Virtual building maintenance: Enhancing building maintenance using 3D-GIS and 3D laser scanner (VR) technology

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ABSTRACT: The renovation and refurbishment market is rapidly expanding within the construction industry, bringing the role of the Facilities Management (FM) department to the forefront. Operating and maintaining a facility however, takes the biggest proportion of the lifecycle cost of a building, which can be costly and time consuming. The wide spread and use of advanced technologies within the construction industry can be used to drive the productivity gains by promoting a free-flow of information between departments, divisions, offices, and sites; and between themselves, their contractors and partners.

The paper describes a scope in the INTELCITIES project undertaken by 75 partners including 18 cities (Manchester, Rome, Barcelona, etc), 20 ICT companies (Nokia, IBM, CISCO, Microsoft, etc) and 38 research institutes (University of Salford from UK, CSTB from France, UPC from Spain, etc) across Europe to pool advanced knowledge and experience of electronic government, planning systems, and citizen participation across Europe. The scope includes capturing digital data of existing buildings using 3D laser scanning equipment and showing how this data can be used as an information base for enhancing the refurbishment process and maintenance.

Furthermore, the paper discusses the state of the art for operating and maintaining facilities, describing the prevailing methods of building maintenance, highlighting their limitations with proposed alternatives, such as 3D Geographic Information Systems '3D GIS' to enable the spatial analysis and static visualisation of critical of query outputs and 3D laser scanning technology for obtaining the digital information of existing buildings for construction maintenance.

1. INTRODUCTION

The new-construction market has been shrinking, while the renovation and refurbishment market is rapidly expanding in the construction industry (Mahdjoubi and Ahmed, 2004). Operating and maintaining a facility takes the biggest proportion of the lifecycle cost of a building. The growing emphasis on lifecycle considerations through new forms of project relationships, together with the increasing refurbishment, retrofit and renovation of existing buildings (instead of new build) is bringing the role of the Facilities Management (FM) department to the forefront.

Furthermore, previous research had shown that there would be no substantial change in aggregate demand for housing over the next decade (Simmonds and Clark, 1999). Therefore, organisations need to be able to quantify costs and communicate management information about their facility and infrastructure (Wix, 2003). To do this, they are turning to new information technologies to drive productivity gains. The most successful companies promote a free-flow of information between stakeholders.

Typically, construction facilities require maintenance and occasional repairs on a regular basis, due to deterioration and aging. This is to keep them functional and in a satisfactory appearance. In fact, many organisations own a large variety of buildings and other types of constructed facilities, which need regular maintenance, occasional renovation and rehabilitation, and sometimes reconstruction of new facilities. Often, these organisations face a crucial dilemma, regarding the urgency and prioritisation of works and associated costs (Rosenfeld and Shohet, 1996). However, not many companies have utilised information technology to increase the efficiency of the refurbishment process for building maintenance.

The above issues are addressed in the INTELCITIES project, which has a focus on the prevailing methods of building maintenance, highlighting their benefits and limitations. The paper also describes a proposed approach for the use 3D Geographic Information Systems 'GIS' and 3D laser scanning system, to enable the analysis and static visualisation of critical query outputs for building maintenance.

2. THE INTELCITIES PROJECT

The INTELCITIES (Intelligent Cities) Project is a research and development project that aims at helping achieve the EU policy goal of the knowledge society. INTECLITIES project brings together the combined experience and expertise of key players from across Europe, focusing on e-Government, e-Planning and e-Inclusion, e-Land Use Information Management, e-Regeneration, Integration and Interoperability, Virtual Urban Planning, etc, (www.intelcitiesproject.com).

The overall aim is to advance the possibilities of eGovernance of cities to a new level through the development of a prototype of the IOSCP (Integrated Open System City Platform), as a clear and easily accessible illustration of a shared civic place in virtual space continuously available to all – whether officials, decision-makers and other professionals, such as planners, developers, politicians, designers, engineers, transport and utility service providers, as well as individual citizens, community groups/networks and businesses, through a wide range of interfaces

This paper focuses on the e-Regeneration work package of the project. The objectives of the package are to;

1. Produce a city vision for the post industrial city in the knowledge society and set of targets for systems to enhance regeneration.
2. Produce a system to support improved decision making about strategic planning of cities.
3. Produce a system to support development planning processes and that engage citizens in planning regeneration.
4. Show how these systems could be integrated with other city systems.
5. Report on how a holistic approach to all elements of building, refurbishment and urban planning and design can lead to successful, sustainable cities.

The objective 5 specifically is addressed in the paper. The task, which is defined to achieve the objective 5, is the building data capture using the laser scanner technology and investigate this technology to enhance the refurbishment process and maintenance. Figure 1 illustrates the vision, which is beyond the INTELCITIES project, for the use of 3D laser scanner for maintenance and refurbishment process. In the INTELCITIES project, the laser scanner technology is aimed at showing how it can be used for building refurbishment and maintenance.

In figure 1, the first step centres on the creating VR models subject to the requirements of use and usage of the VR models such as building redesign and renovation, building survey and evaluation, reverse engineering, fabrication and construction inspection, health and safety, and urban planning and analysis.

In the second step, integration is the main concern. Therefore, integration of the laser scanning system will be endeavoured with the GPS systems for linking the OS (Ordanance Survey) data or for linking the local authority data, with the GIS system for accomplishing the full integration of VR and GIS and with the Workbench for interactively analysing the VR models produced through laser scanning system.

In the third step, it is aimed at building data integration that is related to developing a conceptual model of nD modelling (Lee et al, 2003) system and associating it with the other data structures including relational databases and object-oriented databases to illustrate how data can be integrated to support intelligent city and construction systems.

The rest of the paper considers DSS (Decision Support System) and delves into the integration of the 3D laser scanning technology with GIS system for building maintenance. In the next section, the existing methods of building maintenance and their limitations are explained in order to justify the integration of the 3DGIS and the 3D laser scanner systems

3. PREVAILING METHODS OF BUILDING MAINTENANCE AND THEIR LIMITATIONS

Planning and control of building maintenance works are commonly performed using traditional media, such as paper-based plans and sketches. Other techniques have also emerged as decision support systems (DSS) and integrated environments.

In recent years, major efforts were devoted to the development of decision support systems (DSS) to address building maintenance issues. Several of these systems have been developed to assist managers and decision-makers in planning building maintenance activities. Each DSS has its own functionality and designed for its unique purpose. These tools range from renovation design to initiation of renovation projects.

Rosenfeld and Shohet (1996) have developed a unique DSS, which is capable of suggesting various building/facility-upgrading alternatives. This system was demonstrated on a 25-year-old dining facility in a military base that had suffered serious structural damage due to foundation problems. This system has proved valuable for the maintenance work. It provided managers with alternatives depending on the input criteria, including full descriptions of building evaluation and end-results. However, it only provides information on the general condition of the facility, including costs and subsequently life span of facility depending on how much money is available or what alternative is chosen.

Underwood and Alshawi (2000) developed an integrated construction environment for the UK construction industry – the Simultaneous Prototyping for an Integrated Construction Environment (SPACE). MAINtenance ForeCASTing in an Integrated Construction Environment (MAINCAST) (Underwood and Alshawi, 2000) is an amplification of SPACE, which forecasts building element maintenance of a project as part of a fully integrated environment MAINCAST and was developed to assist the facility manager/owner (Client) in facility/project management by automatically generating detailed maintenance valuations, outlining the required maintenance during every operational year of the projects life, etc.

However, these media suffer from several limitations. Firstly, it is difficult to identify the refurbishment and renovation tasks. Secondly, it is also difficult to monitor the various tasks, because of the complexity of the operation tasks. The Rosenfeld and Shohet system DSS for instance is not capable of enabling managers and decision-makers to view the facility and see the damaged elements or locate them. Overall, the main limitation of these DSS systems is related to their output. They usually provide the results in a text format or tables and, in some cases, bar charts. This form of output is often not appropriate for decision-makers to visualise the results of their queries, especially when lay-clients are involved in the communication process. These tools have yet to adopt spatial analysis techniques such as GIS technology in their operation. A GIS enables the spatial analysis and static visualisation of critical of query outputs (Enache, 1994) was critical of the failure of current DSS systems to make use of advances in GIS technology. In addition, it does not allow them to visualise the final changes, before starting the maintenance work. Clearly, there is a need to improve the management of information and tasks about building maintenance.

4. 3D-GIS AND LASER SCANNING TECHNOLOGY AS VR - EMERGING TECHNOLOGY OPPORTUNITIES

Geographic Information Systems (GIS) are collections of computing techniques and databases that support the gathering, analysis and display of large volumes of spatially referenced data (USEPA, 2002).

On the other hand, the innovation consists of a laser scanner controlled by a laptop computer. The scanner is targeted to the physical objects to be scanned and the laser beam is directed over the object in a closely spaced grid of points. By measuring the time of laser flight, which is the time of travel of the laser from the scanner to the physical objects and back to the scanner, the scanner determines the position in three-dimensional space of each scanned point on the object. The result is a “cloud of points” thousands of points in 3-dimensional space that are a dimensionally accurate representation of the existing object (Schofield, 2001). This information can then be converted in a 3D CAD model that can be manipulated using CAD software, and to which the design of new equipment can be added.

3D Laser Scanner is currently used for a variety of sectors range from industrial applications for process automation in automotive industry, steel industry, robotics, etc, to mining, archaeology, survey, urban planning and railway, tunnel and bridge construction (Arayici et al, 2003).

In recent years, however, the emerging GIS systems have presented organisations and management sectors with significant advances in making informed decisions. Ehler, Cowen, and Mackey (1995) argued that linking GIS with DSS systems has enabled the user to make well-informed decisions, based on the problem at hand. Also, Modis (2001) reported that tools, which are based on GIS technology, have offered managers and decision-makers substantial benefits, including usability, accuracy, and efficiency. Consequently, organisations around the world are reaping considerable benefits by capitalising on spatial technology solutions. GIS applications in (DSS) provide an enhanced means of resolving complex geo-analytical problems.

Furthermore, systems based on 3D GIS technology are starting to supersede the early GIS systems (Jordan, 2000), (Song et al, 2002, 2003). Although still in its infancy, this emerging technology could clearly support the planning process of building maintenance projects. 3D modelling capability of GIS could also enable managers to foresee changes and modifications in an improved manner. However, despite the evident advantages of 3D technology to this type of planning and construction work, its full benefits could not be realised without an improved visualisation of the output. Indeed, the results of 3D GIS systems are usually displayed as a static cardboard model, which does not allow users to explore and rapidly visualise the results of their queries.

Combining 3D GIS with advances in the Laser Scanner VR technology could provide decision-makers more robust tools to visualise in real-time the 3D GIS environment. Verbree et al. (1999) argued that VR technology offers new and exciting opportunities to visualise 3D GIS data that, in turn, improve DSS usability and enable users to walk through 3D environments. It allows them to see building elements and appreciated proposed changes in a real time environment. Sidjanin (1998) demonstrated that linking GIS and VR offered great capabilities for decision-making, as it could produce real-time and realistic visualisation of spatial data. In addition, VR interface could improve understanding of GIS spatial analyses and handling of queries on the data, as well as navigating through the dynamic map model and for using GIS functions.

Similarly, the ability to rapidly sketch and visualise design ideas has been stressed as an important task in urban design (Smith, 1998). Hence the VENUE Project was conceived as a means of experimenting with links between GIS and 3-D visualisation tools (ibid). The project demonstrated that a set of urban features can be visualised as building block outlines in 2D ArchView (based on Ordnance Survey base data). Removing building sub-divisions and line vertex generalisation enabled the production of 3D VRML (Virtual Reality Modelling Language) model by assigning a height attribute in ArchView. This approach is on a macro scale in relation to buildings but can be extended to a more detailed micro scale application suitable for building maintenance (Camara and Raper, 1999).

In line with the foregoing, it can be established that there are several approaches that have successfully linked 3D-GIS with the Laser Scanner VR technology as a means of enhancing decision support. These successful developments further exposes the possibility of employing this combination to enhance current building maintenance DSS. The following section describes a proposed methodology, which is partly inspired by the work of (Mahdjoubi and Ahmed, 2004).

5. METHODOLOGY

The aim of this section is to propose a framework which includes a series of analytical tools that will enable various stakeholders in the building maintenance sector to make informed decisions relating to building maintenance works. This framework, which is depicted in figure 2, includes:

1) The development and population of a geo-spatial project database with the digital data of existing building captured with the laser scanning equipment.
2) The analysis of complex building information maintenance options within a knowledge repository environment, digital building data

captured by the laser scanner is retrieved with 3D GIS system for the analysis

3) The visualisation of the project information through a range of different interconnected graphic windows. The laser scanner VR model can be visualised in different platforms including workbench.

The geo-spatial project database will describe the geometries of both the building frame and its components. Simple open geometric descriptions will be used, but each entry will also be associated with data on inventory information such as name, supplier, date installed/replaced, number of previous replacements, etc.

The procedure for the development will be based on establishing a robust object-oriented database management system (OOMS). The system will enable the capture of all geo-spatial information of the building frame and components using laser scanner. Inventory information relating to each frame and component will also be captured within the relational structure of the database. Such information will be accessible in real-time with some of the attributes (e.g. component supplier information) hyperlinked to the World Wide Web.

Sequel to the development of the OODM, information captured will be linked to a knowledge repository developed purely for rule base and/or case-based interpretation of possible building maintenance schedules. This component of the VBM system will facilitate the generation of alternatives based on user-specified queries.

GIS software will be used to generate and analyse thematic developments relating to the building properties and associated maintenance management strategies. ArcGIS 3D analyst, for example, enables users to effectively visualise and analyse surface data. Using the 3-D spatial analysis capabilities of the tool, a range of possible scenarios of a building can be evaluated. Surfaces can be viewed from multiple viewpoints, queried, interrogated for visibility and viewed for the creation of a realistic perspective image. Furthermore, the evaluation can also be extended to display static images of building components that require immediate or 'near-future' maintenance based on the real-time information captured within the OODM and the knowledge repository. However, a final selection of the most appropriate software will be based on the most suitable representation (i.e. raster or vector) of the captured data.

The VR environment will be developed using the laser scanner technology which also provides data models in different formats including the Virtual Reality Modelling Language (VRML). This approach is complimentary to previous work done on the information infrastructure developed through the OSCON, VIRCON and HyCon projects and the ongoing research for nD modelling project (Lee et al, 2003). Therefore, the results of the spatial analysis obtained within the 3-D GIS environment can be evaluated in real-time with the options of viewing building maintenance alternatives developed from querying the knowledge repository.

6. BENEFICIARIES

The research is of potential benefits and practical applications to the construction industry and professions. It will provide a better support for evaluation and visualisation of building maintenance works so that informed policies can be effectively targeted. It will benefit construction companies, facility and estate managers, and all those concerned with building maintenance issues.

The ultimate beneficiaries of this work will be professionals and stakeholders of the construction industry involved with the:

- building maintenance,
- improved predictability of building maintenance requirements,
- reduced maintenance planning and execution time,
- increased safety,
- Increased productivity.

7. SUMMARY

This paper provides an overview of the e-regeneration package of the INTERLCITIES project, which aims at helping achieve the EU policy goal of the knowledge society. INTECLITIES project aims to bring together the combined experience and expertise of key players from across Europe, focusing on a number of built and human environment issues including e-Government, e-Planning and e-Inclusion, e-Land Use Information Management, e-Regeneration, Integration and Interoperability, Virtual Urban Planning, etc, (www.intelcitiesproject.com).

This project recognises the need for integrating visualisation techniques and systems for building maintenance and refurbishment. In particular, the vision for the use of laser scanner equipment for building refurbishment and maintenance is addressed (see figure 1) and a framework for integrating such 3D GIS and Laser scanner systems is developed to assist the flow of information. Lastly, the beneficiaries of such integration are summarised.

For the time being, the integration of 3D GIS and Laser scanner technology is being conceptually modelled. Once this is completed, it will be implemented.

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9. FOTOGRAPHS AND FIGURES

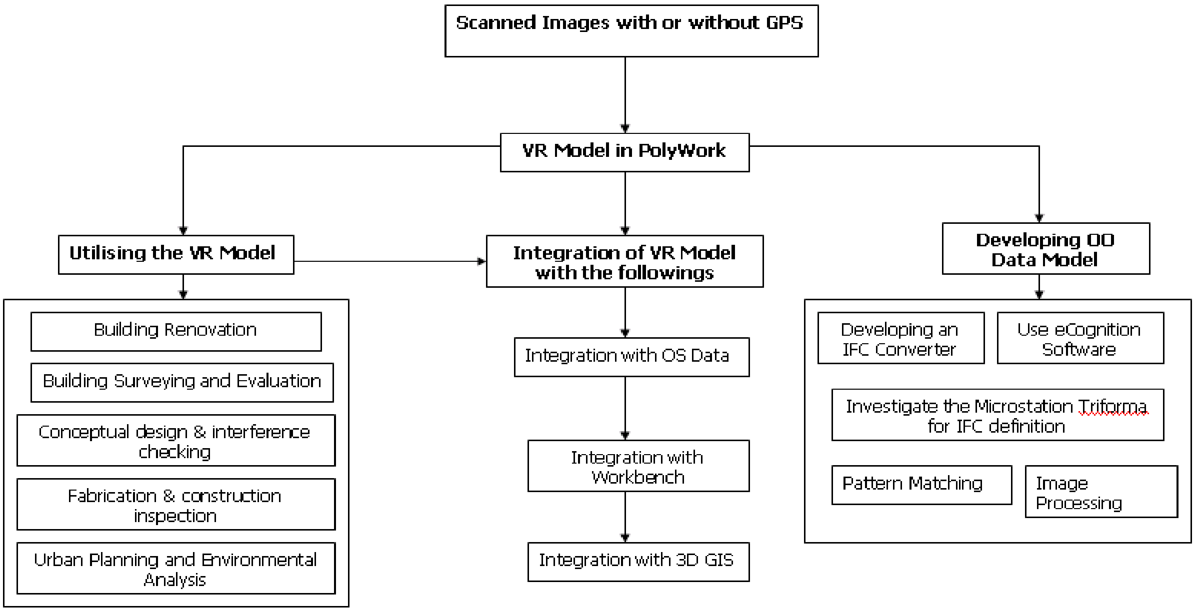

Figure 1: Show how laser scanner technology can be used for maintenance and refurbishment process in the INTELCITIES project.

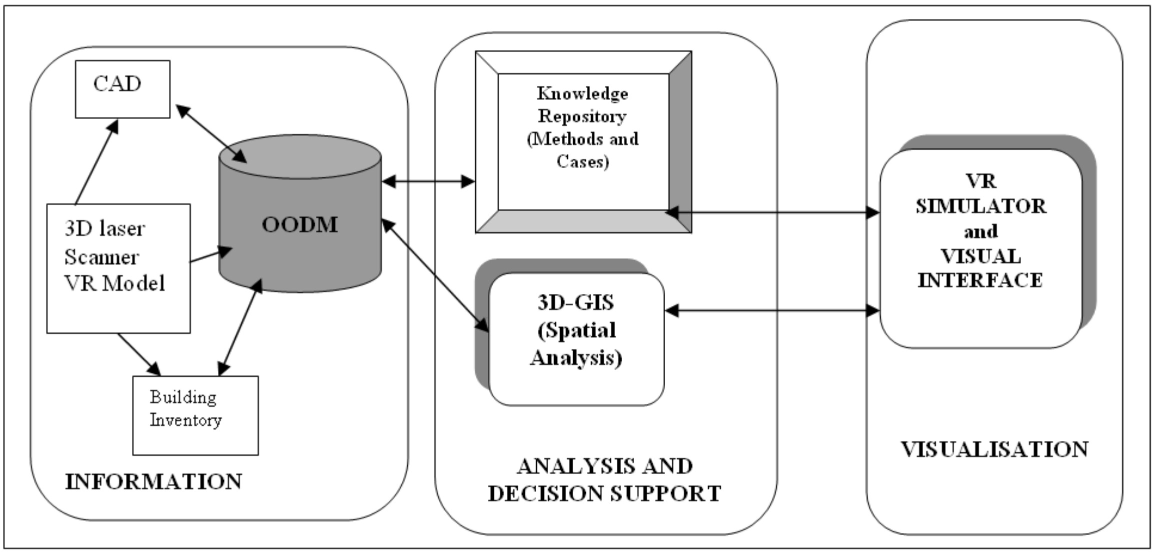

Figure 2 the Virtual Building Maintenance System Framework