling strategy (Graedel & Allenby, 2010). Multiscale modelling is needed to analyse the movements and exchanges that can be observed in cities. The model incorporates the complex relationships between infrastructural systems and to what extent the nexus of these subsystems might influence the overall performance of the system. it is therefore definable as a functional and performance model, registers and calibrates to the vital parameters of the urban and social fabric.

Geodesign as a procedural model

Finally, geodesign is a procedural model that manages the surveying and decision-making process from data visualisation, data analysis, project generation, monitoring, and finally impact assessments through collaboration between stakeholders. This type of model requires several rounds of iterations before decisions are made. Geodesign is also seen as a procedural method that combines design with social, cultural and environmental impact simulations influenced by geographical contexts, systems thinking and digital technology. In short, it brings 'design for change' back within geographic information systems (GIS) (Steinitz, 2012; Steinitz, 2014).

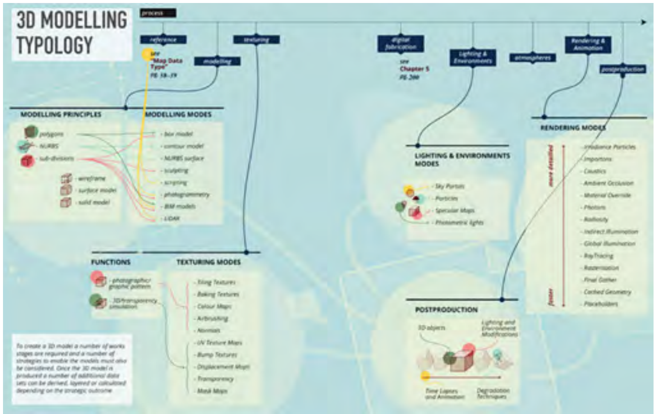

Fig. 7 Serena Pollastri, Imagination Lancaster, Lancaster University, 3D Modelling Typology, 2016 (source: Cureton, 2017, p.157).

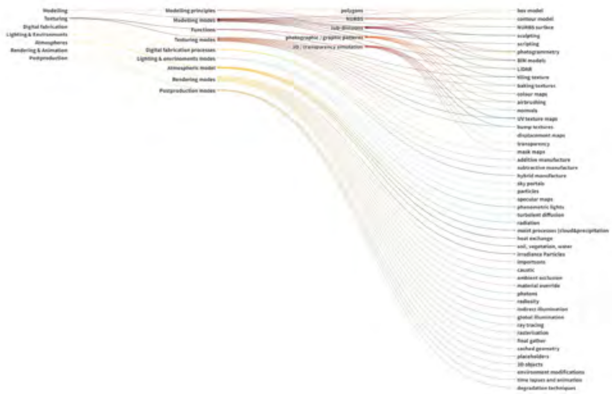

Fig. 8 Geometric digital modelling, parameters and production environments (source: Author's elaboration on Pollastri infographic, 2016).

The design of urban systems with cultural value is based on performance modelling to better understand the consequences of decisions. Three concepts are further clarified in their relation to urban systems: types of modelling, determination of metrics in performance modelling, and constraints on urban systems.

Among the interpretative models described above for the active protection and conservation of the built heritage, the following paragraph focuses mainly on the one more explicitly connected with information systems and models that integrate three-dimensional modelling with information components, GIS, BIM and distributed databases.

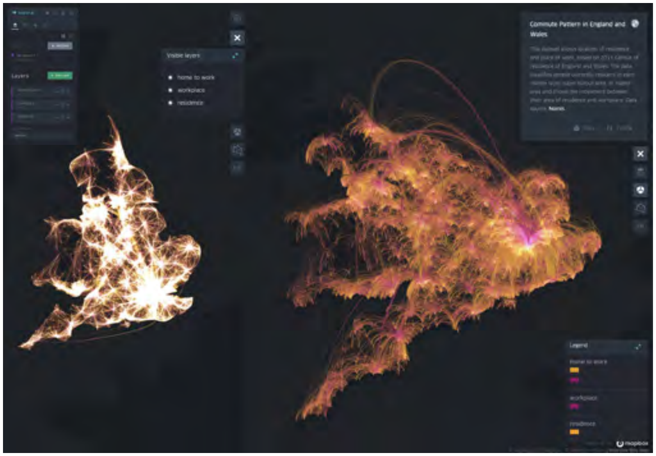

Fig. 9 Integrated GIS applications: Kepler.gl.

From geometric modelling to information systems and models

For a wider audience, the map is the agent that enables understanding of the place it is intended to protect and preserve. The data that various associated disciplines collect reflects scientific commitment and application in understanding environments. Such a super-scale datascape means that we need to think clearly about what is useful, selectable and applicable to natural and built heritage. Alongside this need, it can be argued that contemporary computing seeks fidelity to the territory it represents. As in Jorge Luis Borges' tale, there is a great popular cartographic drive to simulate the world from all disciplines in a high resolution map in real time (Cosgrove, 2012, pp. 1-2). Digital modelling combined with reality computing has come more to the fore, a digital simulation with near accuracy of a place that can also be immersive through the use of Augmented Reality (AR), Virtual Reality (VR) devices and many other technologies. Different modelling options can be employed and it is important to understand the processes to achieve

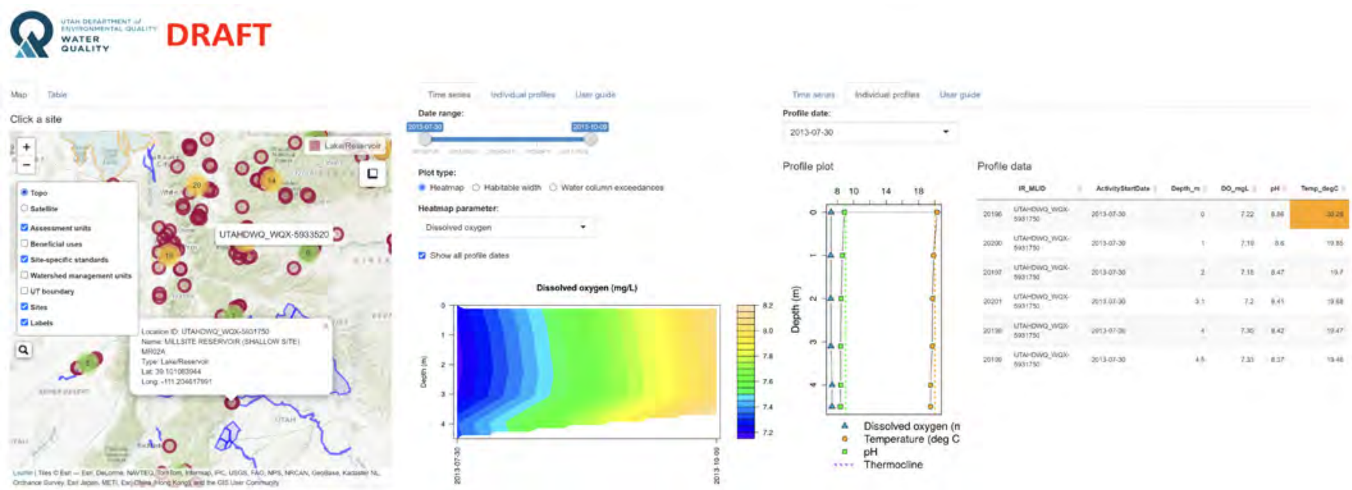

Fig. 10 Integrated GIS applications: Shiny.

the desired results. This obviously improves modelling efficiency and production time.
Quantitative and qualitative analyses of Cultural Heritage (CH) assets need to interconnect individual pieces of information, including a variety of multi-modal acquisitions, to form a holistic and composite view of the studied objects. The need for joint acquisition brings with it the need to define a protocol to store, structure and support the interoperability of multi-source data. Given this multivariate input, hierarchical data organisations have been defined; furthermore, supporting tools have been developed to manage the multimodal data: one for annotating metadata and another for recording geometric, alphanumeric and image information (Ioannides et al., 2018).
The problems of lack of design dimension and adaptability in traditional GIS models have been addressed in the emerging discourse of Geodesign, an initiative that has focused more on the project-oriented method of modelling (Batty, 2013b). Geodesign provides a potential to further elaborate a transformative model to the problem of urban systems, a data-driven process to integrate urban design, performance modelling and cultural and social context (Yang & Yamagata, 2019). To go beyond a linear method, Geodesign offers a collaborative platform for operational iterations that enable communities and stakeholders to manage decision-making processes. The four models in the previous paragraph listed possible models underlying the design of urban cultural systems, a method to model smart cities by integrating design and systems science. It is particularly important when human experiences and senses in cities are extended to multiple dimensions. Skills and knowledge in big data analysis, the tools of digital technologies such as GIS and BIM, and creative design thinking are equally important. The articulation of people, systems and design in collaborative processes offer a transformative approach to creating sustainable smart cities.
Various types of GIS-related technologies have emerged, new challenges to manage large amounts of data,

Fig. 11 Integrated GIS applications: Mapbox.

Fig. 12 Integrated GIS applications: ArcGIS Urban.

introduce interactive systems and integrate different technologies and formats. These include:
- Kepler.gl, which is developed by Uber Technologies, Inc., is a high-performance web-diagnostic application for the visual exploration of large-scale spatial data. By simply dragging and dropping any (large) data with geospatial information from the browser, they can be visualised;
- for the purpose of producing interactive GIS applications in an easy way, Shiny, which is developed by RStudio, Inc., is an opensource R package that makes it easy to build interactive and communicable web applications. Web

applications created in Shiny can be used to run R programs on the fly, and interactively using user input parameters from a browser. Subsequently, the results can be visualised in a dashboard or movie/database explorer;

- a further tool for free integration, Mapbox, which is developed by Mapbox, Inc., is an online location data platform for mobile and web applications (maize mapbox). Mapbox has been installed in many popular software or applications such as Facebook, Foursquare, Snapchat, etc. In addition, new bottom-up opensource data that have emerged (e.g. OpenStreetMap and Mapillary) and API tools can also link to Mapbox;
- finally, ArcGIS Urban, which is developed by Esri, Inc., is a web-based system to support urban planning and decision-making. This system can interactively visualise the natural and urban territory and changes in building and street parameters such as height and width in 3D.

Elements of the city's behaviour are captured by urban informatics - i.e., by obtaining real-time data from sensors and other probes of urban behaviour - which are then stored and analysed in information models of the city. This then allows individuals, organisations, neighbourhoods to evaluate their own behavioural change.

Conclusions

A brief discussion of common data types demonstrates the incredible development that has taken place over the last century. Data sets can be used in study or practice as a basis for collecting and describing elements of interest in the natural and built heritage. The use of such datasets raises a relevant question: what are the required results, what is to be discovered? Government departments may hold vast swathes of publicly accessible information; these repositories should be considered in the initial strategy for collecting mapping data, but may require reading internal manuals and processing guides for use in software packages and chosen hardware. While these large-scale institutional organisations host very substantial mapping data packages, there are also options for using these sets as base layers for mobile mapping applications. Processing environments allow for the mapping and emphasis of any feature associated with cultural heritage, the hosting and sharing of this information, and the production of mapping infographics. The development of graphical codes and representation languages for knowledge and understanding (sensation-perception-awareness and environmental well-being) is a current and vibrant area of research to hybridise the knowledge system within digital, dynamic, interactive and layered information systems and models.

Notes

1 Linked data, in computer science, is a way of publishing structured data that allows data to be linked together. The publication of linked data is based on open web technologies and standards such as HTTP, RDF (Resource Description Framework) and URIs. The purpose of this data structuring is to allow computers to directly read and interpret information on the web. The presence of links also allows data to be extracted from various sources through semantic queries. When linked data links open data, it is referred to as linked open data (LOD) (Bizer et al., 2009; McKenna, 2013).

2 DBpedia is a project started in 2007 with the aim of extracting structured information from Wikipedia and publishing it on the Web as Linked Open Data in RDF format. GeoNames (from the particle geo-, from ancient Greek γεω-, from γῆ, "earth", and from English names, "names") is a database of geographical data accessible through various web services, usable under the terms of a free content licence. Some online references may be geonames.org, pro.europeana.eu, linkedheritage.cab.unipd.it.

3 Refers to data related to geospatial information as geometric data. Further comprehensive definitions of spatial data can be found in Anselin (1988, pp. 16-17) and Waller & Gotway (2004, pp. 38-39).

4 For example: DSM (Digital Surface Model) refers to the earth's surface including the objects on it: buildings, trees and other artefacts. The DTM (Digital Terrain Model), on the other hand, represents the course of the land surface without the anthropic and vegetation elements.
The DTM can also be associated with the term bare earth. Finally, the DEM (Digital Elevation Model) is a generic statistical surface in which a finite number of pairs (X,Y) are assigned a corresponding value, parameter. In common use, the DEM refers to terrestrial topography but can also cover other surfaces.

5 See also Hill (2008), https://www.cityofsound.com/blog/2008/08/two-or-three-re.html.

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