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GIS and graph models for social, temporal and spatial digital analysis in heritage: The case-study of ancient Kingdom of Seville Late Gothic production[☆]

Patricia Ferreira-Lopes[a,*], Francisco Pinto-Puerto[b]

[a] *Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Av. Reina Mercedes, 41012 Seville, Spain*

[b] *Instituto Universitario de Arquitectura y Ciencias de la Construcción, HUM799, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Av. Reina Mercedes, 41012 Seville, Spain*

A R T I C L E I N F O

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A B S T R A C T

This article describes the development of a database management system (DBMS), to use as the basis for a dynamic spatial model or historical geographic information system (HGIS), and an abstract-relational model or dynamic graph model to allow historians and architects to visualise and analyse the complexity of built heritage on a territorial scale. Reutilisation, interoperability, standard terminology and usability were all taken into account in the development of the models. The database was developed within the framework of the International Late Gothic Network and involved an interdisciplinary team of architects, historians, geographers and computer scientists to ensure maximum adaptability of the methodology to other case studies. The result is a DBMS, a GIS model and a graph model, which we hope will provide useful tools for understanding, analysing and disseminating heritage.

1. Introduction

The aim of this project is to develop a methodology for combining a historical geographic information system (HGIS) and a graph model with existing tools to identify, record, research and analyse architectural heritage, transcending the building dimension to focus instead on the territorial context. This case study is based on the phenomenon of the reconstruction of Andalusia through the building programs conducted between the Reconquest and the formation of the Kingdom of Seville, specifically during the 15th and 16th centuries. Known as the Late Gothic, this period represents the transition towards the Early Modern Age. The main reason behind the decision not to customize a new tool is that we wanted to exploit the potential of technologies already used in Spanish research projects and institutions and formulate a process that could be easily adopted by other researchers working in the same area and with the same tools.

In the publication “Los últimos arquitectos del Gótico”, Alonso Ruiz (2010) notes that one of the main problems encountered in the field of historical and architectural research is the absence of a global vision mapping historical phenomena with clear spatiotemporal coordinates. Although there has been significant progress in this area since then, it consists of individual projects on specific aspects rather than shedding light on the overall network of buildings which Gestoso y Pérez (1899) addressed in the 19th century and which more recently has drawn the attention of a number of researchers (Alonso Ruiz and Jiménez Martin, 2009; Alonso Ruiz, 2011; Serra Desfilis, 2016; Alonso Ruiz and Villaseñor Sebastián, 2014; Alonso Ruiz and Rodríguez Estévez, 2016). In earlier projects we were able to model the local transportation network represented by the routes that permitted the provision of materials and the mobility of agents. We also researched the spatio-temporal identification of the agents involved in certain building activities (professionals, patrons, etc.) using GIS, and we used a graph

Abbreviations: DBMS, Database Management System; GIS, Geographic Information System; HGIS, Historical Geographic Information System; SDI, Spatial Data Infrastructure; BIM, Building Information Modelling; HBIM, Historic Building Information Modelling; IAPH, Instituto Andaluz de Patrimonio Histórico (Andalusian Institute of Historical Heritage); IPCE, Instituto del Patrimonio Cultural de España (Spanish Institute of Cultural Heritage); MECD, Ministerio de Educación Cultura y Deporte (Ministry of Education, Culture and Sport of the Government of Spain); OASIS, Open Archival Information System; ISO, International Organisation for Standardization

☆ This is a collaborative research project between the University of Seville, University of Cantabria and University of Western Ontario. Development of the database model commenced in 2014. The project is led by the research group Heritage Knowledge Strategies (HUM799) of the University of Seville and conducted in collaboration with the Andalusian Institute of Historical Heritage (IAPH) and the International Late Gothic Network led by the University of Cantabria

* Corresponding author.
E-mail address: pwanderley@us.es (P. Ferreira-Lopes).

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model to examine the relationships in the network of professionals who worked on Seville Cathedral (Ferreira-Lopes et al., 2016). These models used different databases, namely an SDI and a graph database. However, the models developed did not provide an overall vision of the phenomenon and lacked both uniformity and an appropriate scale in terms of activities, therefore offering a highly fragmentary picture of the reality. By contrast, the option of building a single source of data for both models expanded the scope of the study while providing us with a wider range of analysis and allowing us to use the two models to complement each other. Our main objective is therefore to demonstrate that by creating a single DBMS for use with a GIS and graph model we can provide a new investigative perspective and unite hitherto isolated efforts in researching the phenomenon of the Late Gothic in the Iberian Peninsula.

Since the base model represents both entities and relationships with different levels of details and characteristics depending on the data used, the following criteria were adopted: 1) The relational database created had to permit editing, expansion and restructuring without needing to reproduce the whole database every time. This meant that the design had to be flexible and capable of accommodating future structural changes; 2) It had to be possible to associate information obtained from heritage management institutions with the database. This meant standardising the terminology adopted and using the codes already defined by those institutions; 3) The models had to be able to export data to more interoperable formats so that the information could be used and reused in other platforms and tools; 4) The tools used to create the model had to be user-friendly and have quality instruction documentation/tutorials to increase their workability potential. This meant choosing tools that had long been used in the field and did not require an advanced knowledge of programming so that they could be easily applied by researchers from different disciplines. Specifically, this approach meant that the entire model construction process would be cyclical to ensure its continuity and use, since the discoveries and acquisitions of new data would form part of an open, dynamic process.

The case study undertaken offers a magnificent opportunity to test an innovative perspective in the study of building production in a specific territory through spatiotemporal representation and analysis, allowing us to observe new connections between the spatial dimension and the development of human activities in a historical process (Gregory, 2003; Knowles and Hillier, 2008). We believed that the ideal methodology for this purpose was to create a database that related two key questions: i) A spatial database showing the territorial structure of the ancient Kingdom of Seville and the Iberian Peninsula, i.e. a historical SDI with different geometric features (points, lines and polygons) distributed in thematic groups—political/administrative, infrastructure, production/materials, buildings, etc.—in turn distributed in sub-groups (Table 1). This did not mean that the elements represented would only be objects of analysis but rather would be tools of analysis; and ii) Several elements in the spatial database needed to be associated with a standard database combining the activities of the agents, the relationships and entities, and the place of action, with a special emphasis on the role of the agent. Both of these questions would integrate spatial and temporal data in the actual information system. The database was developed by a multi-disciplinary team of architects, historians, geographers and computer scientists (University of Seville, University of Cantabria and University of Western Ontario). The project differs from previous studies in its focus; to ensure its maintenance and open access, the DBMS had to allow reuse by Spanish institutions. The study therefore aims to demonstrate new possibilities and opportunities for sharing knowledge between universities, researchers and institutions. We have witnessed how this approach offers a solution for enriching knowledge and for maximising the efforts of different research teams. Moreover, since the formats generated are interoperable, it is much easier to maintain and disseminate heritage information.

In general terms, the project has three main objectives:

- To establish a procedure for the social and spatiotemporal analysis of a historical/architectural context;
- To develop a DBMS schema for heritage knowledge by identifying, analysing and verifying patterns; and
- To obtain a comprehensive vision of the multiple entities and relationships that shaped architectural production in Spain during the Late Gothic period.

At the instrumental level, the specific objectives are:

- To identify the main limitations of the tools used, especially when implemented in a large-scale project with heterogeneous data.
- To develop a database, as standardised as possible, related to architectural production and the political/administrative, social, historical and cultural context.
- To create a digital model that can be easily updated, enlarged and reused.
- To propose analyses and visualisations that can offer new study and development perspectives for future researchers.
- To ensure access to the data by including them in institutional databases (IAPH).

2. Application of GIS and a graph database in heritage: previous studies

Recent advances have made it possible to use digital information technologies in a variety of disciplines and fields. They have proved to be an especially useful tool with enormous potential in the study of the history of architecture and archaeology. The management of architectural heritage differs from other fields because of the heterogeneity of the information handled. There are four aspects that are particularly difficult to manage: the multi-layer nature of the data, the third and even fourth dimension, the diverse formats of sources, data and information, and the generation of documentation during the heritage management cycle. In spite of these difficulties, the organisation and systematisation of the information gathered has proved to be highly beneficial for its preservation, management and sustainability. Digital information technologies were first used in the heritage field for recording and documenting purposes, and graphical representation was the end product achieved. However, in the last two decades other technologies and applications used to analyse a vast heterogeneous mass of data, such as GIS and the Network Graph Database, have shed light on new aspects, factors and questions. Specifically, we can point to four applications of GIS in the field of cultural heritage:

- First, the use of GIS to support the creation of an inventory of heritage. In this case, the SDI is created by selecting and processing data obtained from different documentary sources as well as the heritage asset itself and the associated environment (Guillot and Leroy, 1995; Willems et al., 1997). The data can be processed manually, although this is more time consuming, or alternatively acquired by text mining software, which is less time consuming. The key benefit of including data in the construction of an SDI is the ease of editing, expanding, updating and storing heterogeneous data, making it possible to add dates, authors of the work, techniques, dimensions, images, composition, materials, etc. of the elements represented. In most cases, institutions already have these records in a non-digital format but they need to be digitalised, processed, design and restructured for the implementation GIS (Fernández Cacho, 2002; Galliani and Sánchez Díaz, 1998). An inventory created with GIS is also a valuable tool for the researchers of institutions and universities, and the adoption of an interoperable format is therefore an important factor to bear in mind for reuse and maintenance purposes. Once an inventory has been created with GIS, contents, maps and thematic visualisations can be created for a wider audience, therefore encouraging greater dissemination.

Table 1
Summary of the historical SDI structure.

Late Gothic HSDI				
Group	Sub-group	Layer	Entitiy type	scale
RTS_01_Administrative	Kingdom	ad01_kingdom_1266	polygon	Peninsula
		ad02_kingdom_1482	polygon	Peninsula
	Diocese	ad03_dioceses_1410	polygon	Peninsula
		ad04_dioceses_1486	polygon	Peninsula
		ad05_dioceses_1550	polygon	Peninsula
	City	ad06_capitalsv_1546	point	Peninsula
RTS_02_Infrastructure	Path	if01_roman roads	polyline	Peninsula
		if02_villuga roads	polyline	Peninsula
		if03_rivers	polyline	AKSeville
		if04_o_sources	polyline	AKSeville
RTS_03_Production	Quarry	pd01_quarry	point	AKSeville
	Lime	pd02_lime	point	AKSeville
	Wood	pd03_wood	point	AKSeville
RTS_04_Buildings	Religious	ed01_religious	point	Peninsula
	Civic and Religius	ed02_civic and religious	point	Peninsula
	Civic	ed03_civic	point	Peninsula
	Military	ed04_military	point	Peninsula
	Military and Civic	ed05_military and civic	point	Peninsula

– The second use of GIS is to gain a greater knowledge and understanding of heritage. These assets cannot be understood as isolated objects, only as part of a constantly changing physical and social context (Box, 1999). In this case, the technology is applied in research projects (mainly multi-disciplinary) that aim to shed light on certain questions, discover patterns of spatial, physical and temporal characteristics, and evaluate the results obtained to determine future actions to manage heritage assets. Additionally, 2D GIS can be used to calculate dimensions, undertake topological studies and analyse spaces and their attributes (Zant et al., 2013; Deng et al., 2009; Deidda et al., 2015). These may be considered to be the initial phase of a project that aims to create a 3D SDI. The level of detail of the elements included in the SDI will depend on the project objectives, although the main factors are execution time and cost. A related application of GIS is the study of historical, economic and socio-cultural contexts. As important aids in understanding the heritage landscape, these studies usually address topics from the spatiotemporal perspective, as shown by Gregory and Ell (2007), Greengrass and Hughes (2008), Fortin and Bonnell (2014) and Crespo Solana (2014).
– Third, the use of GIS in the development of control and predictions for the conservation of known heritage and also for identifying the potential location of archaeological sites. These advanced spatial analyses are mainly conducted using sensors located at the site itself, in movable and non-movable assets, and in the surrounding environment. Their purpose is to capture data and monitor values such as dampness, movement, ventilation, light, energy, probability of flooding, soil characteristics, etc. to assess possible risks. This third application of GIS is usually related to 3D models, either created in the actual GIS system (Scianna and La Guardia, 2017) or in conjunction with other models, as in the case of GIS combined with BIM (He et al., 2015; Dore and Murphy, 2012).
– The fourth use of GIS is to create strategic plans for natural and/or cultural heritage management (Pinto Puerto et al., 2011). GIS may be used as a tool to analyse existing data which, superimposed on the layers of heritage assets, can identify, calculate and assess limits and degrees of protection. Besides, when combined with local and regional land use plans, GIS is useful for managing building permits and changes in land and building use. Strategic plans may even include studies on the impact of new projects or interventions, such as the construction of more infrastructure or changes to and the expansion of public transportation

In the field of cultural heritage, these different types of GIS applications may be, and usually are, used together or as part of a chain. For example, an inventory SDI may be used as input for researchers, which when combined with new associated data can generate new discoveries and knowledge. Alternatively, the same inventory SDI may serve as input for the creation of future strategic plans. Equally, risk prediction analyses may be useful for drawing up the actual strategic plans, or these may benefit from the research undertaken (La Spina et al., 2012).

In the case of graph models, these are used in the second line of GIS application, in the field of research as a method for exploring, discovering, identifying, visualising and questioning interaction patterns and processes in past societies. They are based on a mathematical theory, namely graph theory. A graph is a set of nodes (vertices) joined by a set of edges, where the edges represent the interactions between them (Robinson et al., 2013; Brughmans, 2010). A network is a graph with attributes/characteristics associated with its nodes and edges. These attributes/characteristics are used to classify the nodes and edges into categories so that patterns may be explored. Although we now have modern technology to apply this theory, graph models have already been used to understand complex relationships in cultures of the past (Pitts, 1965). The great benefit of their use in cultural heritage is the capacity to articulate and analyse different scales and their potentiality for integrating actors and elements. The limitation of a graph model is the complexity of implementing it, because the definition and construction of the nodes and edges in a historical network are not so easy to resolve (Knappett, 2013).

Although graphs have been used in many different disciplines, including art (e.g. de la Rosa and Suarez, 2015), literature (e.g. de la Rosa and Suarez, 2016) and biology (e.g. Bascompte, 2009), it is the social sciences, using the theory of social network analysis (SNA), that have had the greatest impact on their application in the heritage field, mainly in historiographic studies and archaeology. In relation to heritage, network analysis has been applied to studies on the movement of people and objects (Jackson, 2017; Brughmans and Poblome, 2012), transport and trade (Polonia et al., 2014), descriptions and symbologies (Suarez et al., 2013), political power (Scholnick et al., 2013), and the transmission of ideas/knowledge (Graham, 2006). Although approaches, tools and objectives may vary, there are two fundamental points common to all applications: the relevance of relationships over entities, advancing towards the non-linear study of heritage to permit more complex, polyhedral perspectives; and the use of graphs not only to discover patterns and explore properties but as tools in themselves for posing new questions.

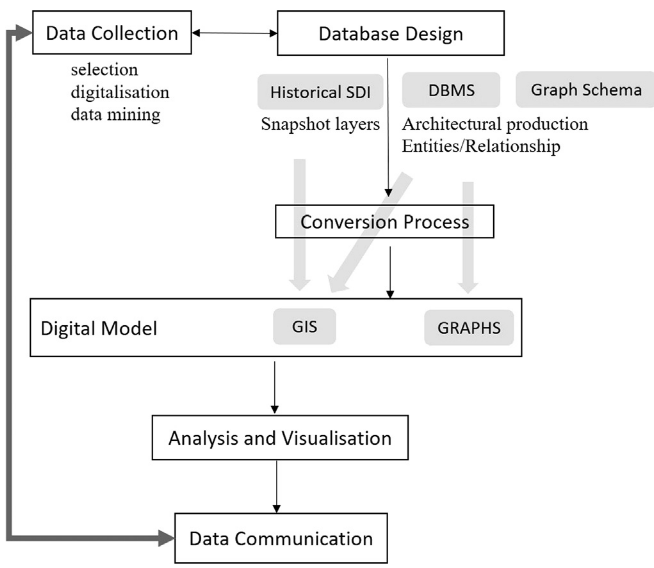

Fig. 1. Cyclical process, phases of the modelling process.

3. Case study and methods

3.1. Late Gothic architecture in the ancient Kingdom of Seville

Two key factors need to be considered in understanding how the ancient Kingdom of Seville was transformed after the Reconquest into a territory with intense architectural production: i) how the architectural factory operated as a catalyst for changing and revitalising the economy and society; and ii) how the territory was gradually forged to accommodate the exchange and consolidation of these new roles through the construction of key routes and roads. These two factors not only enabled building production in the Iberian Peninsula to benefit from a rich exchange of knowledge and techniques with other territories like France, Belgium, Germany and Portugal, but allowed the social and physical space we have defined to act as a hinge with America. Villaseñor Sebastián (2010) describes that moment in time as the sum of a vast density of economic, social, cultural and political relationships that developed in a period that spanned little more than one century and provided the framework in which new ways of building emerged and spread, ultimately leading to the introduction of humanist trends in the Peninsula. In this open system, the influences of other nations sustained each other and were simultaneously governed by physical and natural factors of territory, something which clearly suggests a complex scenario.

In this context, a geographically integrated historical approach and the visualisation of data and their relationships afford new possibilities for analysing and challenging the traditional historical narrative. This historical narrative offers no concepts and hardly any standard terminology or methods to facilitate the analysis of complex historical systems (Owens, 2007). In this project we have adopted three basic principles for analysing building production: a) Historical facts must be interpreted in light of their connection with the places where they occurred and based on political, physical, cultural and sociological factors. b) Historical systems are complex, rhizomatic, open and dynamic, therefore demanding the use of technology to analyse their changing structure. c) Agents and places are connected by the activities undertaken at the local and regional levels, and even at the European and transcontinental levels. These agents - building professionals, artists, merchants, patrons, aristocracy and the church - were the main actors in building production. The construction of major buildings like Seville Cathedral would not have been possible without the development of quarrying and the fluvial transport system that supplied stone from quarries more than a hundred kilometres away, in the San Cristóbal mountains, or without the exchange of different types of professionals, each with their own techniques and building knowledge, and merchants who were already familiar with the Gothic buildings of cities like Cologne, Bruges, London, Nantes and Rouen (Jiménez Martin, 2016). Much of the research undertaken on building activity in Spain during the 15th and 16th centuries make reference to how the network of agents operated through organised groups of professionals and patrons, as well as the church, the power behind the main military and colonial enterprises. The prestige of the masters who worked on religious buildings was often transferred to civic architectural production, from buildings to infrastructures like bridges, industrial facilities and different types of machinery (Rodríguez Estévez, 1998; Gestoso y Pérez, 1899).

3.2. Modelling process

The first step in creating the database model was to understand GIS technology and graph theory so as to be able to evaluate their limitations and design the spatial database correctly. This process was divided into six phases: data collection, database design, data processing, creation of the digital model in GIS and Graphs, analysis and visualisation, and communication and association with institutional databases (Fig. 1).

Several programs were used during the different phases, including Google Engine®, Microsoft Excel®, Microsoft Access®, ArcGIS® and Gephi®. ArcGIS® and Gephi® were the crucial tools. ArcGIS® was the main software package used to create the historical SDI because this can digitalise and vectorise data from traditional historical sources like maps and plans and link alphanumeric values to geometric entities, and it also comprises a series of tools that we used in the spatiotemporal analysis phase. Meanwhile, Gephi®, the database management system based on graphs (URL1) was the main tool used to create the graph model associated with the database. We used Microsoft Access® software for the DBMS since it can be linked with ArcGIS® and, by

Table 2
Software, functions, formats and systems.

Software	Application	Data Input formats	Visualisation and Representation formats, output formats	System specifications	Licence
My Maps	Tool for digitalising cartography, georeferencing - points and lines	. CVS,. TSV,. KML,. KMZ,. GPX,. XLSX	bitmap images (.jpg,.pdf),. KMZ,. KML	Mac OS; Windows; Chrome OS; Linux	Open Version, online (Google My Maps)
Access	Tool for gathered data, design DBMS	. CVS,. XLS	. CVS,. XLS	Mac OS; Windows; Chrome OS; Linux	Paid licence (Microsoft)
ArcGIS	Tool for digitalising, integrating alphanumerical and spatial data, create historical SDI, analysis and visualisation for spatio-temporal data	. XLS,. SPH,. KLM,. KMZ, OLE DB	. SPH,. JPG,. PDF,. XLS,. KMZ,. KML	Windows	Paid licence (ESRI)
Gephi	Network analysis and visualisation software that uses Graph representation.	. CVS, GEXF	. CVS,,DL,. GBF, GEXF,. GML,. GRAPHML,. NET,. VNA,. PDF,. PNG, SVG.XLS	Mac OS; Windows; Chrome OS; Linux	Open Source (GEPHI)

exporting files in CVS format, with Gephi® as well (Table 2). The other programs were used as initial tools for data mining and in the final phase for converting formats to permit greater interoperability with the general public and institutions.

3.2.1. Data collection

This phase consisted in selecting, digitalising and processing data and converting analogue formats to digital formats. Most of the data, graphs and alphanumeric values used were found in old documentary sources such as maps, plans and texts or in recent publications, mainly in print format and with a prevailing narrative style.

However, some of the data on architectural production were found in a digital database (Archibase) with an information format resembling a biographical dictionary of the main authors of Late Gothic heritage during the period 1440–1575. Created between 2007 and 2014 by the International Late Gothic Network (researches from University of Seville, University of Cantabria, University of Palermo and University of Lisbon), the Archibase database provided a consultation tool, using professionals' names to filter the data, but the information was in narrative format without any hyperlinks or mapped relationships between actors and buildings.

3.2.2. Database design

Once we had collected a vast mass of heterogeneous and supposedly interrelated data, we proceeded to design the database, bearing in mind its future export to GIS and graph models. Our aim was to organise and structure the data so that they would reflect the particular features of the modelled system. We therefore conducted a preliminary phase consisting in conceptualising, abstracting and simplifying the case study. To work with complex systems like the ones used in this study, such as social networks and historical GIS, the model also had to include the historical SDI and the entities and their relationships.

We therefore created a snapshot model or historical SDI associating the temporal information to thematic layers, as demonstrated in the projects Great Britain HGIS and Parish Description Project (URL2; URL3). This enabled us to analyse and map the historical information with a fixed temporal value for the spatial entities of a specific layer (Dioceses 1410, Dioceses 1486, Dioceses 1550, Roads 1546, Roman Roads, Kingdoms 1482, etc.) (Fig. 2). However, snapshots often reflect the temporal reality incorrectly. We know that the spatial entities of the same layer sometimes correspond to different dates. For example, when processing and digitalising maps such as "Repertorio de todos los caminos de España en el año de gracia de 1543" by Juan Villuga, we noted that the author probably started recording the routes before 1543, which is not reflected in the temporal layer. However, since we knew that the main temporal movements that we wanted to analyse were related to architectural construction, we were able to associate the time factor to any of the spatial entities, as explained below.

A DBMS schema was created to integrate the entities and relationships of the data gathered on the activities undertaken by the different agents. The design of the database, i.e. the way in which the data are organised, was crucial for implementing a dynamic model in GIS and Graphs. The DBMS comprises entities and relationships that are represented by tables of entities (main entity set), tables of classified values (secondary entity set) and relational objects (Fig. 3).

- The entity tables represent a group of entities (*E*) belonging to the same type (e.g. E_1 professionals, E_2 patrons, E_3 buildings, E_4 quarries, E_5 architectural/building products) with specific attributes for each entity (e.g. E1 professionals contains biographical data) and non-key attributes for each entity (name, source, neighbourhood, date of birth, date of death, activity start date, activity end date). There are no two entities with the same name or key attribute.
- The tables of classified values (*Ee*) represent a standard list of classified attributes for the relationships: a) Ee_1 professional category (master builder, surveyor, stonemason, sculptor, etc.). This classification was established in line with the documents and studies already undertaken (Rodríguez Estévez, 1996; Rodríguez Estévez, 1998; Gestoso y Pérez, 1899); b) Ee_2 list of products associated with the architecture derived from the action of the agents who may have been involved in the creation, preparation and evaluation (document, design, reports) or in the production or construction (building element, functional space of the building, site management, workshop/factory tasks). This list of products was derived from the terms in the Thesauraus of Cultural Assets published by the Spanish Ministry of Education, Culture and Sport (URL4); c) Ee_3 list of researchers who have contributed data. This list provided us with the metadata for the information entered in the database. The tables of lists were included in the database to reduce data input errors because the user chooses the classified alphanumeric value from a predefined list. It also speeds up the input process; d) Ee_4 list of bibliographic/documentary references from where the data were obtained.
- The relational objects (*RS*) that represent the relationships between entities are shown in our database as "activities" and "kinship". In the "Activities" table, each entity represents the action undertaken by the agents and associates the data referring to professionals, patrons, action, professional category, buildings, quarries, action dates (start-end), bibliographic reference and user who entered the entity. For example:

ACT_PROF_RS (prof, mec, parq_ed, catprof, fi, ff, amet, refb)

Where ACT_PROF_RS refers to the "activity" relationship within the set of relationships associated with a professional, who is defined by his name, the patron who sponsored the activity, the architectural product and its construction, the professional category, the start date, the end date, the author/user and the bibliographic reference where it is documented. The first and second values, prof and mec, are linked respectively to the attributes of names in the entity tables E_1 professionals and E_2 patrons. The third value is linked to the entity E_5 architectural product, which in turn is linked to an entity in table E_3 building (E_5 is part of E_3 and therefore has the same relationship). The fourth value is linked to a value in the secondary entity set Ee_1 professional category. The seventh value is linked to Ee_3, which represents the name of the researcher who entered the relationship. And the last value is linked to Ee_4 and refers to the bibliographic/documentary reference where the activity data are recorded. As shown, all the values except for the activity start and end dates are linked to entity sets. Accordingly, the same type of activity may have been performed by more than one agent, which was very common in our object of study because of the lengthy execution times, habitual interruptions of the works and constant consultations with experts. For example, the masters Juan Gil de Hontañón, Alonso Rodríguez, Juan de Ruesga, Martin de Bruselas and Enrique Egas all produced reports on the collapse of the dome at Seville Cathedral; in 1528 master Diego de Riaño, the stonemasons Hernando de Morgua and Martin de Alvisto and the surveyor Francisco Vuelta all worked on the construction of the vault over the church of San Miguel in Morón de la Frontera, sponsored by the Count of Ureña, Juan Téllez de Girón. The set of relationships grouped under "Kinship" defines the connections between the agents and their direct line of descent. We created this relationship because during the 15th and 16th centuries it was fairly common for the members of the same family to pass on their trade, e.g. from father to son, from father-in-law to son-in-law or from one brother to another, and access to the different professional categories was restricted to specific social strata. All of these professional transfers and categories are reflected to a certain extent in the architectural language produced and the building techniques applied.

The omission of particular data in the database is contemplated. We acknowledge that working with data from the 15th and 16th centuries is extremely challenging and that the database should therefore allow users to omit certain information, especially in the case of dates.

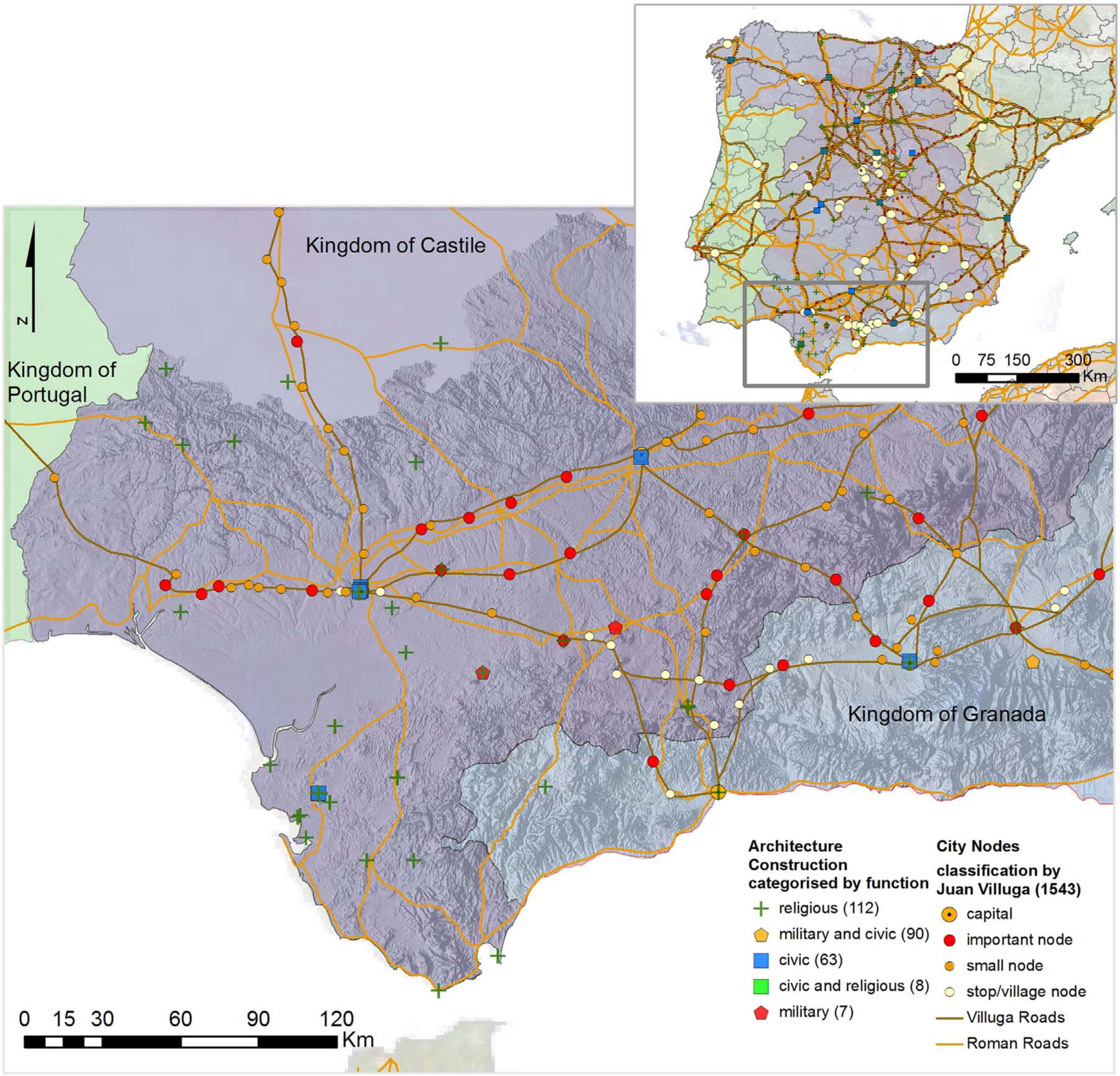

Fig. 2. Historical SDI. It shows part of the road infrastructure during the 15th and 16th centuries, including the network of royal roads according to Juan Villuga (1543) and the Roman roads. It also shows the layer representing the buildings that were either built or altered during the Late Gothic period. They are classified according to their function.

Naturally, it should also have the flexibility to allow for new data to be added since the expansion of the database is an open and on-going process.

3.2.3. Data conversion process

Once the data had been systematised in the database designed, they had to be converted for inclusion in the ArcGIS® software, which was carried out via an OLE DB connection with Access, and they also had to be converted to CVS format for inclusion in Gephi® (Fig. 4).

3.2.4. Digital model

To conduct the analyses, we considered two different digital models: a spatiotemporal model capable of organising the information in layers and elements with attributes, geo-referenced to a specific date and place, a geographically-integrated historical GIS model; and a graph model based on an abstract model in which the main elements are the relationships, a relational-integrated historical model. As Owens has pointed out, models aim to offer a representation/visualisation of a reality (Owens, 2007), in our case by mapping and analysing relationships, flows and data regarding the phenomenon of architectural production in the Late Gothic period. The structure and representation of the data in the two models are different. The representation in GIS is more tangible and physical, enabling us to work with distances and the geometry of the entities, whereas in the graph model the representation is conceptual and occurs between nodes and lines and does not include the geometry of the object's form, which means that the distance is measured by whole numbers.

3.2.5. Analysis and visualisation

Having created the GIS and graph models, we were able to analyse and visualise the data. In certain analyses where we only wanted view part of the information, we filtered the data. The tools we used enabled us to filter the information according to specific criteria. For example, the analyses conducted in the GIS model revealed the location of the agents and their activities, the number of buildings and events per municipal district (Fig. 5), the optimal routes, the agents' scope of action and the overlaps, the coincidence of different agents at the same building at the same time, the density and distribution of related activities according to the building type/function or the activity category, etc. The analysis of the temporal density of building activities reveals an increase from 1500 onwards and a greater concentration in the south of the Iberian Peninsula, in modern-day Cádiz province (Fig. 6). This could be explained by the influx of capital in the south of the peninsula after the discovery of America and the conquest of the

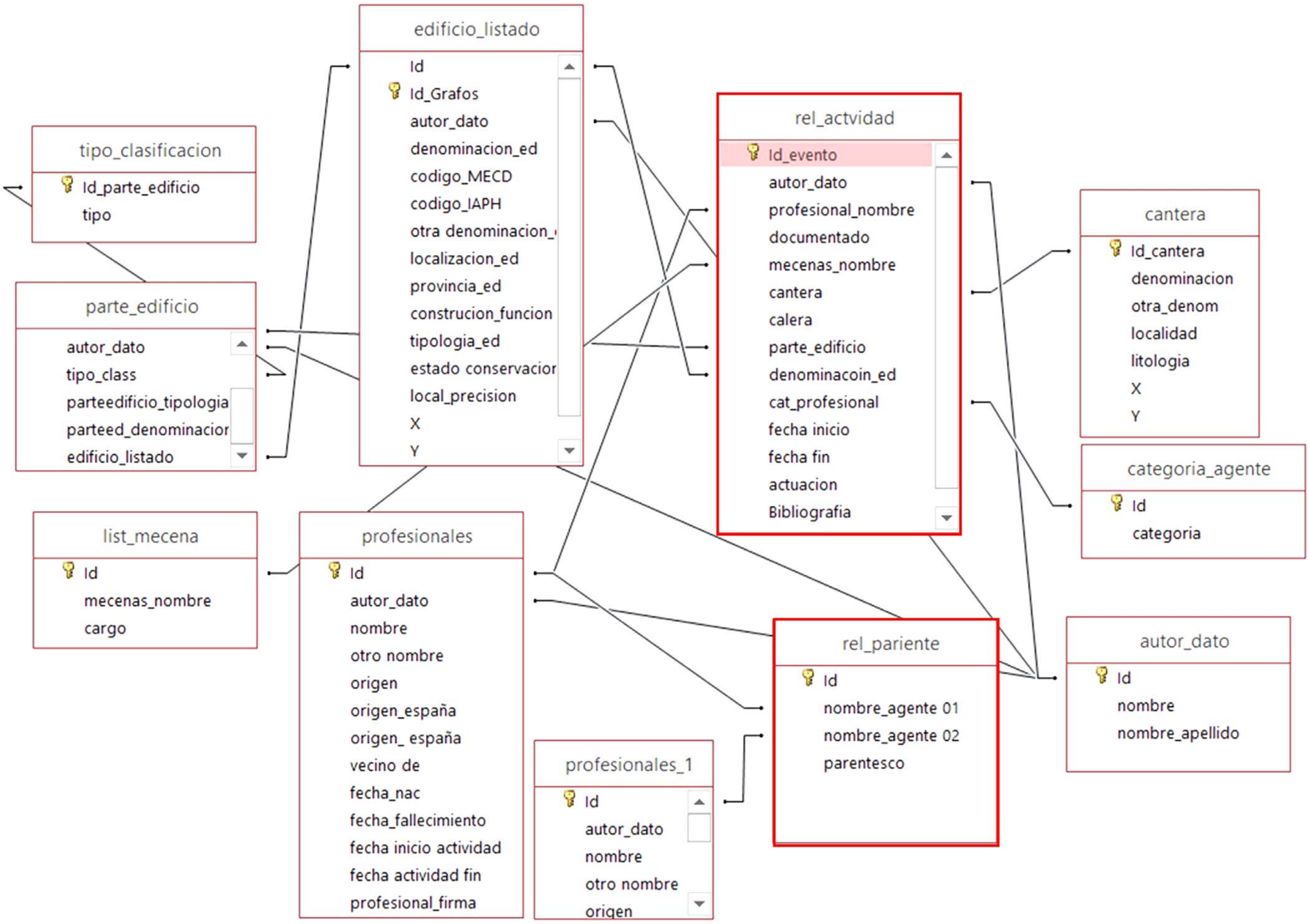

Fig. 3. Structure of DBMS relationships and definition of entities in the database.

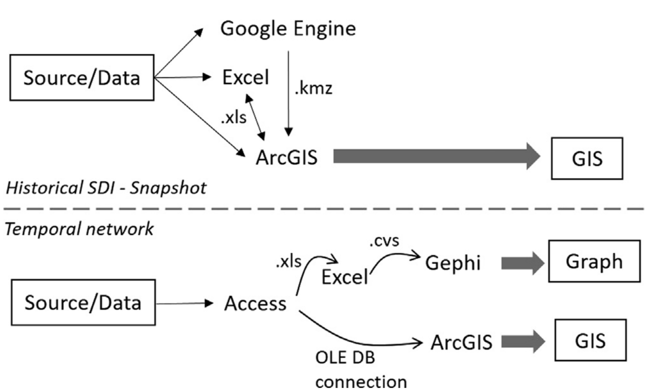

Fig. 4. Conversion of file format and software used during the modelling process.

Kingdom of Granada by Castile, which stabilised territories that were formerly border areas. In another analysis, we verified the main professionals in the graph model and were then able to identify the activities they carried out by filtering different layers, each representing a professional, and using those points we inserted an elliptical polygon based on standard axes of point distributions in ArcMap® (Wang et al., 2015). Adding the layers enabled us to visualise the differences and similarities between the agents. For example, we were able to confirm that although some of the professionals carried out a considerable number of activities, many of these were concentrated in a more limited region, as in the case of Diego de Riaño and Alonso Rodríguez. However, other professionals like Juan Gil de Hontañón, Simón de Colonia, Enrique Egas and Juan de Álava were active in a wider area (Fig. 7). The GIS model also enabled us to create temporal track lines for each agent, e.g. for the professional Diego de Riaño, and visualise the timeline of their activities on the map (Fig. 8).

We can also calculate the least costly routes and formulate a hypothesis on the most likely roads used according to a defined set of variables. We tested this in our study by considering the gradient generated from the 3D digital model of the land. For example, the analysis of Diego de Riaño's activities reveals that between 1528 and 1534 he was managing the works on Seville Cathedral while also carrying out activities at the church of San Miguel in Morón. Using the GIS model, we generated hypotheses about the possible road he used. In our first hypothesis, we calculated the least costly route between the cathedral in Seville and the church in Moron as a distance of approximately 60 km. Since this would have been a two-day trip, covering 30 km per day (Uriol Salcedo, 1990), Riaño would have had to stop en route. However, if we look closely at his activities, the proximity of dates suggests that he may have also been working on the parish church of Santiago El Mayor in Utrera (Ruiz de las Casas, 1527), which is practically half-way between Seville and Morón. This pointed our calculation of the least costly route in another direction, from the cathedral in Seville to Utrera, and from Utrera to San Miguel (Fig. 9).

The graph model (Fig. 10) enabled us to analyse several aspects: the potential importance of professionals and patrons (Fig. 11); the influence of agents at the buildings where they were active; the works and professionals that were sponsored by a specific patron or group of patrons, and their influence on certain building types and forms; and the agents that were active at the same building, either performing the same activity or different activities at the same building during the same period of time (Fig. 12).

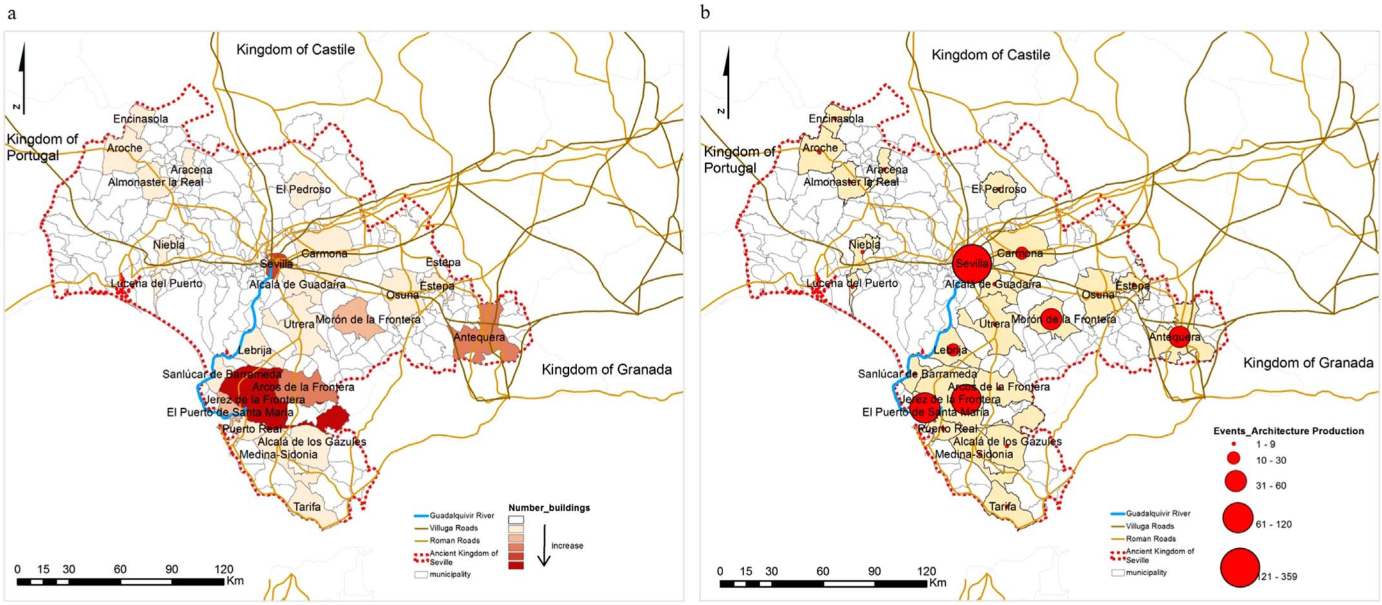

Fig. 5. Visualisation in the GIS model of building production: (a) number of buildings per municipal district, and (b) events/activities per municipal district. The red circle is proportionate to the number of events (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

These analyses offer new perspectives for understanding the phenomenon of the Late Gothic and re-evaluating its dynamism in light of the interaction between agents. Nevertheless, the results of the analyses and visualisations are determined by the data we have gathered. The addition of new data may well alter these results.

3.2.6. Communication and association with institutional databases

Apart from the problem of scattered information that we encountered in the research and heritage documentation, which we tried to resolve by creating the DBMS, we also had to consider the maintenance and dissemination of all the data collected and systematised, and the conservation of the heritage information. This is undoubtedly a great

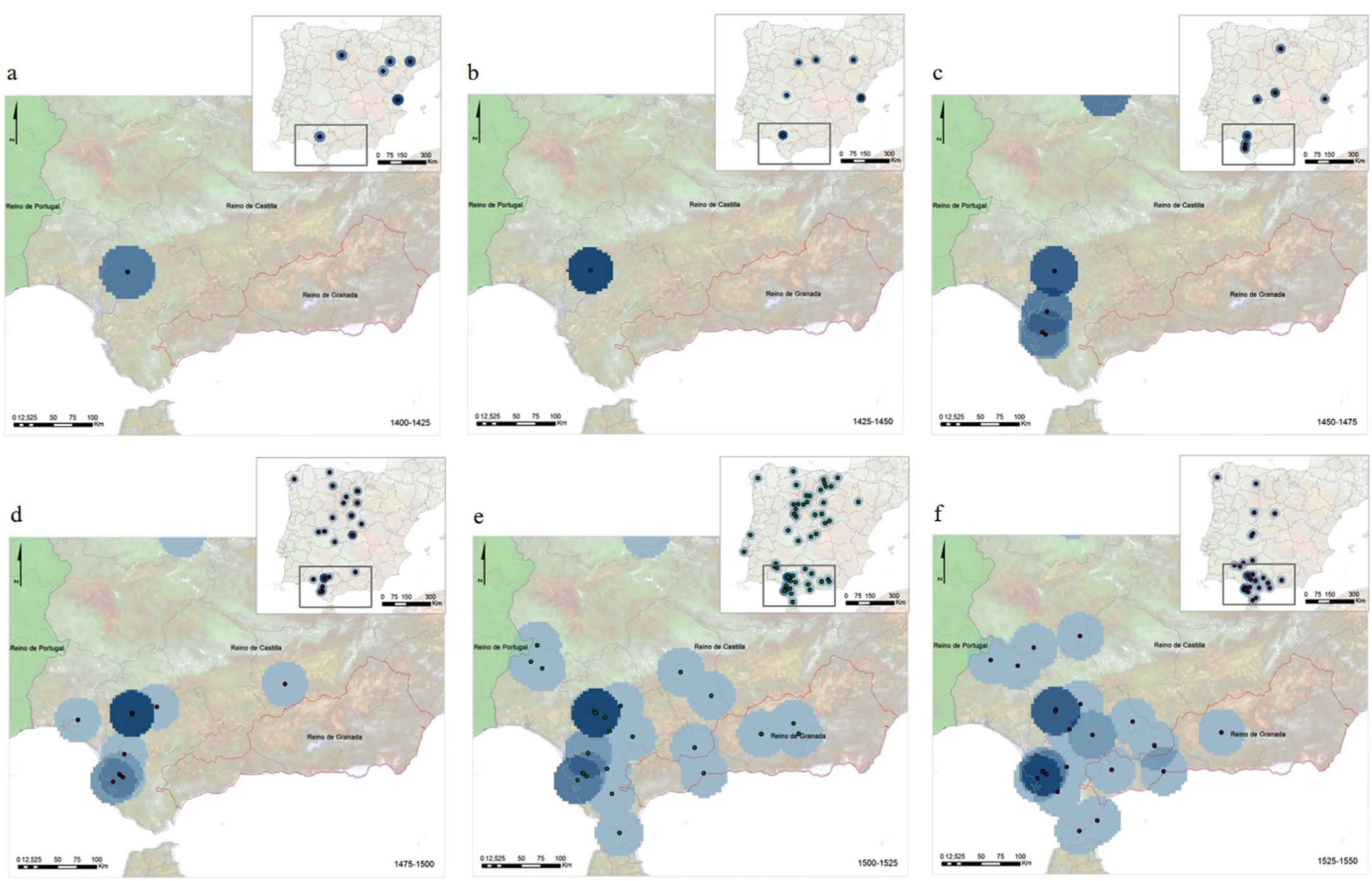

Fig. 6. Timeline of activities related to architectural production from 1400 to 1550. In the territorial scale represented in this visualisation, the points of action often overlap because of the proximity of the buildings. However, the density analysis reveals the "weight" of activities. As shown, there was a greater intensity of activities in (e) and (f), between 1500 and 1550.

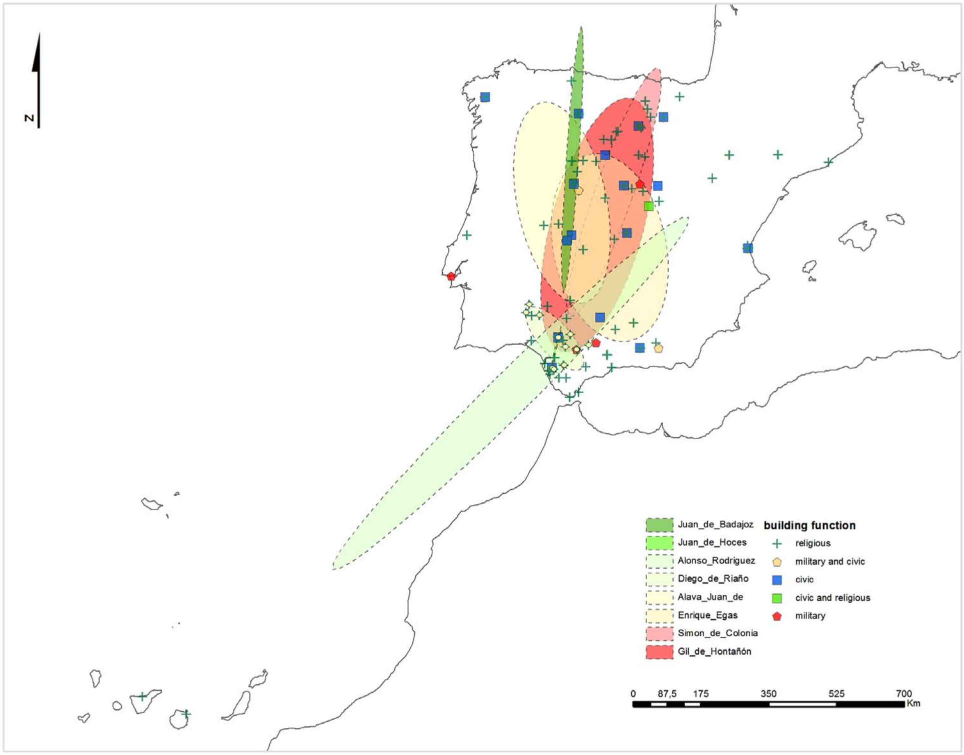

Fig. 7. Insertion of an elliptical polygon based on standard axes of distribution of the activities of potentially important professionals in ArcMap.

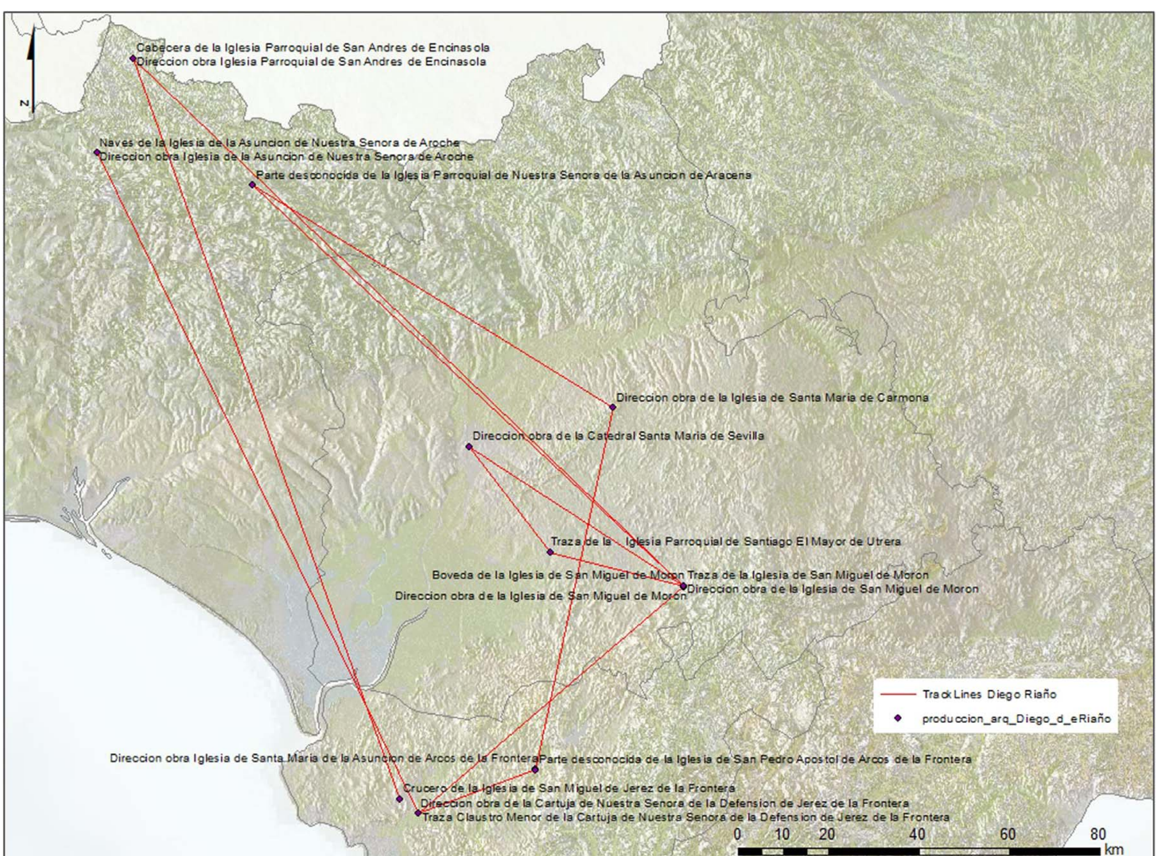

Fig. 8. Temporal track lines for the professional Diego de Riaño.

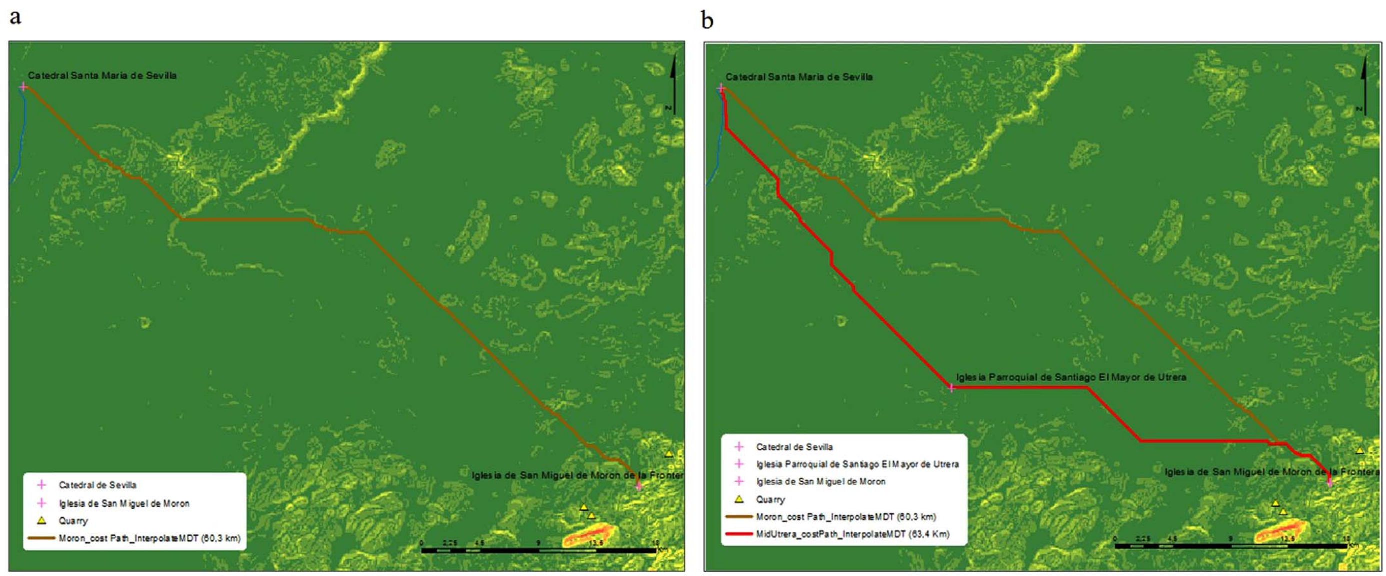

Fig. 9. Hypothesis of the possible road used by Diego de Riaño when he was managing the works on Seville Cathedral and the church in Morón de la Frontera. The calculation takes into account the gradient generated by the digital model of the terrain and the visualisation of its profile based on the insertion of the shape through ArcGIS. (a) Hypothesis 1: Least costly route from Seville Cathedral to the church of San Miguel in Morón. (b) Hypothesis 2: Least costly route from the cathedral to the church of San Miguel in Morón, via the church of Santiago in Utrera.

challenge that has yet to be met and that often causes the duplication of research studies and efforts. To contribute to the solution to this problem, we included in the DBMS the codes of IAPH and MECD heritage asset databases to facilitate the process of associating the information (Fig. 13). We implemented this solution for three reasons: 1) it reduced the incidence of error/duplication in the DBMS itself when associating activities performed by the agents on a particular building; 2) it enabled us to standardise the naming convention for the buildings—the same building appeared in documents and publications under different names, e.g. Catedral de Sevilla, Catedral Santa María de Sevilla, Catedral Sede de Santa María de Sevilla and Catedral Hispalense. By adopting the naming convention of these two institutions and their corresponding codes, we were able to organise the collected information more efficiently; and 3) we believe that the maintenance and dissemination of this information remains the role of these institutions; our research offers a methodology for facilitating the transversal connections between research, institution and access to the data by a wider audience.

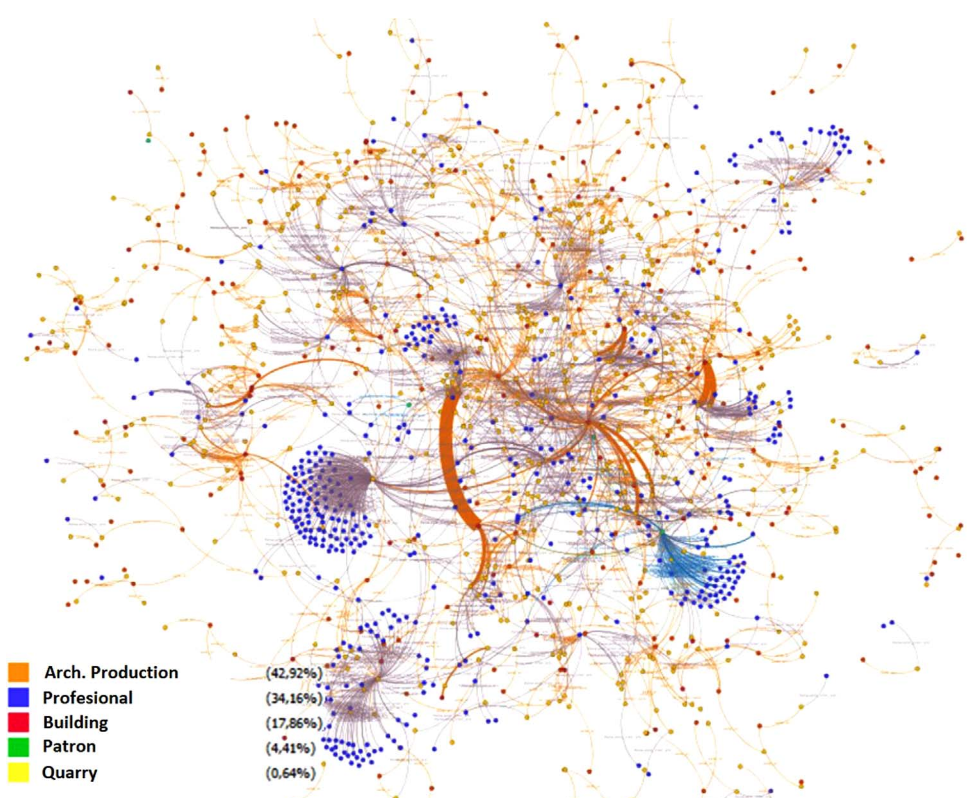

Fig. 10. Graph model with a total of 1400 nodes and 1787 lines. In this image the thickness of the lines between nodes is proportionate to the number of relationships connecting them.

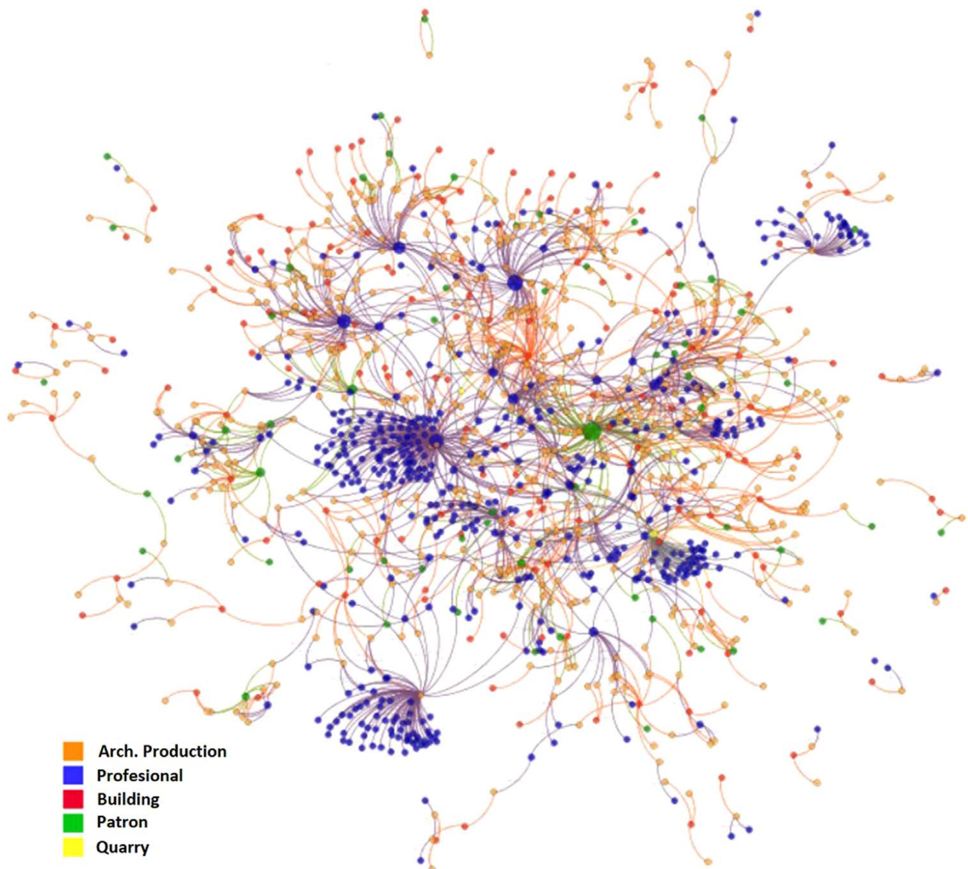

Fig. 11. The node is proportionate to the number of activities carried out by professionals. By volume of activity, the order is as follows: Juan Gil de Hontañón (48), Simón de Colonia (44), Enrique Egas (42), Juan de Álava (31), Diego de Riaño (26), Alonso Rodríguez (23), Juan de Hoces (16), Juan de Badajoz (15), Antoni Dalmau (14), Martin de Gainza (14), Ysambarte (13), Francisco Rodríguez Cumplido (10), Diego de Vergara (10) and Juan de Ruesga (10). This analysis indicates the potential importance of those agents in the network.

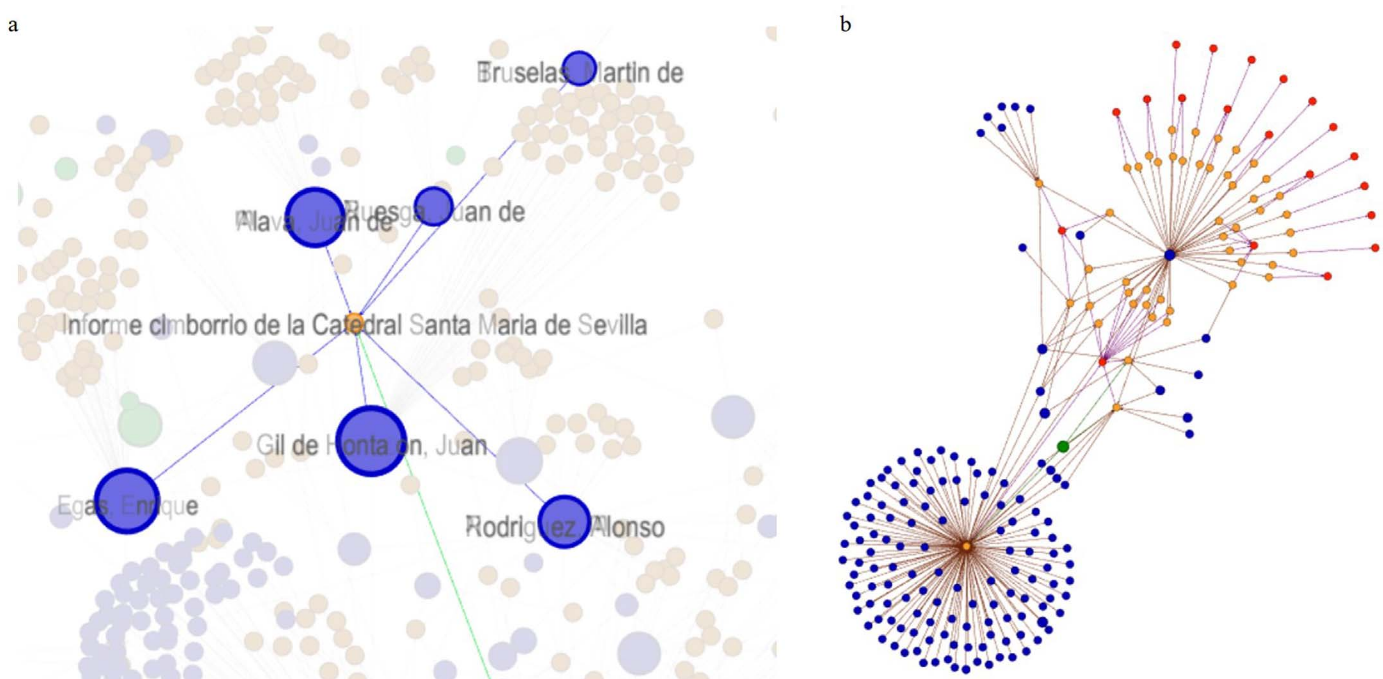

Fig. 12. Ego centrality analysis. (a) Visualisation of the network of professionals who issued reports on the cimbor of Seville Cathedral: Martin de Bruselas, Juan de Álava, Juan Gil de Hontañón, Alonso Rodríguez, Juan de Ruesga and Enrique Egas. (b) Ego filtered network to depth two around Juan Gil de Hontañón.

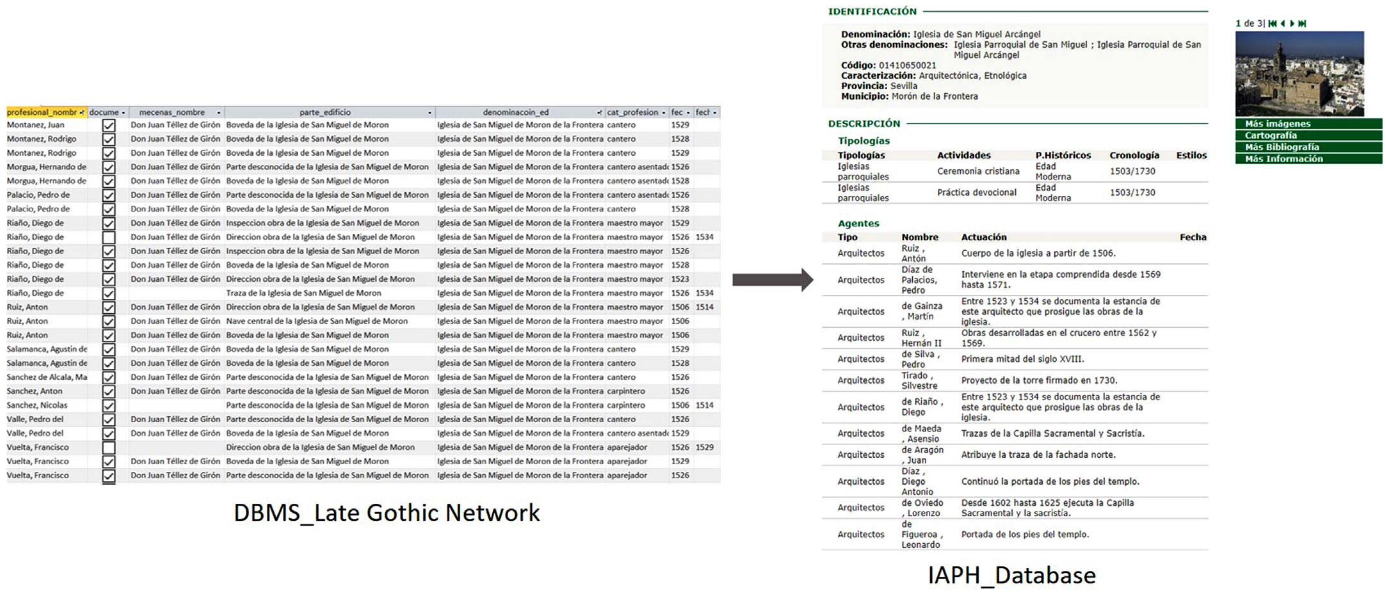

Fig. 13. Information transfer, dissemination and management by implementing the same building ID codes.

4. Conclusions and future developments

This study aims to shed light on the complexity of architectural production during the Late Gothic period, spanning the 15th and 16th centuries, by creating a DBMS as the basis for the GIS and graph models. Its principal premise is that all cultural assets must be interpreted in the context of the relationships between the object and its environment, between the object and other objects, between the human being and the object, and between the human being and other people. Based on this premise, the data collected were processed and systematised using different sources of information, partial or fragmented, for subsequent analysis and visualisation.

The project has furnished significant contributions to Late Gothic knowledge, including the following:

– An approximation to Late Gothic building production as a network. This project is the first to address Late Gothic production as a complex and interconnected system. Hitherto, there have only been biographical studies of agents or analyses related to specific buildings. The DBMS and the GIS and graph models have enabled us to trace the trajectory of a process that not only transformed building and design but also impacted on the organisation of the territory.
– The heritage potential of the information gathered. In many cases, the construction process of the different buildings had not been recorded or had been lost, and there were only oblique references to a particular agent or building. The creation of the DBMS and the use of the GIS and graph models have enabled us to perceive and verify existing attributions and hypotheses, and to put forward new ones. To a certain extent, we have therefore succeeded in filling in documentary gaps, although in the database itself we have been careful to reflect this information as "attributed" rather than "documented".
– The reconstruction of the history of building companies and their impact on the anthropisation of the territory. To date, very few studies have addressed this theme, and none of them have used a systematic methodology. In fact, they have all adopted a discursive approach based on the existing documents. The most complete approximation is the study that identifies the workshop or production centre at Seville Cathedral and its influence on the main churches in the towns and cities of the diocese (Rodríguez Estévez, 1996). The project described in this article has resulted in the construction of digital models that shed crucial light on the process of territorial transformation that took place during the period marked by the reconquest of Spain and the discovery of America.

The study has achieved significant success in integrating important documents and research on the topic, which will facilitate its dissemination and reuse by a wider audience, including historians, architects and geographers. The current features of the DBMS and the information it contains are naturally tailored to the issues raised by the researchers and institutions in this particular context, but they provide a basis for future adaptation and growth to meet users' requirements.

In this respect, the following conclusions may be drawn:

– The design of the DBMS was crucial for adding new data and using them in the GIS and graph models. In the case of GIS, the modification of the DBMS automatically updates the model by modifying or adding information to the entities. In the case of the graph model, once the DBMS has been modified, the searches generated for nodes and relationships are also updated but have to be added to the model, so this process is more time consuming than updating the GIS model.
– In view of the number of built assets and the volume of activities (events) still to be collected, and in many cases still to be discovered, this study also reinforces the need to define a methodology for the efficient integration of information related to heritage. It also provides a solution for interoperability between data and institutions because once the data entered have been associated, the institutions can use them on their websites.
– The models generated are suitable for creating sub-models by filtering data and conducting simple analyses. As well as being used for research purposes, they offer applications for the education and tourism fields.
– The GIS and graph models offer a new way of researching the Late Gothic phenomenon, constituting a first step on the path to a greater understanding of the network of agents and their actions and interactions.

The next step could be to record the procedure or technique used by the professional, because the DBMS currently only records the agent, the object/product derived from his action and the category of the action, without specifying the technique or material used. The first requirement in undertaking this step would be to select a specific product/object, such as the production of vaults, an architectural element whose form, materials and building techniques evolved during the historical period analysed. The techniques and materials used to build vaults is currently the subject of research project DOCOGOTHIC (URL5), which involves input from the authors of this study. Another future line of development is the detailed analysis of architectural production based on the creation of HBIM models and the GIS model to identify and examine the similarities and/or differences between professionals active in the same area at the same time.

An additional and equally important issue to resolve is the future use and sustainability of the database. In fact, the recommendations, corpus of archives and document management, such as the NINCH (URL 6), OAIS model (URL7) and ISO 15489 (URL8), all approach this issue via what is known as an "exit strategy" (Rodríguez Miranda, 2014). This is arguably one of the most complex issues to resolve and is currently the subject of international debate. To date, we have diagnosed three types of actions to undertake: 1) The data are published as part of an article and the publisher manages their maintenance. Although this action provides greater visibility, it has a drawback: the data remain stagnant without any possibility of updating them, and to a certain extent they are also scattered due to the absence of a thematic repository; 2) The database is made available to the public through the creation of a platform as part of the project that conceived it. In this option, the database is updated and managed by a group of specialists, although the long-term maintenance of the platform is not guaranteed because each project has time and financial limitations, and once a website ceases to function the information usually gets buried in the institution's server; 3) The database is published in an institutional repository. In this case, the data are transferred to another organisation like a library service, university repository or research institution. In projects like the "Atlantic Trade Database" by the Spanish Research Council (CSIC), "Digital Atlas of Roman and Medieval Civilisation" by Harvard University and "Heritage Geometric Documentation Laboratory" by the University of the Basque Country (URL9; URL10; URL11), the data are updated by the project group in question and made available to anyone who wishes to access and use them.

In the case of this project, two existing criteria helped us to establish our exit strategy: 1) Who might be interested in accessing the information. In relation to this criterion, we believe that the people most interested in the data furnished by our project are Spanish and international researchers, as well as professionals active in the field of heritage renovation; and 2) How to facilitate access to this group of users. In relation to the research community, we believe that the best strategy is to open access to the DBMS and the SDI through the research registry of the University of Seville (URL12), an action that will be undertaken very shortly. In relation to the professional community in the heritage field, as indicated in Section 1 of this article, we believe that access should be through the IAPH portal, an action that will be undertaken in the medium term. In both cases, the institutions have supported the project and the repository is managed by the institution itself, therefore guaranteeing its maintenance over time.

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References

Alonso Ruiz, B. (Ed.), 2011. La arquitectura Tardogótica castellana entre Europa y America. Silex, Madrid.
Alonso Ruiz, B., Jiménez Martin, A., 2009. La traça de la iglesia de Sevilla. Cabildo Metropolitano, Seville.
Alonso Ruiz, B., Rodríguez Estévez, J.C. (Eds.), 2016. 1514. Arquitectos tardogóticos en la encrucijada. Universidad Sevilla, Seville.
Alonso Ruiz, B., Villaseñor Sebastián, F. (Eds.), 2014. Arquitectura tardogótica en la Corona de Castilla: Trayectorias e intercambios. Servicio de Publicaciones de la Universidad de Cantabria y Secretariado de Publicaciones de la Universidad de Sevilla, Seville.
Alonzo Ruiz, B. (Ed.), 2010. Los últimos arquitectos del gótico. Ministerio de Ciencia e Innovación, Madrid.
Bascompte, J., 2009. Disentangling the web of life. Science 325 (5939), 416–419. http://dx.doi.org/10.1126/science.1170749.
Box, P., 1999. GIS and Cultural Resource Management: A Manual for Heritage Managers. UNESCO, Bangkok.
Brughmans, T., 2010. Connecting the dots: towards archaeological network analysis. Oxf. J. Archaeol. 29 (3), 277–303. http://dx.doi.org/10.1111/j.1468-0092.2010.00349.x.
Brughmans, T., Poblome, J., 2012. Pots in space: understanding Roman pottery distribution from confronting exploratory and geographical network analyses. In: Barker, E., Bouzarovski, S., Pelling, C., Isaksen, L. (Eds.), New Worlds Out of Old Texts: Developing Techniques for the Spatial Analysis of Ancient Narratives. Oxford University Press, Oxford, 225–280. http://dx.doi.org/10.1093/acprof:oso/9780199664139.003.0011.
Crespo Solana, A. (Ed.), 2014. Spatio-temporal Narratives: Historical GIS and the Study of Global Trading Networks (1500-1800). Cambridge Scholars Pub, Newcastle.
De la Rosa, J., Suarez, J.L., 2015. A Quantitative approach to beauty. perceived attractiveness of human faces in world Painting. DAH-J. 1, 112–129. http://dx.doi.org/10.11588/dah.2015.1.21640.
De la Rosa, J., Suarez, J.L., 2016. The life of Lazarillo de Tormes and of his machine learning adversities. Lemir 20, 373–438 ⟨http://parnaseo.uv.es/Lemir/Revista/Revista20/09_Rosa_Javier_de_la.pdf⟩.
Deidda, M., Musa, C., Vacca, G., 2015. A GIS of sardinia's coastal defense system (XVI - XVIII century). Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XL-4 /W7, 17–22. http://dx.doi.org/10.5194/isprsarchives-XL-4-W7-17-2015.
Deng, H., Chen, Y., Jia, J., Mo, D., Zhou, K., 2009. Distribution patterns of the ancient cultural sites in the middle reaches of the Yangtze River since 8500 a BP. Acta Geogr. Sin. 64 (9), 1113–1125 ⟨http://www.geog.com.cn/EN/10.11821/xb200909009⟩.
Dore, C., Murphy, M., 2012. Integration of Historic Building Information Modelling (HBIM) and 3D GIS for recording and managing cultural heritage sites. Proceedings of the 2012 18th International Conference on Virtual Systems and Multimedia, pp. 369–376. ⟨http://arrow.dit.ie/cgi/viewcontent.cgi?Article=1072&context=beschreccon⟩.
Fernández Cacho, S., 2002. Una aplicación para la gestión integrada de la información alfanumérica, gráfica y espacial: ARQUEOSMapa 6, 117–131, (Cuadernos Técnicos del IAPH).
Ferreira-Lopes, P., Pinto-Puerto, F., Jiménez Mavillard, A., Suarez, J., 2016. Seeing Andalucia's Late Gothic heritage through GIS and Graphs. In: Digital Humanities 2016: Conference Abstracts. Jagiellonian University & Pedagogical University, Kraków. pp. 501–504. ⟨http://dh2016.adho.org/abstracts/237⟩.
Fortin, M., Bonnell, J. (Eds.), 2014. Historical GIS research in Canada. University of Calgary Press, Calgary.
Galliani, D., Sánchez Díaz, F.J., 1998. Desarrollo de la base de datos geográfica de conjuntos históricos y patrimonio arquitectónico. PH Bol. IAPH 22, 102–105.
Gestoso y Pérez, J., 1899. Ensayo de un diccionario de los artífices que florecieron en esta ciudad de Sevilla desde el siglo XIII hasta el XVIII. T. I. Seville.
Graham, S., 2006. Networks, agent-based models and the Antonine itineraries: implications for Roman archaeology. J. Mediterr. Archaeol. 19 (1), 45–64. http://dx.doi.org/10.1558/jmea.2006.19.1.45.
Greengrass, M., Hughes, L.M. (Eds.), 2008. The Virtual Representation of the Past. Digital Research in the Arts and Humanities. Ashgate, Farnham.

Gregory, I. (Ed.), 2003. A Place in History: A Guide to Using GIS in Historical Research. Oxbow Books, Oxford.

Gregory, I., Ell, P. (Eds.), 2007. Historical GIS: Technologies, Methodologies, and Scholarship. Cambridge Studies in Historical Geography. http://dx.doi.org/10.1017/CBO9781107415324.004.

Guillot, D., Leroy, G., 1995. The use of GIS for archaeological resource management in France: the SCALA project, with a case study in Picardie. In: Lock, G., Stancie, G. (Eds.), Archaeology and Geographical Information Systems: A European Perspective. Taylor & Francis, London, 15–26.

He, J., Liu, J., Xu, S., Wu, C., Zhang, J., 2015. A GIS-based cultural heritage study framework on continuous scales: a case study on 19th century military industrial heritage. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XL-5/W7, 215–222. http://dx.doi.org/10.5194/isprsarchives-XL-5-W7-215-2015.

Jackson, C., 2017. Using social network analysis to reveal unseen relationship in medieval Scotland. Digit. Scholarsh. Humanit. 32 (2), 336–343. http://dx.doi.org/10.1093/llc/fqv070.

Jiménez Martin, A., 2016. 1514: el principio del fin. In: Alonso Ruiz, B., Rodríguez Estévez, J.C. (Eds.), Arquitectos tardogóticos en la encrucijada. Universidad de Sevilla, Seville, 17–30.

Knappett, C., 2013. Introduction: Wwhy Networks? In: Knappett, C. (Ed.), Network Analysis in Archaeology. New Approaches to Regional Interactional. Oxford University Press, Oxford, 3–16.

Knowles, A.K., Hillier, A. (Eds.), 2008. Placing History: How Maps, Spatial Data, and GIS are Changing Historical Scholarship. ESRI Press, Redlands.

La Spina, V., Mileto, C., Lopez-Manzanares, F.V., Aliaga, E.C., 2012. La aplicación de un sistema de Información geográfica (SIG) para la conservación del patrimonio arquitectónico: el estudio de los revestimientos continuos tradicionales del centro histórico de Valencia. Arché 6, 323–332 ⟨http://hdl.handle.net/10251/34291⟩.

Owens, J.B., 2007. Towards a geographically integrated, connected world history: employing Geographic Information System (GIS). Hist. Compass 5, 2014–2040. http://dx.doi.org/10.1111/j.1478-0542.2007.00476.x.

Pinto Puerto, F.S., Angulo Fornos, R., Guerrero Vega, J.M., Castellano Roman, M., Pastor Gil, F., 2011. Construcción de una base cartográfica activa para el Conjunto Arqueológico de Itálica 77. PH. Boletín del Instituto Andaluz del Patrimonio Histórico, 116–119.

Pitts, F.R., 1965. A graph theoretic approach to historical geography. Prof. Geogr. 17 (5), 15–20. http://dx.doi.org/10.1111/j.0033-0124.1965.015_m.x.

Polonia, A., Pinto, S., Ribeiro, A., 2014. Trade Networks in the first global age: the case study of Simon Ruiz Company: visualization methods and spatial projections. In: Crespo Solana, A. (Ed.), Spatio-temporal Narratives: Historical GIS and the Study of Global Trading Networks (1500-1800). Cambridge Scholars Pub, Newcastle, 140–177.

Robinson, I., Webber, J., Eifrem, E., 2013. Graph Databases. Information Management. O'Reilly Media, Sebastopol.

Rodríguez Estévez, J.C., 1996. Los canteros de la obra gótica de la catedral de Sevilla (1433–1528). Labor. De. Arte. 9, 49–71.

Rodríguez Estévez, J.C., 1998. Los canteros de la Catedral de Sevilla: del gótico al renacimiento. Diputación de Sevilla, Seville.

Rodríguez Miranda, A., 2014. Documentación espacial del patrimonio: preservación de la información. Necesidades, posibilidades, estrategias y estándares. Servicio Editorial de la Universidad del País Vasco, Vitoria-Gasteiz⟨https://addi.ehu.es/handle/10810/13617⟩.

Ruiz de las Casas, J., 1527, June 18. Archivo Protocolos Notariales de Utrera, 1527–1529, Fondos del Distrito de Utrera, Oficio 6, Seville.

Scholnick, J.B., Munson, J.L., Macri, M.J., 2013. Positioning power in a multi-relational framework: a social network analysis of Classic Maya political rhetoric. In: Knappett, C. (Ed.), Network Analysis in Archaeology. New Approaches to regional Interactional. Oxford University Press, Oxford, 95–124.

Scianna, A., La Guardia, M., 2017. Main features of 3D GIS for a monumental complex with an historical-cultural relevance. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-5/W1, 519–526. http://dx.doi.org/10.5194/isprs-archives-XLII-5-W1-519-2017.

Serra Desfilis, A., 2016. La logia abierta: transferencias y movilidad en la arquitectura tardogótica hispánica. In: Alonso Ruiz, B., Rodríguez Estévez, J.C. (Eds.), 1514. Arquitectos tardogóticos en la encrucijada. Universidad Sevilla, Seville, 339–351.

Suarez, J.L., Sancho-Caparrini, F., Ortega, E., de la Rosa, J., Caldas, N., Brown, D., 2013. Towards a digital geography of Hispanic Baroque art. Lit. Linguist. Comput. 28 (4), 718–735. http://dx.doi.org/10.1093/llc/fqt050.

Uriol Salcedo, J.I., 1990. Historia de los caminos de España I. Hasta el siglo XIX. Colegio de Ingenieros de Caminos, Canales y Puertos, Madrid.

Villaseñor Sebastián, F., 2010. Recensiones. In: Alonzo Ruiz, B. (Ed.), Los últimos arquitectos del gótico. Ministerio de Ciencia e Innovación, Madrid, 185.

Wang, Y., et al., 2015. Linked activity spaces: a new approach for spatializing social networks. In: Helbich, M., Arsanjani, J., Leitner, M. (Eds.), Computational Approaches for Urban Environments. Springer, 313–336. http://dx.doi.org/10.1007/978-3-319-11469-9_13.

Willems, W.J.H., Kars, H., Hallewas, D. (Eds.), 1997. Archaeological Heritage Management in the Netherlands. Fifty years State Service for Archaeological Investigations. Rijksdienst voor het Oudheidkunding Bodemonderzoek, Amersfoort.

Zant, J., Quartermaine, J., Hodgkinson, A., 2013. The Distribution of Waterlogged Deposits in Carlisle: Final Report. Oxford Archaeology North, London.

Websites

URL 1: ⟨https://gephi.org/⟩ (Accessed 16 September 2016).

URL 2: ⟨http://www.gbhgis.org/⟩ (Accessed 15 October 2016).

URL 3: ⟨http://atlas.fcsh.unl.pt/cartoweb35/atlas/apresentacao-en.html⟩ (Accessed 10 February 2017).

URL 4: ⟨http://tesauros.mecd.es/tesauros/bienesculturales/1001128.html⟩ (Accessed 16 May 2017).

URL 5: ⟨http://vaultsconstruction.com/⟩ (Accessed 16 September 2017).

URL 6: ⟨http://chnm.gmu.edu/digitalhistory/links/pdf/chapter1/1.17.pdf⟩ (Accessed 16 September 2015).

URL 7: ⟨https://public.ccsds.org/pubs/650×0m2.pdf⟩ (Accessed 6 January 2018).

URL 8: ⟨https://www.iso.org/standard/62542.html⟩ (Accessed 24 December 2017).

URL 9: ⟨http://digital.csic.es/handle/10261/28394⟩ (Accessed 31 October 2017).

URL 10: ⟨https://darmc.harvard.edu/⟩ (Accessed 14 December 2017).

URL 11: ⟨https://addi.ehu.es/handle/10810/5483⟩ (Accessed 14 December 2017).

URL 12: ⟨https://idus.us.es/xmlui/⟩ (Accessed 14 December 2017).