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DEVELOPMENT OF AN URBAN AS-BUILT MODEL: THE CASE STUDY OF ABERDEEN

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Abstract: This paper is focusing on the local strategic development plan for the city of Aberdeen, UK, and examines the initiation of applying a regeneration plan to the city centre. For that purpose, Aberdeen City Council commissioned Robert Gordon University to develop a 3D as-built model of the city centre. The researchers developed a novel process to tackle data acquisition for urban scale as-built visualisations that would afterwards promote stakeholders' collaboration. A workflow was developed and tested with the aim to provide not only geometric accurate data of the current state but also meta-data in relation to historic and future applications. Terrestrial LiDAR systems were employed and rapidly advancing hardware and software was tested, evaluated and utilised.

This project aims to have an impact to the 3D data acquisition in relation to urban scale projects that apply Terrestrial Laser Scanning technologies. Furthermore, the suggested workflow can be generalised for the production of urban scale as-built models for the purposes of design and planning decision making and delivery of sustainable infrastructure, transportation systems and overall sustainable communities. The paper concludes with further suggestions for the generalisation of the process and its adaptation depending on the application, i.e. transportation, green spaces.

Keywords: 3D laser scanning, as-built modelling and visualisation, data acquisition.

1 INTRODUCTION

This paper focuses on the application of 3D scanning, photogrammetry and digital modelling for the purpose of developing an urban scale as-built model, within the context of an urban strategic development project. The project was focused on research and development in collaboration with Aberdeen City Council (ACC); it involved consultation and explorations with ACC regarding 3D data acquisition, the development of the 3D model and its potential uses and applications afterwards. The physical context of the work is the city of Aberdeen, in Scotland, with a recorded history dating back over 1000 years. The complex and hilly topography of the city includes an area between two rivers in the north and south that incorporates an old historic town, a former fishing village, and, most importantly, a vibrant business, commercial and housing city centre. However and in common with many towns in the UK, a regeneration plan was required, with a focus in

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attracting and retaining investment initiatives for economic growth. A city centre masterplan was developed that involved a multi-million pound regeneration with "12 community based initiatives, 13 infrastructure proposals, 13 economic outputs and 11 environmental developments across the city. Key housing, building, transportation and public realm concerns raised during the consultation process were taken in to consideration as the city gears up for the next 25 years and beyond" (Aberdeen City Council, 2016). In addition to other initiatives, the Aberdeen City Council (ACC) identified the necessity to develop a fully detailed as-built 3D model of the city centre with a strong research focus; for that reason, the Robert Gordon University and the Scott Sutherland School of Architecture and the Built Environment was commissioned to develop this model.

2 Urban Scale Data Acquisition

2.1 Technologies

Urban scale 3D scanning and data acquisition is typically produced with Light Detection and Ranging systems (LiDAR) and Airborne Laser Scanning methods (ALS) in particular, to achieve rapid and high resolution scans of the areas required (Wehr et al. 1999). ALS has been applied for mapping and monitoring forests (Sverdup-Thygeson et al. 2016; Holopainen et al. 2013), archaeological investigations (Lasaponara et al 2011) and urban environments (Kinks et al. 2015; Xu et al. 2014). However, a range of difficulties occurs when analysing the collected dense 3D scanning data. These issues are typically focused on data filtering and processing together with patterns extraction (Sithole and Vosselman 2004) an issue that becomes even more challenging with complex urban scenes due to the environmental features like height of buildings, breaklines, bridges, vegetation, etc., thus prohibiting data collection (Kinks et al. 2015).

In addition to ALS, further LiDAR systems have been developing into a standard tool for 3D data acquisition for cultural heritage and infrastructure. The technologies in these cases involve 3D terrestrial laser scanning (Bosché and Haas 2008, Bretar et al. 2011, El-Omari and Moselhi 2008) and handheld 3D scanning equipment (Barber and Mills 2011). In these cases, the cultural heritage applications involve heritage preservation and sites conservation up to architectural heritage visualisations (Hakonen et al. 2015, S. Al-kheder et al. 2009, Lambers, et al. 2007). Furthermore, construction and infrastructure projects have highly benefited from the collection and processing of as-built 3D data collection, either for purposes of comparison with planned drawings and identification of discrepancies (Bosché et al. 2015) or for monitoring structural work progress (El-Omari and Moselhi 2008, Cheok et al 2000).

The specific project’s objectives included the collection of highly accurate data and the development of an equally accurate 3D model of the city centre that would feed into the Aberdeen City Council architectural database, thus supporting planning decisions and also providing precise urban dimensions when required. Therefore, terrestrial laser scanning (TLS) was the predominant surveying technique suitable for the project as it facilitated data capture to a high degree of accuracy and covered entire urban areas without missing any data, as it is the case with ALS. The scanner utilised for the project was Leica P30 3D scanner, and it provided a rapid and accurate record of the built environment, not only in relation to buildings but also with a focus on monuments and landmarks. The end result consisted of a substantial point cloud that represented the collected (scanned) points, while photogrammetry methods were overlapped to provide site specific colour data, together with a volumetric as-built BIM model. The resultant point clouds were dense, precise and highly accurate, hence appropriate for the specific project.

2.2 Spatial tools

It has been acknowledged that spatial tools allow for smoother decision making especially in relation to the effectiveness of urban planning decisions (Trubka et al. 2016). Harris (1989) first introduced the Planning Support Systems (PSS) tools. Based on that, different types of tools have been developed accordingly that combine geographical information systems (GIS) and design data with applications for assessing performance and designing for sustainable development, or else known as geodesign (Newton et al. 2013, Geertman and Stillwell 2002). Research on the topic includes, among others, tools like the "Envision Scenario Planner" (ESP), a web-based 3D precinct geodesign, visualisation and assessment tool (Trubka et al. 2016), CommunityViz ((Kwartler and Bernard, 2001), "What if" a collaborative planning support tool (Klosterman, 1999) and CityEngine 2016 (ArcGIS Desktop 2016). In all cases, GIS data are applied on the level of precinct and neighbourhood to support different types of analyses and scenario planning and the use of these tools is focused on creating and considering specific scenarios with a sketching and simulating approach.

In all the previous examples the geodesign is based on GIS data. However, GIS information often includes inaccuracies that can affect the quality of the produced models, thus leading to visualisations being not as precise as expected. The reason for that being the age of data, differences in terms of resolutions, issues with data scale, etc. (Benz et al., 2004; Zald et al., 2014). Quite often, data from multiple sources often have issues with spatial resolution and geographical projections, thus resulting in substantial errors in plot locations. LiDAR systems imaging is also affected by atmospheric turbulence, absorption, and scattering effects, and even though solutions have been proposed by previous research, a significant error is still unavoidable, from a few meters to a few kilometres (Lu and Li, 2016).

The funding context of the work was the development of an as-built model, undertaken in collaboration between the Aberdeen City Council and Robert Gordon University. The key requirement of the project was to produce an accurate model of the city centre that would be beneficial to the Council for planning, performance and analysis purposes. Therefore, neither GIS technology nor ALS systems were suitable technologies and methodologies for developing this project as highly accurate models were required. For that reason, terrestrial laser scanning (TLS) was the chosen technology and *a novel methodology was developed to manage the size and volume of the collected data accordingly*.

3 Methodology and Data collection

3.1 Workflow

The Aberdeen City model creation required to initiate with the identification of the areas that would consist part of the urban regeneration plan. On that front, extensive meetings with the local council preceded to specify the extend of the required model. Afterwards, a methodological process was developed to fit the specific project, as summarized in Fig.1. Generic processes for the creation of semantic rich models within a BIM context require data acquisition, segmentation and the model creation (Hichri et al., 2013; Pătrăucean et al., 2015). Based on the work of Laing et al. (2015), Pătrăucean et al. (2015) and Hichri et al., (2013) a process was developed that included: identification of regeneration areas, 3D data acquisition, pre-processing and registration, creation of the full as-built point clouds and 3D modelling. The following sub-sections are describing the workflow in greater detail.

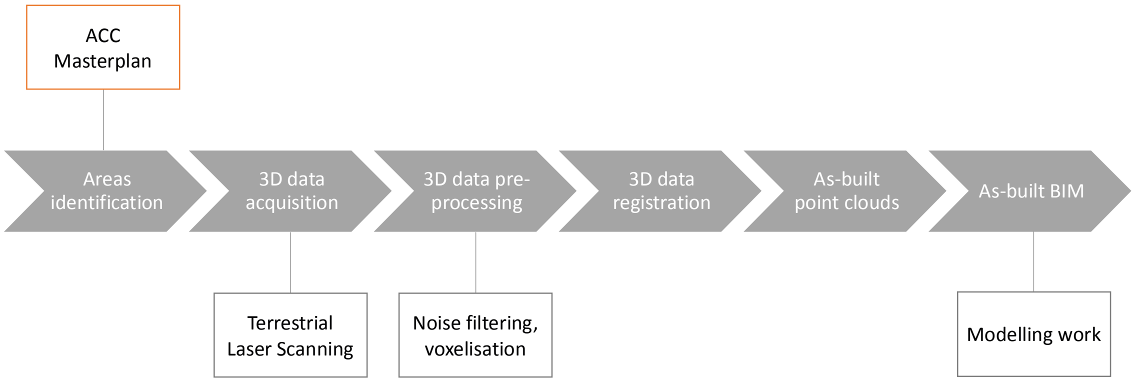

Figure 1: As-built urban modelling process.

3.1.1 3D data acquisition

The 3D data acquisition took place with TLS, for the purposes of the specific project as described in Section 2.2. The map in Fig.2 showcases the extend of the scanning work. 90 terrestrial positions were required on the road level and 10 positions on a higher level, from the top of landmark buildings scattered within the city centre, a process that required two to three months of data collection.

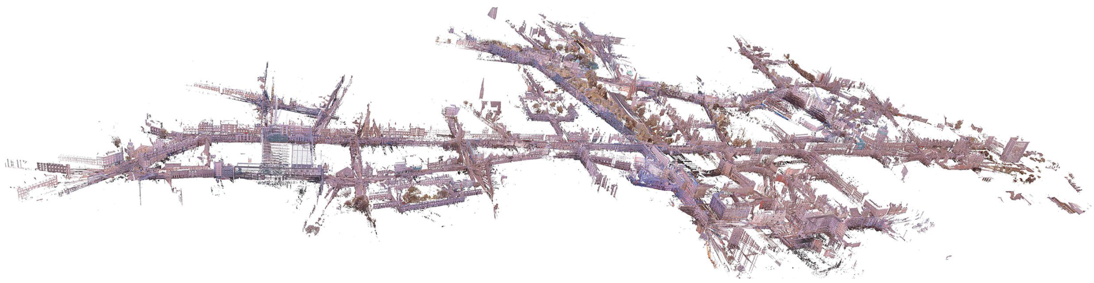

Figure 2: Aberdeen City Centre as-built point cloud.

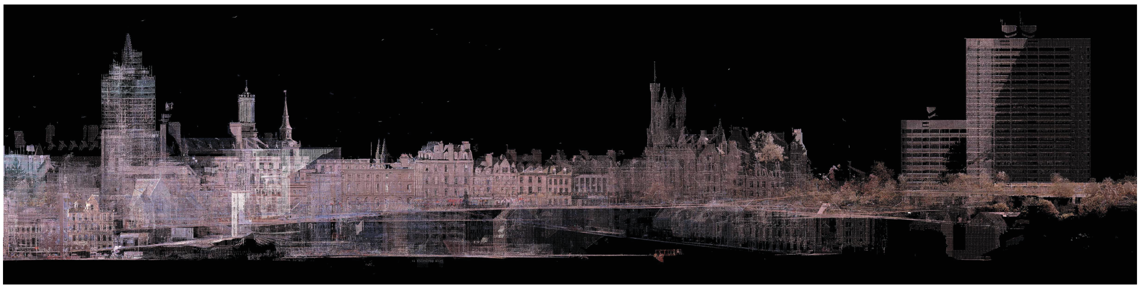

Figure 3: 3D point cloud section of part of the city centre (underground tunnels are visible).

These positions were depended on the TSL equipment accuracy and in this case it involved consequent scanning positions with a distance of less than 40 meters. Furthermore and due to the complex and hilly topography of Aberdeen, further positions were necessary to capture the different levels complexity, as presented in Fig.3. The TLS system was also recording HDR photogrammetry data that were overlaid on top of the point clouds, thus providing real-life imaging.

3.1.2 3D data pre-processing

This part involved securing the accuracy of the collected data by reducing the noise of 3D scanned points that were distorting the built environment point cloud data, including traffic, vegetation, pedestrians and seagulls. In previous research, a segmentation of the point clouds is also taking part at this stage (Poullis, 2013), however, for the requirements of this project, only the noise reduction was performed at this stage, while the segmentation took place before the modelling work initiated. In other cases, voxelisation is required for downsampling the point clouds while smoothing the produced outcomes (Fitzgibbon, 2003; Cifuentes et al., 2014). For accuracy purposes of this project, the collected data were not downsampled at all, thus leading to laborious data analysis.

3.1.3 3D data registration and as-built point clouds

Once the 3D data were pre-processed, the 3D reconstruction followed. This step included connecting the 3D acquired data, which is this case they were composed out of scan worlds, into the same coordinate system. Each scan world was connected to its consecutive one through a registration process, a method that leads to less errors and entails less user involvement (Musialski et al, 2013; Cifuentes et al., 2014). However, and due to the size of the site, this process was more complex. Typically, this process is guided by appearance cues, therefore, the whole city centre was divided into smaller and distinct areas for collecting and connecting the data. The totality of the data were also incorporated into a single point cloud of the city centre, as illustrated in Fig.1.

3.1.4 As-built BIM

The creation of a full geometric model (Fig.4) of an urban environment is a sophisticated problem, not only due to the data processing difficulties but most importantly, due to the high number of infrastructure elements (Pătrăucean et al., 2015). Importantly, automatic surfaces detection, recognition and generation is currently limited to M&E facilities while currently being developed for architectural and urban purposes (Edum-Fotwe et al., 2016).

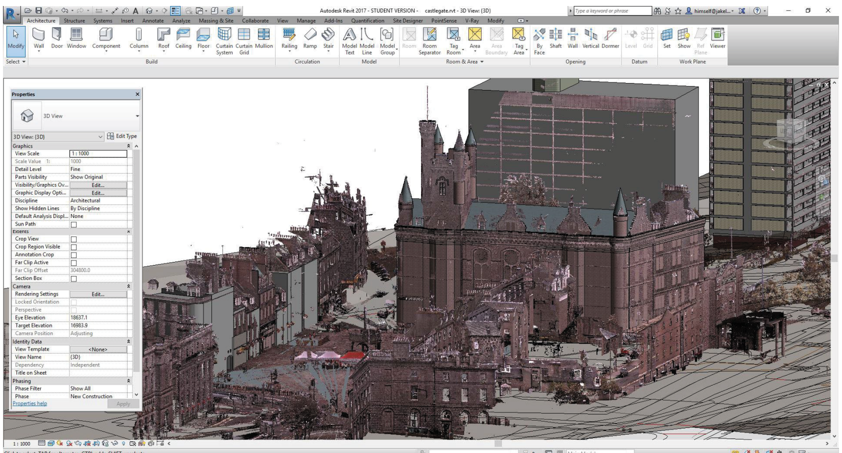

Figure 4: Point cloud data and Revit modelling, on top of the developed 3D topography.

Automatic generation of as-built BIM models was applied mainly to produce the landscape and streetscape of the city centre. Afterwards, segments of the total point cloud were imported and modelled within Revit. Hence, a combination of automated/parametric and non parametric/ manual modelling processes were combined to achieve the complete city centre visualisation, with level of Development (LoD) 200, based on ACC's requirements.

3.2 Meta-Data

Following the modelling workflow, the produced point cloud and the 3D urban mass model were imported within infrastructure software to support the requirements of the City Council in terms of supporting planning decisions and promote stakeholders' collaboration. The software utilised in this case was Autodesk Infraworks 360 that allows central and cloud based model sharing, thus allowing for meta-analysis of the urban fabric. Within the scope of the specific project, ordinance survey data and historic maps were layered with the collected data within Autodesk Infraworks 360 to demonstrate the historic evolution of the city centre. Much of the building level modelling has been undertaken using Autodesk Revit, which provide a basis constructed on a building information modelling platform (as opposed to a purely aesthetic model). Therefore, from a social-heritage perspective the model provides scope to embed meta-data pertaining to historical changes in the city (including topography), or heritage data related to social history. From a wider perspective, there is scope to utilise the model within stakeholder engagement, and this could form the basis for further research and model development.

4 Discussion and Conclusions

This project produced an urban as-built model of Aberdeen, UK, city centre. The aim of both the local council and the university was for this project to initiate longer term model development, where the 3D data will be updated regularly as the city centre evolves and adapts for its future needs. This urban as-built model holds the potential to augment and assist influence map based, city wide and local planning practice, and provides the platform for structured discussion and collaboration among local authorities, local and wider business, industries, research and academia. At the same time, this model will form a solid basis for future urban development since it is capable to support a series of simulations focused on transportation and road design, environmental issues in relation to flooding, green infrastructure and sustainable communities. Finally and for the purposes of this specific case study, a methodology was developed for the creation and management of such an extensive and detailed urban model, and there is certainly scope to further develop the collection, manipulating and use of scan data, with the scan data in itself providing a compelling and comprehensive record of the city over time.

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