BUILT ENVIRONMENT DATA INTEGRATION USING nD MODELLING

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SUMMARY: *Using n-Dimensional (nD) modelling techniques in the European Union funded IntelCities project (6.8 Million Euros, Framework 6 Integrated Project) the "Built environment Data Integration System" (BDIS) has been produced. BDIS combines building scale and urban scale data to give a holistic view of the built environment, and thus support the purchase and refurbishment of buildings. This paper will introduce BDIS and its sub systems for converting various spatial data sets into appropriate formats necessary for the integration of 2D geo-spatial data, 3D Industry Foundation Classes (IFC) building data and non-spatial data. This paper also shows, through examples and demonstration, that commercial services could be developed from BDIS. The benefit of this development would be the provision of the wide range of information necessary to support building projects through one system. Furthermore, based on the integrated nD-modeling database, holistic analysis of the project becomes possible. The system would support remote cooperative planning, analysis and decision-making by the design team. This paper also describes the software development of BDIS and in particular addresses integration issues.*

KEYWORDS: *geographic information systems (GIS), n-Dimensional modeling, relational database, data conversion, refurbishment, building survey, property development, urban regeneration.*

1. INTRODUCTION

It is always a challenge for those involved in urban development to get access to the wide range of information needed in a building development process. In particular, if the information needs to be integrated in such a way that holistic analysis of the project is possible, the challenge is much bigger. This document describes the design and implementation of the BDIS software developed to address the integration issue.

There is a range of data sets, some complex in nature, used in construction and urban scaled activities. This makes processing and modelling based on these data sets difficult. The system introduced in this paper focuses on the integration of multiple data sources including GIS data, IFC building data (obtained by Laser Scanning) and other local data such as transport and hotel accommodation. All these data sources are combined to give the holistic view of the built environment, from the building scale to the city scale that is needed for urban development.

To form the Built Environment database that underpins BDIS, data are collected and converted to form an nD-modeling database. The design and implementation reflect the idea of information sharing and system interoperability. Whilst the conceptual system was designed with complete automation in mind, on the current BDIS, some of the transfer work still has to be done manually. However, this development demonstrates how a unified database would have the potential to provide effective services to construction professionals engaged in a refurbishment project.

BDIS was developed as part of the IntelCities FP6 Integrated Project (2004-2005) funded by the EU through IST

(6.8 Million Euros) with 75 partners. To guide the development work, the project team created the fictitious "Gaudi Bank" scenario as a typical multi-national development project. In this scenario, the Gaudi Bank, based in Spain, with branches in the UK, is planning to set up a training centre in Manchester for staff working in the UK. To set up the centre, a building has to be selected and refurbished. The 'selection' is done by property developers and the 'refurbishment' is carried out by construction professionals. Many planning and construction professions are involved, and a wide range of data sets are needed, including transport, building survey information etc. These data sets are needed in different stages of the project by different property and construction professionals. The overall structure of the system is shown in Fig. 1.

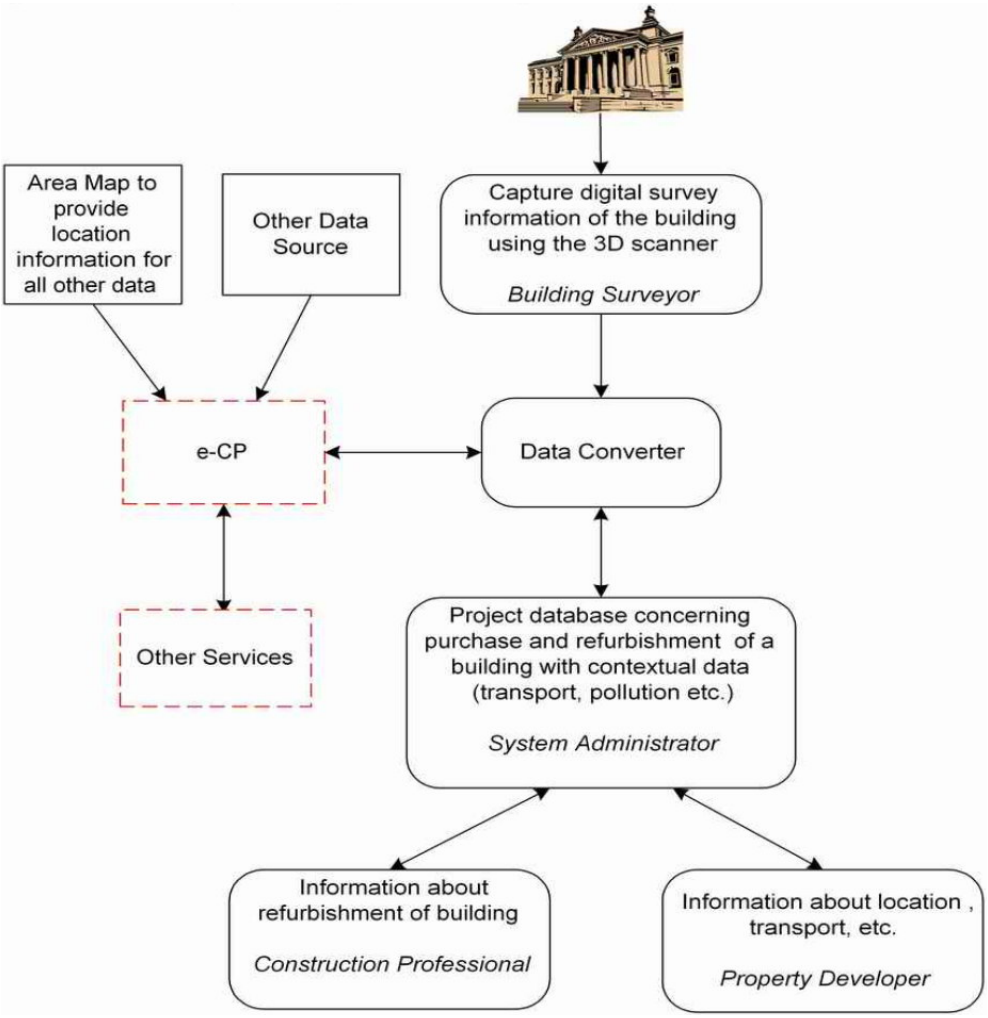

FIG.. 1: Built environment Data Integration System showing main components and key actors

Note that the e-CP is the electronic City Platform developed in IntelCities to integrate systems such as BDIS with other urban services (Hamilton et al., 2005b).

In section 2, the contextual background to BDIS is discussed. Section 3 explains how BDIS was developed, and section 4 shows how the application could be used. Section 5 discusses aspects of the current system and possible future development.

2. BACKGROUND

2.1 nD modelling

In "3D to nD Modelling" research in the Research Institute for the Built and Human Environment, BuHu, at the University of Salford, an nD model concept has been developed. nD modelling is seen as an extension of the building information model by incorporating all the design information (such as a 3D building model, time, cost, accessibility, sustainability, maintainability, acoustics, crime, and thermal etc.) required at each stage of the lifecycle of a building facility (Lee et al., 2003; Aouad et al., 2005). Although this concept is defined at the construction scale, it can be extended into the much wider urban scale, since urban planning processes and construction processes have similarities in terms of built environment development. However, to do this, it is necessary to consider the integration of a wide range of datasets.

The concept of an nD urban information model is defined as a representation of urban data sets and their relationships to provide a conceptual view of urban information (Wang and Hamilton, 2004b, Hamilton et al, 2005a). The n-Dimensions include the 3-dimensions of the urban physical structure, time, economy, society, and environmental dimensions. This nD urban model can integrate diverse and scattered data sources together to implement the interoperation between various datasets. So this nD urban model essentially is an information framework or infrastructure for data integration and interoperability. This framework employs emerging data management technologies and considers elements like data standards, data modeling, metadata/ontology, and integration architecture (Wang and Hamilton, 2004b).

The nD urban information model provides a comprehensive framework for various urban planning application systems. It can meet the information requirement for the whole life cycle of urban planning. This can enhance the capability of analysis, visualisation and support decision-making during the urban planning process. (Wang and Hamilton, 2004a).

BDIS is based on the nD urban model described above, and makes use of some of the comprehensive range of data sets provided. A centralized project database is designed and setup to host all the relevant information. The relational model is chosen for this data model due to its popularity with all actors and its mature technologies (SQL and main-stream database products). It is adopted by partners in the IntelCities project (Hamilton et al., 2005b). The top level data model of the BDIS nD database will be discussed in the Section 3.3.

Geographic features and IFC objects are organised in the database using an nD modelling schema (Wang and Hamilton, 2005). In this paper, when attribute data are mentioned, it means the attribute information used to describe a geographic feature or IFC object, such as the name of a building. However, when thematic data are mentioned, it means generic information of different themes like population, census data, crime, housing and transport etc of urban environment.

2.2 GVIS development

An estimated 80% of actions taken by municipal authorities are supported by geo-spatial information (Hnojil and Potuckova, 1998, Lemments 2001). In Urban planning and building design processes, there is a particular emphasis on spatial aspects. Thus geo-spatial information-based technologies are used by most researchers in this field, as well as by planning professionals (Song, 2004). Traditional GIS software uses geo-relational data models, but current research includes the integration of different data models with the GIS applications (Hamilton et al. 2005a, Tanyer et al. 2005a, 2005b).

Nowadays, GIS functions and their applications are mature and widespread. There is a trend towards Internet distributed applications and Web applications, including GIS applications, (Peng and Tsou, 2003). This use of GIS enables urban scale cooperative planning, analysis and decision making.

In previous research at the University of Salford, the authors have developed the Geographical Visual Information System (GVIS). This system incorporates a specially designed “Communications Server”, facilitating the delivery of datasets and GIS functions over the Internet (Song et al., 2003). This system supports a GIS tool kit, which fits into the nD-modelling database design: the system retrieves GIS data through a GIS application server, meanwhile, receiving attribute data from the Relational Database. Thus the system presents the geo-spatial information in a 2D or 2.5D manner and supports basic GIS functions. With the retrieving of relevant feature attribute data the system provides its users with analysis features (Song 2004).

The development aim for BDIS was to link the GVIS system with the nD-modelling database through development of appropriate middleware (Fig. 2), the system would then be able to provide its users with the information located in the database, such as a building’s owner. This enables other users of the database to share the GIS dataset without considering the GIS data structure (Hamilton et al., 2005b). How this was achieved is described in the next section.

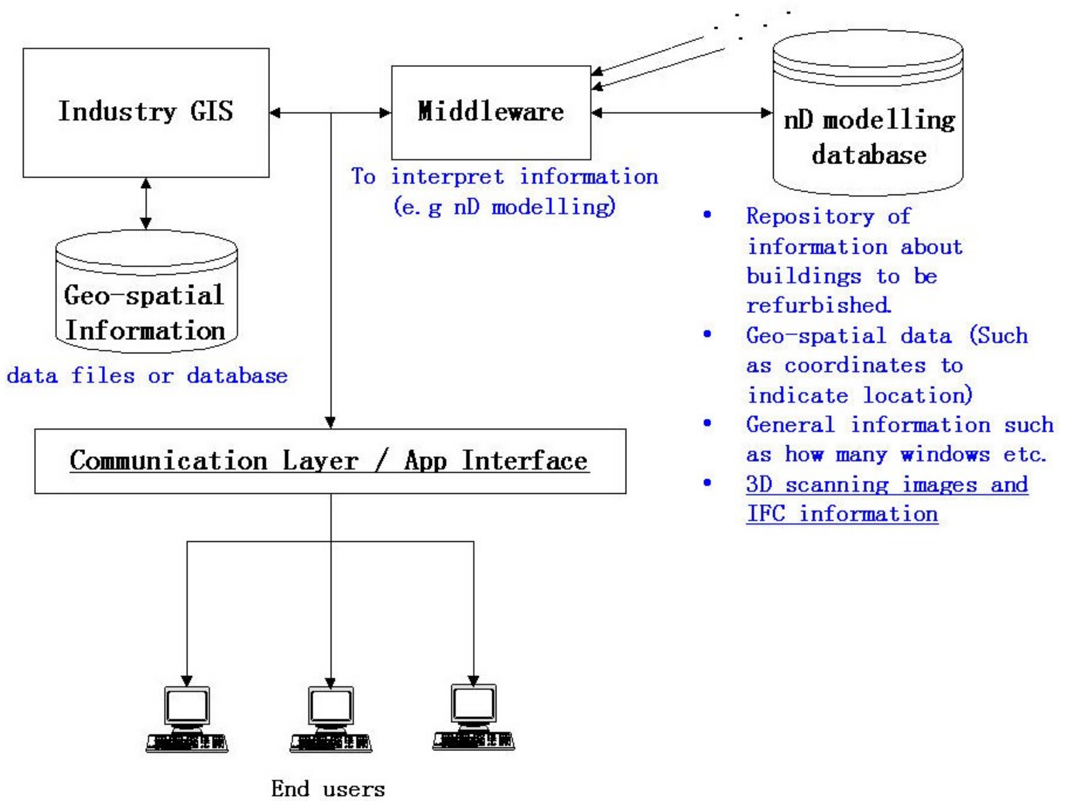

FIG.. 2: Linking GVIS with an nD database using the communication layer

As a result of data integration using GVIS (shown in Fig. 2), use of a GIS system would be more flexible. Depending on the individual requirements, users of GIS systems can possibly switch their connection to the nD-modelling database to get not only the same services as before, but even more due to the rich information in the database. The same applies to the users of other data sources, such as IFC or CAD. Every user only connects to the nD-modelling database interface, and then is able to share the information such as geo-spatial information contributed by the GIS system, while contributing their own information such as IFC data into the database.

To achieve the information sharing, it is necessary to have access to a wide variety of data sets. When data are accessed from different sources the different data formats need to be converted to enable integration into a central database to support standard service provisions. Fig. 3 presents a universal data converter, created as part of the purpose-built communication layer in BDIS. The data converter can abstract all kinds of geo-spatial information and convert it into the nD-modelling format. Although this design concentrates on only the GIS data set, the DB converter includes mechanisms to convert other data sets into the nD-modelling database, such as IFC data (Tanyer et al., 2005a, 2005b).

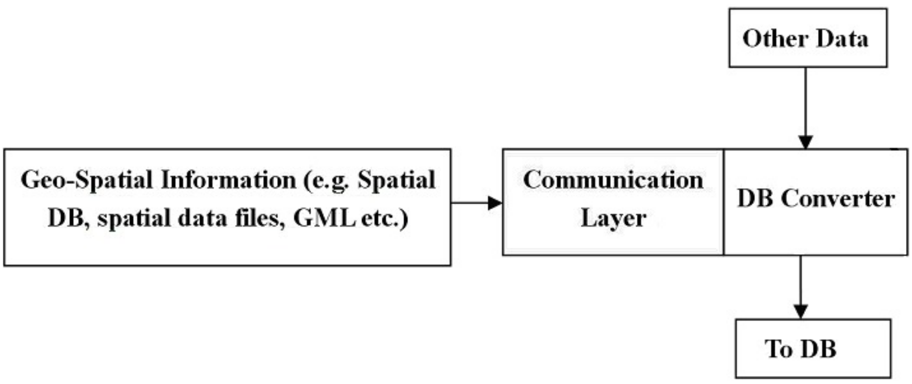

FIG.. 3: Design of a data converter to integrate geo-spatial information with nD-modelling database

The design of the BDIS is based on the development of the GVIS system (Song 2004). Although, the current retrieving of geo-spatial information only works on ESRI GIS data, converters for other formats of geo-spatial information could be developed.

3. BUILT ENVIRONMENT DATA INTEGRATION SYSTEM IMPLEMENTATION

BDIS is built on GVIS, and incorporates many of the GVIS functions described above. It integrates various data sources into an nD modelling database and provides data services to users. This section starts by stating the functionality of BDIS and then shows how the data sets are integrated through the data converter to support the functionality. The interfaces and operation of BDIS are described in section 4.

3.1 Functionality

The main functions of BDIS are listed here in two categories:

System Administrator functions (mainly geo-spatial data conversion):

- The system is built on the previous GVIS system. The system administrator uses the system to deal with the integration of GIS data with nD modelling information.
- Connect to the Communication Server to load GIS data sets.
- Support review of spatial data before and after conversion.
- Convert spatial data into the nD modelling database.
- Support rolling back.

Construction Professional functions (retrieving and entering information):

- Display general information about a building and its surroundings, such as transport.
- Produce reports of building elements, such as the number and type of windows and doors, based on the information in the nD modelling database (e.g., for a refurbishment schedule). In future systems, these reports could be worked on and the newly processed report would be left on the system for others to use.
- Generate illustration images and Virtual Reality Markup Language (VRML) models of buildings and building elements, based on the 3D information in the nD modelling database.
- Connection to, and integrate with, other systems. For a stand-alone application, the integration can be through the unified data interface, while for a web-based application, it is easy to have access to other systems as a hyperlink.

In order to arrive at the functionality defined above, it was necessary to create the “Gaudi Bank Scenario” to guide the work of the authors, as described in section 1 of this paper. In developing the functionality, the authors worked closely with expert consultants in the field, Labein of Bilboa, and the University of Catalonia in Barcelona, who were also Partners in the IntelCities project. With the Gaudi Bank Scenario, it is assumed that Jactin house in Manchester is under consideration as the UK training centre, as this property is seen to meet the needs of Gaudi Bank by property developers.

As part of the research project, Jactin house was scanned by the University of Salford team, using a Reigl 3D Scanner. This captured a complete a 3D dataset of the building to 25 mm accuracy. Through a series of processes, the point cloud data are converted to CAD files and then IFCs (Arayici et al, 2004, Arayici and Hamilton, 2005)

Surrounding information of Jactin house such as other buildings and roads etc is taken from existing urban data sets, such as Ordnance Survey (OS) landline maps. All the data captured from various sources such as maps and the scanned data are organized together in the nD database. All the information can be mapped together through geo-reference and displayed to users. In the current version of BDIS, web based services have not been developed.

3.2 Data Flow

The following diagram (Fig. 4) shows how captured data (Lidar/ 3D scanner) is integrated with sourced data (Geo-spatial and other) and combined in the central relational database.

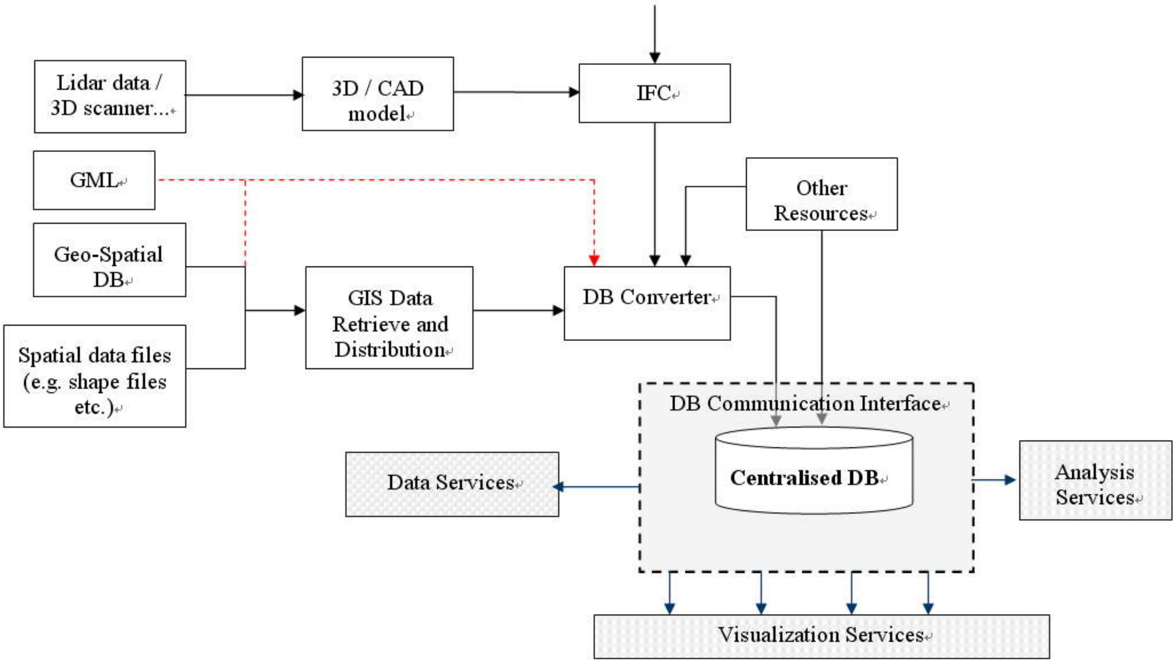

FIG.. 4: BDIS top level data flow diagram

As shown in the Fig. 4, the central nD database gathers various data sources and data formats through a DB Converter or a series of converters. Currently, spatial data (e.g. shp file) and IFC data can be converted and saved in the central database. However, the conversion of Geography Markup Language (GML) is not implemented in the current version of the BDIS (red dotted arrow in Fig. 4).

As mentioned in section 3, it should be noted that BDIS is a conceptual system development. Some processes are not fully automated yet, such as pattern matching and object recognition. Full automation is currently being developed.

The following sections will focus on the integration of GIS datasets with nD-modelling database.

3.3 nD Modeling Database Design

As introduced in Section 2.1, BDIS makes use of a range of data sets in the nD database. These data sets focus on modelling several types of objects categorized into four groups: buildings, common geometries, transports and geographical boundaries which are essential for building redevelopment tasks (Fig. 5). The links between these objects are mainly based on their locations and geometrical representation. In Fig. 5, the purple part is the geographical boundary. The blue part is the common geometry description. The green part shows the road network model. The building model is shown in red. This data model can also be employed by other building and urban planning projects by extending the contents to cover more attributes and aspects of the urban environment.

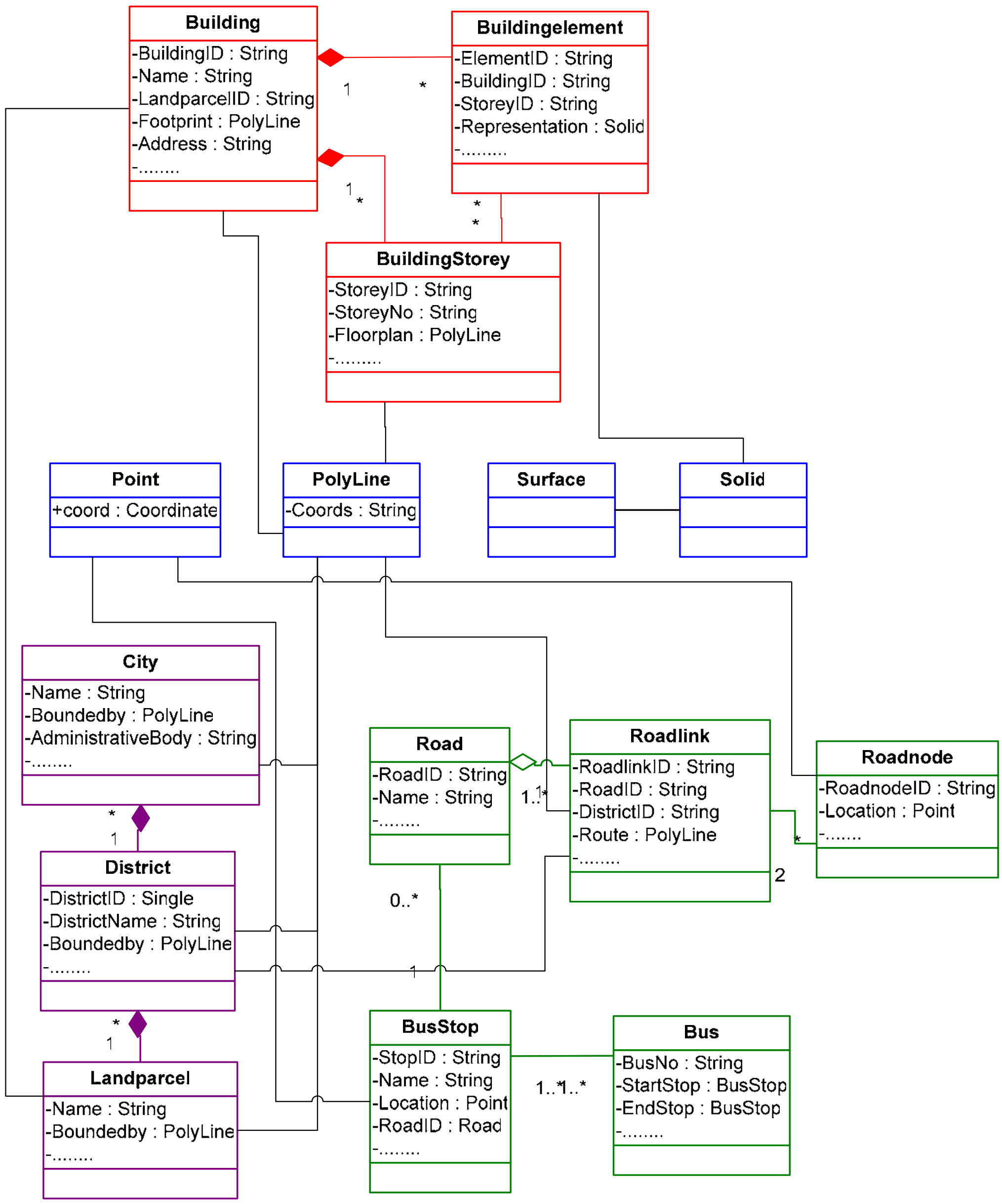

FIG.. 5: nD database model that BDIS concerned

3.4 Aspects of Data Integration

As described Section 2.2, the development of the BDIS is based on the GVIS system with a specially developed Communication Server (Song 2004; Hamilton et al., 2005b). The BDIS incorporates a Communication Server through which geo-spatial information is abstracted. It follows all the communication protocols defined in the GVIS system. However, after the geo-spatial data are abstracted, the BDIS then uses ODBC (Open Database Connectivity) to link to the nD-modelling database and uses SQL to store the geo-spatial data into the database.

The BDIS supports previewing of the geo-spatial data for the system administrator to check the correctness and validity of the data. The system administrator is able to choose a particular layer to retrieve from GIS data sources and start a conversion to the nD-modelling database. This application also supports a roll back operation by offering the system administrator the ability to clear the converted data to get to the initialised database state. This is because there is a log of information on conversion operation for each record converted.

Fig. 6 illustrates the interface of the BDIS. The left hand side is the log of information about each operation. And the right hand side is the previewing area of the spatial data. The system connects to the nD-modelling database automatically once the system starts. The system administrator hits relevant tool_buttons to finish the data conversion. Fig. 7 shows a floating window to preview the geo-spatial data that had been converted and presented in a more realistic way.

FIG.. 6: BDIS interface

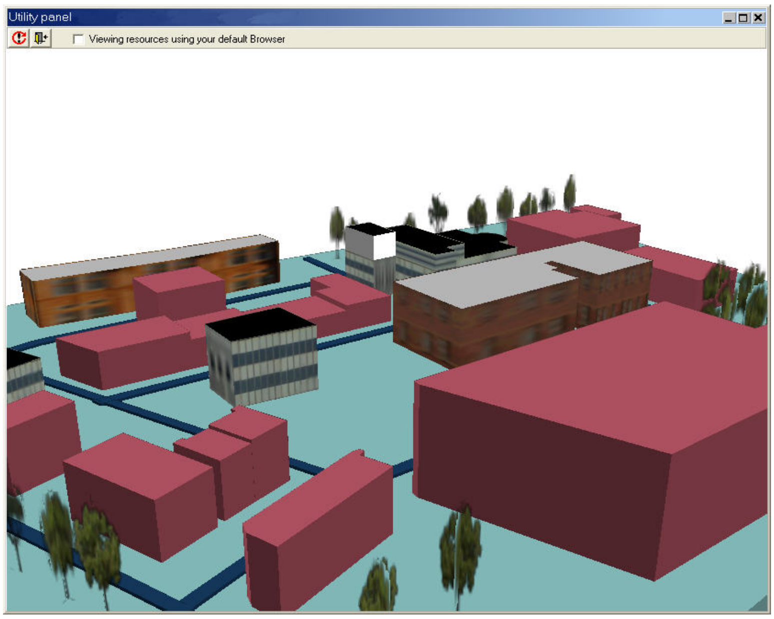

FIG.. 7: A floating window of previewing the geo-spatial data in a 2.5D manner

Currently, the following layers of GIS data are retrieved and converted: Parcel, Building and Road. The nD-modeling database defines and accepts only these layers in its current form. Obviously, it does not meet full GIS managing capability. However, as a conceptual system development, it clearly shows the integration concept.

BDIS integrates various data sources into the nD database, and provides data services to users. This section introduced how the data can be used and how GIS data sets are integrated through the converting mechanism in the BDIS. In a similar way, multiple data sources of all types are integrated in this nD modelling database.

4 BDIS FEATURES

The last section introduced the BDIS (Built environment Data Integration System); in this section the services that the BDIS system offers are demonstrated. These services are discussed in the next section, which assesses the approach of the BDIS.

4.1 Retrieving information about the location of a building

As mentioned in Section 3, a building called Jactin House in East Manchester was taken as an example in the Gaudi Bank scenario. This is the proposed location of a new training centre to be planned for the Gaudi bank. The map, including Jactin House and the surrounding area, was obtained from an OS landline map. The application loads the map from the GIS database. A user can preview the map data in both 2D and 2.5D manner. When the user clicks on Jactin House, information is obtained and displayed as in Fig. 8. This includes the basic information of the building and possibly some stored images and documents indexed or hyperlinked in the information. The user then can follow the index by simply clicking on the hyperlink to view the images or the relevant documents such as transport information or local hotel information. This is an extension of the data integration with nD-modelling: web-accessible information, online documents etc. can all be reached through this mechanism.

Building name	Jactin House
Building address:	Corner of Hood Street and Murray Street
Building outline:	
Height:	Unknown
Location:	Ancoats, Manchester
Orientation:	Hood Street elevation faces north west Murray St faces north east
Parcel ID:	
Size:	Plot size: 1018 sq m - four storeys plus basement (approx. 5000 sq m total)
Erection time:	Unknown
Demolition time:	Unknown
Use of the building:	Originally a men's hostel now vacant
Age of the building:	Built 1903
Any other information available: (optional)	
Open Space Investigation	http://127.0.0.1/jhmodel/
	1) http://127.0.0.1/jhmodel/01.gif 2) http://127.0.0.1/jhmodel/02.gif 3) http://127.0.0.1/jhmodel/03.gif 4) http://127.0.0.1/jhmodel/04.gif 5) http://127.0.0.1/jhmodel/05.gif 6) http://127.0.0.1/jhmodel/06.gif 7) http://127.0.0.1/jhmodel/07.gif
Local Service	
Transport:	http://127.0.0.1/jhmodel/Map%20Information.doc
Local Hotel:	http://127.0.0.1/jhmodel/Local%20Hotel.doc

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Initial property database for bank premises ... ...

http://dss.vtu.lt/realestate/

FIG.. 8: Information about Jactin House, with hyperlinks to further information (documents or images)

The provision of transport, accommodation and other public services would be useful for property developers to select possible buildings within the Gaudi Bank Scenario. The current BDIS shows how such information can be provided. Future versions of BDIS could be linked to local service providers.

4.2 Online survey using BDIS

In BDIS, CAD models of building elements obtained from data matching and recognition processes on laser scanning data are mapped into the IFC schema (Arayici et al., 2005; Tanyer et al., 2005a; Wang and Hamilton, 2005). The model is then saved into the nD database. Just as the database users can then share the GIS data since it is converted into the database, the building and building element data abstracted from 3D scanning data set can be retrieved and represented as text and images. This would enable the scanned data to be ready for a variety of users for building refurbishment. Construction professionals are able to see the building in 3D and do a building survey from their office, on the web. For example, Fig. 9 is a schedule of windows and doors in Jactin House generated by BDIS.

Scanning-Survey Report of Jactin House Elements - Windows and doors

Generated from Centralized nD Database

There are together 199 windows, in 4 sides of Jactin House, located in 5 floors and in different size

- **In each elevation of the Jactin House, the number of windows are:**
  Front elevation window-number: 82
  Left elevation window-number: 40
  Right elevation window-number: 22
  Rear elevation window-number: 55
- **The 199 windows are located in 5 floors (from the ground to the 4th floor)**
  The ground floor window-number: 27
  The 1st floor window-number: 47
  The 2nd floor window-number: 56
  The 3rd floor window-number: 43
  The 4th floor window-number: 26
- **There are 6 different types among all these windows**
  0) There are 34 windows of type 1: 1.7 (w) x 2.5 (h)
  1) There are 41 windows of type 2: 1.0 (w) x 2.5 (h)
  2) There are 29 windows of type 3: 0.5 (w) x 1.7 (h)
  3) There are 33 windows of type 4: 0.60 (w) x 1.3 (h), with a curved shape on top (radius: 0.3)
  4) There are 31 windows of type 5: 2.0 (w) x 1.8 (h)
  5) There are 31 windows of type 6: 1.35 (w) x 1.6 (h)
- **Windows size illustration:**
  http://127.0.0.1/jhmodel/Win&Doors/Windows.gif

There are together 5 doors, in the front side and left side of Jactin House, in different size

- 4 of the doors are at the front of the house
- 1 of the doors is at the left of the house
- **Doors size illustration:**
  http://127.0.0.1/jhmodel/Win&Doors/Doors.gif

From the survey, it is suggested that all windows and doors need to be replaced.

A VRML model is generated following this report to show just the windows and doors around Jactin house

http://127.0.0.1/jhmodel/Win&Doors/Jactin_Housewindows.wrl

FIG.. 9: A report of the survey of windows and doors in Jactin House

The Building elements are converted from IFC files, including the dimensions of the windows and doors, enabling them to be displayed (Fig. 10, Left). With the spatial information, the real coordinates and location relationship are used to generate a VRML model of all the windows and doors for on-line users to view (Fig. 10, Right).

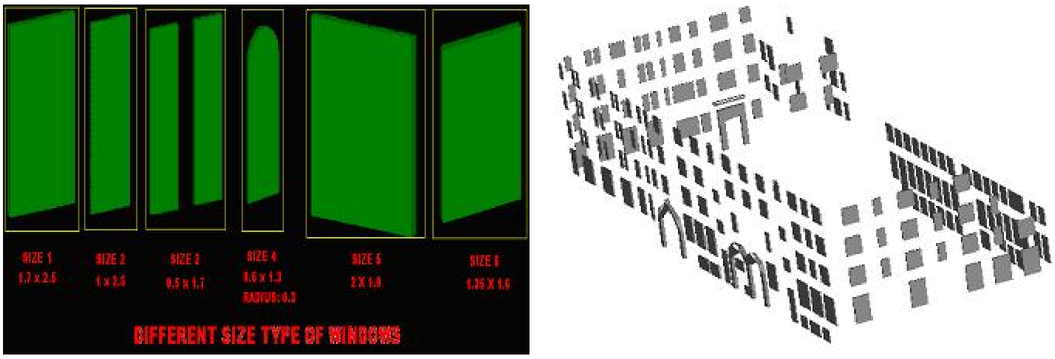

FIG.. 10: Left, images of windows generated by BDIS; Right, 3D VRML model of just windows and doors in Jactin House

Such representation of models is helpful for people to understand the building in a way that normally can only be achieved from an on-the-spot survey.

5 ASSESSMENT AND FUTURE DEVELOPMENT

In this section, BDIS features are summarised and assessed. Also the future development of web-based services, using the BDIS concept is discussed.

BDIS was designed for various stakeholders to contribute to and share integrated data sources. For example, in commercial use, the construction costs, ownership, CAD design, spatial information etc. are input by different construction and IT professionals, at various locations, and will be shared by all. The important point that would attract construction professionals to contribute to the database with information they hold is that the database would have a standard and open interface for one user to share all data stored in the database contributed by various colleagues in the building project team.

When a construction professional works on a project in a traditional way, there is a need to go to many different sources to get copies of different data sets. These then have to be converted to standard formats to enable some sort of integration. However, in BDIS, professionals contribute data to the system and share the data within the system. A professional (client) doesn't have to copy data from different DB owners, but just retrieve data from an all-inclusive database. Thus, it is also easy to maintain the data integrity and data consistency (Fig. 11).

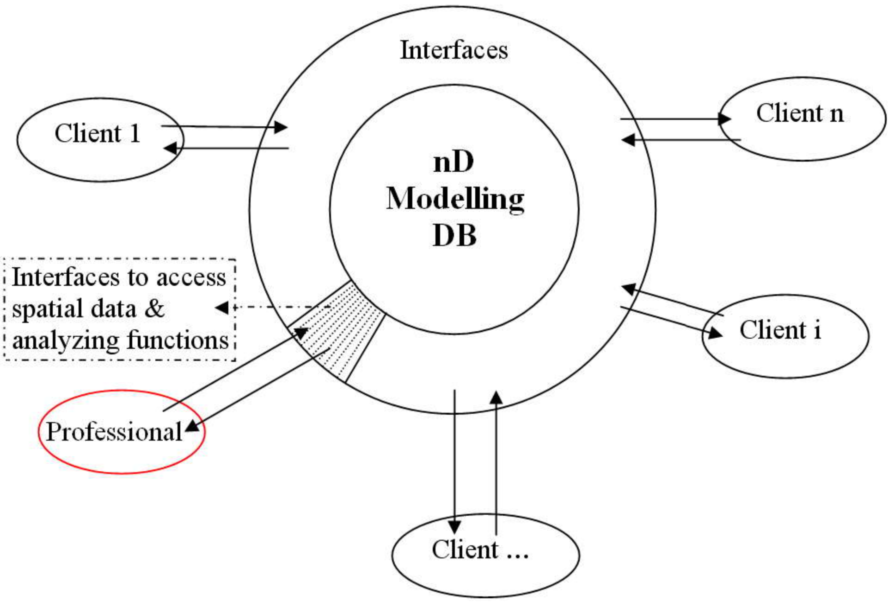

FIG.. 11: All users contribute and share data within the database

5.1 DB conversion is included in the service interface

The BDIS interface facilitates the presentation of information and is thus the method of providing services. With the interface provision, the database converter is not the concern of the user of the system because functions of conversion are provided in the service interface. This is illustrated in the diagram (Fig. 12).

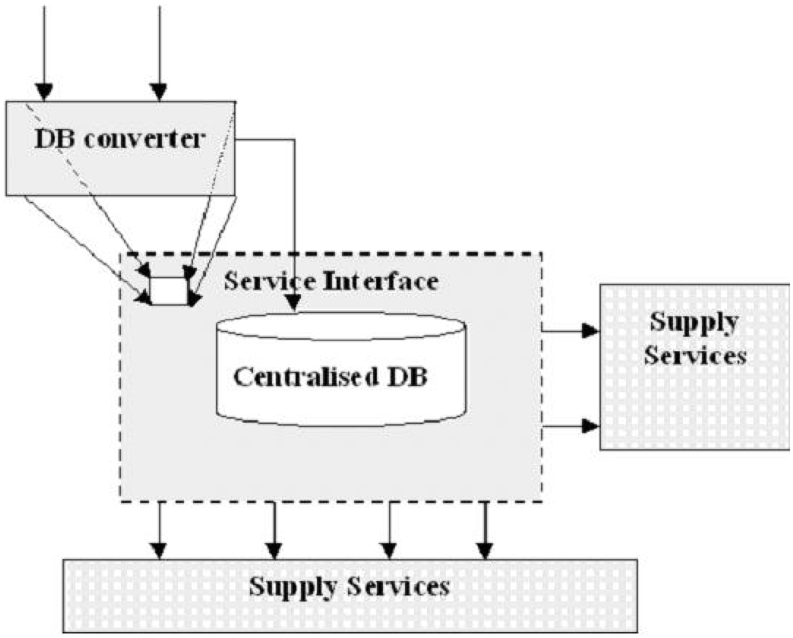

FIG.. 12: The data converter forms part of the database service interface

5.2 The centralized database and distributed database

In BDIS, the word ‘centralized’ indicates that the database is “logically” centralized, i.e. it appears centralised from a system user’s point of view. However, the database does not need to be physically centralized. It could include distributed databases. The important point is that service is provided through a standard interface. Accessing and sharing multi-data sources and mixed data formats is a unified service provided by BDIS in order to assist in the complex decision making process that built environment development requires at the building and urban scale.

5.3 Assessment of the conceptual model

The BDIS model, based on the concept illustrated in Fig. 1 and described in this paper, was assessed in the final formal review of the IntelCities project in October 2005. The BDIS was well received as making significant quality and efficiency improvements as an intelligent city service. It is regarded as a good example of the new way of working envisaged by IntelCities. Cities within IntelCities project, such as Barcelona and Manchester, are interested in providing an intelligent service to promote investment in urban development projects.

The BDIS model was also assessed as part of the USA-EU e-Government collaboration project led by Albany University, New York and the University of Salford, and funded by the National Science Foundation of America (90,000 US dollars). At the meeting in Manchester, 27th – 28th June 2005, the Americans agreed that the data integration work shows the value of integrating all different data sources and data formats to provide business services. There was a debate about the database structure, e.g. centralized or distributed. However, everyone recognised the benefit of the integration of different data sources and formats.

6. CONCLUSION

This paper describes the operation and architecture of BDIS. BDIS uses an nD modeling-based data integration approach for multiple data source integration: including data collecting, converting and retrieving. This paper demonstrates that a unified nD modelling database has the potential, with further development, to support construction professionals with easy data accessibility and data services through appropriate database interfaces.

The design and implementation reflect the idea of information sharing and system interoperability. With appropriate provision for sharing of urban data, such as through the adoption of the IntelCities e-CP, the data integration design and development would show its significant value. Different data sources and data formats could be combined to provide a consistent data infrastructure and service interface to facilitate Internet-based and Web-based services for a range of construction, planning, and development professionals. This would enhance built environment decision making.

However, although the BDIS achieved the integration of the building model with some urban datasets, it needs to be extended into all the relevant domains with consequential challenges in data maintenance and linkage to other applications. For both urban planning and the construction process, a holistic solution is needed in order to produce more generic and flexible information systems for decision support. The challenge for the future is to build integrated systems that address both building and urban scale issues seamlessly. BDIS makes some progress in meeting this challenge.

7. ACKNOWLEDGEMENTS

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- Labein, Spanish research institute based in Bilbao,
- The Department of Construction Economics and Property Management, Vilnius Gediminas Technical University,
- Dr Pedro Gamito, Visiting Professor in Real Estate Management ESAI, Lisbon, Portugal.

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