Original Article

3D high-definition scanning: Data recording and virtual modelling of the built heritage

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ABSTRACT This article discusses the use of high-definition 3D scanning in the recording and modelling of the built heritage. In particular, it explores how such technology can be used as a complement to both traditional measurement and historic records, as well as in the 3D surface modelling of heritage detail. The article uses examples from cinema buildings of the twentieth century, which arguably embody both an important physical record of society and a challenge in terms of representing a complex range of historical, cultural, economic and physical data sets. The work provides an overview of visualisation techniques that are appropriate to the subject, and provides a case study taken from the city of Aberdeen. In particular, attention is drawn towards the manner in which large and physically complicated structures can be recorded rapidly, to provide a permanent record of dimensions and building form. Furthermore, the data set produced through use of a 3D scanner can be readily translated for incorporation within architectural models such as a 3D surface mesh. The article concludes that emerging technologies will facilitate the rapid collection of highly accurate information pertaining to the still intact physical structure, where still in place, but that such data must be related directly to wider contextual information so that informed plans can be formulated for future developments, including conservation strategies.

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INTRODUCTION

This article concerns the collection and visual representation of data pertaining to historic buildings, and to cinemas in particular. The work aims to discuss the complex range of data available to help describe and record such buildings, including information on the structure, materials, design, history, social context and plans for the future. It is arguable that such a complex range of data types requires a multi-stranded approach to visualisation, and one that takes the view that all strands are essential to support a deep understanding of the implications of intervention or change in the future of a building or, more precisely, the built heritage.

Cinemas are a particularly interesting building type, given the relatively short window of time in the twentieth century when a large number were constructed, which saw the rapid development of approaches to the design of auditoria. Recent changes in the past 50 years have seen a decline in the number of operating theatres; although a considerable number of the buildings remain, they house new uses. Although the main visualisation technique used here (3D representations drawn from high-definition scans) uses a highly technical approach to data acquisition, it is also clear that understanding the wider context of cinema development requires an appreciation of qualitative, historical and socio-cultural (non-spatial) qualities.

VISUALISATION METHODS

Traditionally, architects and urban designers have presented design ideas to clients using static representations such as scale plans and sketches. Architect's 2D orthographic presentations, although accurate in terms of measurement, struggle to give the non-expert viewer a 'feel' for what the space will be like when it is finished. It is commonly acknowledged that people often have trouble understanding architects' drawings, which can lead to discontentment with the end result or misunderstandings (Appleyard, 1976). As an alternative or additional method of presentation, sketches are often favoured by architects as a method to present ideas in a more fluid style, and are believed to promote feedback and discussion through their 'unfinished' appearance (Schumann *et al*, 1996). An additional factor that should be brought to bear on the subject of cinemas is the fact that important aspects of heritage or social value are not necessarily physical parts of the built environment, but may relate instead to less tangible aspects of historical importance. A further complexity of built heritage, and many existing buildings in particular, is that drawings, if used as a tool for data recording, of these historic buildings represent the 'finished' static product, a fixed view in time and fail to pick out the many additions or the timeline of a building that may add further depth, insight and value to the understanding of a building.

A key point when considering any method of information visualisation is the result of looking at a diagram, picture, image or data resource (Spence, 2007). Where understanding has been acquired in the mind of the observer, rather than as a result of text or statistical analysis, we can say that 'insight' has been acquired. In this sense, we must try to remember that visualisation is essentially a cognitive activity, which is not reliant on computers. Recent research by a range of authors ((Lim *et al*, 2004), (Sener and Wormald, 2008), for example) has successfully studied the relationships between the professional, medium and the resultant visualisations. Such studies have shown that the approach taken to visualisation itself can affect the insights drawn, and that care should be taken to match the visualisation method (for example, sketching, CAD, 3D modelling, physical modelling, painting and so on) to the desired and intended purpose of the exercise. This is a particularly important factor when considering the visualisation of

historic buildings, where a complex range of variables will require a range of techniques to convey their meaning effectively.

It is also true that by using visualisation we open up the possibility of juxtaposing information of different types on the same image or model. For example, it should be possible to incorporate details of material and construction design with temporal (that is, time data) or social data (for example, demographics changes). Spence (Spence, 2007) suggests that we could also categorise such data in terms of whether it is quantitative (or qualitative), ordinal or categorical, and that we can then aim to draw relationships between these.

Recent research (Rohrmann and Bishop, 2002) demonstrated that, although computer simulations can obviously only approximate reality, they are acceptable to most people as valid representations of the real world. For example, Heft and Nasar (2000) found that, although research on environmental perception and aesthetics has traditionally been conducted using photographs or slides, reactions to static displays do not parallel those of dynamic displays. Interestingly, they found that preferences were significantly lower for dynamic compared with static conditions. This finding has implications for the way in which architectural and urban designs are presented to people – a building may look appealing in sketch or CAAD model, but we do not ‘use’ a building in static form.

This article argues that cinemas represent a rich seam of information regarding the changing society in the twentieth century. This information provides tangible evidence of social change, economic mobility and user preference in addition to design of the buildings themselves, and may require innovative approaches to modelling and visualisation within conservation, planning and design. Certainly, Historic Scotland advocates that plans for the future conservation of the built heritage should include consideration of the site, significance, recorded history, materials, condition and an action plan (Historic Scotland, 2000). Importantly, Historic Scotland also advocates recording gaps in such knowledge. Where such an undertaking could be assisted or driven by visualisation of such data, this would arguably improve the reliability and clarity of decisions reached.

CASE STUDY

Overview: Aberdeen and the Tivoli Theatre

During the twentieth century, the city of Aberdeen contained as high provision of cinemas per head of population as anywhere in the United Kingdom, only challenged in Scotland by Glasgow. In the late 1930s, the city contained 19 cinemas, with the city population at 175 000. Figure 1 provides some illustration of the density of cinemas existing across a small geographic area of under one square mile.

During the 1970s and 1980s, for a complex range of reasons, the number of cinemas in operation in the city dropped considerably, to the point that in 2008 only two cinemas remained in the city centre, one of which was only rebuilt and opened as an art cinema in the 1990s. Although the city also has a large multiplex located at the beachfront, with another built in the city centre in 2010, it is also true that the architectural legacy of the growth of cinema over the past 100 years has left a mark on the townscape, which remains, despite changes in the industry that prompted their original construction.

The case study used for this article is a currently unused theatre located at the main transport hub, the Tivoli. The Tivoli, similar to many buildings used for the showing of early cinema (and in this case newsreels), was built as a theatre, and remained in use as a variety theatre until the mid-1960s, following which time it housed a bingo hall until

Figure 1: Locations of cinemas in Aberdeen (city centre).

final closure in 1997. The theatre was one of the earliest buildings used to show examples of cinema in Aberdeen, particularly before the first World War (Thomson, 1988). The building was originally built by CJ Phipps and James Matthews in 1872, named Her Majesty's Opera House, with further work undertaken by Frank Matcham in 1909, and the theatre being renamed 'Tivoli' in 1910. It also has a range of important additions, currently under threat of removal and/or major restructuring. The building is Grade 'A' listed, which provides the highest level of statutory protection available in Scotland.

The main external façade of the Tivoli theatre remains largely intact, and presents a (potentially) impressive welcome to a visitor to the city. The theatre is located opposite the main transport hub (rail and bus), although its role as a theatre is not obvious given the lack of signage. Internally, the main auditorium (Figures 2 and 3) is in a reasonable condition given the time since it was last used and maintained to an acceptable standard. Amendments to the seating layout to accommodate recent use as a bingo hall could be removed easily, although much of the rich internal decoration and paintwork has been replaced by much simpler and typically monotone colours.

However, a large proportion of the peripheral rooms (bars and changing rooms) are suffering badly from water penetration, and the building would require considerable remedial work to bring it up to current health and safety, access and building standards. Of particular concern is the fact that the auditorium ceiling is beginning to show signs of water damage from above, indicating that work should be undertaken urgently to help preserve those parts of the building that arguably contribute the greatest to heritage value.

The building was used as a bingo hall for many years, meaning that only the stall area was actually in use. The circle and balcony levels are therefore largely intact, with many original features untouched (for example, brasses and door details). Behind the stage, the original scenery equipment is fully intact (although not usable at present), and would be preserved in any future modernisation scheme.

The building underwent a period of modification and 'modernisation' in the 1950s, which saw the removal of some features (including the projection box) and the obscuring of other features behind partially removable boarding. Current owners have secured Heritage Lottery funding to repair the roof, and to make the building watertight.

Figure 2: Tivoli auditorium.

Figure 3: Tivoli auditorium.

Geographic and socio-economic representations

The preceding sections described how the growth of cinema across the early part of the twentieth century resulted in the construction of a significant number of large buildings, which together had a major impact on the appearance and use of the city centre.

Although the overall revenue generated by cinema in the United Kingdom increased steadily during the 1990s, there was also a corresponding shift away from city centre towards out-of-town facilities (Mintel, 1999).

There is an obvious hypothetical link to be drawn between the geographical spread of cinemas, and the travel time and costs associated with visits. With the increasing prevalence of multi-screen cinemas in the United Kingdom towards the end of the last century, the travel options open to most visitors also moved from obvious public transportation and pedestrian options, towards car travel. Thus, access arguably becomes related to the users' ability to access appropriate transport, in addition to costs associated with entrance charges and so on. In some respects, this relates to previous work by the author concerning access to public open space, in that a geographical analysis of the relation between residential sites and target sites can be linked to pedal, public transport and car options (Laing *et al*, 2006).

With regard to cinemas, however, there appears to be a non-homogeneity issue that influences the manner in which users regard out-of-town multiplexes, as opposed to city centre cinemas (Collins *et al*, 2005). That is, although travel time and cost appear to negatively influence whether people will visit 'traditional' cinemas, users appear willing to spend more time and money travelling to out-of-town locations, with data appearing to suggest that convenience of parking and the ability to book tickets in advance are crucial factors in their choice. Although the latter factor is arguably less relevant at present than a few years ago, there would also appear to be some evidence that car owners are willing to travel farther than city centre occupants, and that this coupled with a suburbanisation of the UK's cities might also have contributed to increasing attendance at multiplexes. On a perhaps deeper social level, research has also shown that the choice of cinema frequented by individuals is also heavily influenced by the overall atmosphere and additional facilities provided by a place, and the feeling of safety afforded by that environment (Hubbard, 2002).

Hubbard takes this notion further, and argues that the change has been driven by a widening desire by society to find meaning in life through the consumption of experience, where one can be sure to avoid uncertainties and stresses brought about through contact with people from different backgrounds to their own (following Thomas and Bromley, 2000, for example). It is perhaps of note that plans for the future of the Tivoli and other such buildings (see Figure 4, for example) recognise the need for facilities such as cafés

Figure 4: Development model for foyer area.

and restaurants that cater to users wishing to participate in wider activities while at the building (also relating to Hubbard's findings regarding multiplexes (Hubbard, 2002)).

What becomes clear is that there is a need to reflect such societal changes in the methods selected to visualise cinema trends in the United Kingdom across the past 100 or so years. To simply reflect the basic geographical spread (as shown in Figure 1) or the physical structure (as in section 3.3, below) would miss both the social context that contributed to the closure of such buildings, and the economic drivers that have led to an uplift in the industry as a whole, but that have not in any significant way preserved the historical 'location' of cinema in the city centre.

A three-dimensional record of the intact structure

The study collected geometrically accurate data pertaining to the fully intact auditorium using a high-definition 3D laser scanner. The scanner collects a 'point cloud', and was assembled at four locations inside the auditorium (the stage, stalls, circle and balcony). The process followed was similar to that reported previously in the literature (Barber *et al*, 2006; Arayici, 2007), where a range of techniques have been used to utilise the resultant data set within architectural modelling.

The process itself, although producing a three-dimensional visual representation of objects, operates quite differently to modelling processes normally followed using 'additive' software such as AutoCAD or 3DS. In such software, buildings are virtually 'constructed' in empty space, with the designer initially adding objects and shapes to create the illusion of real material. The scanner, in contrast, operates by identifying where points lie on a surface, and effectively works by 'hollowing' space around the scanner head. Therefore, surfaces that cannot be seen directly and without obstruction from the scanner are not recorded, and appear as areas of shadow. Thus, a series of locations are used to ensure that more points are recorded, with scans joined subsequently to produce a more expansive model. The scan information shown in Figure 5 can then be used to present straightforward images from the scan site, or potentially rotated and scaled, as in Figure 6. The interior of a cinema or theatre presents particular challenges in this regard, given the overlap of horizontal spaces created by balconies, and the necessity of having

Figure 5: Scan of the stage area.

Figure 6: Still from scan showing the auditorium shape.

areas of the stage hidden from the audience. This is also well illustrated in Figure 6, which shows how the interior shape of the auditorium has been picked out by the scanner, leaving the internal content of the balconies hidden. Of course, it would be possible and desirable in many cases to undertake further scanning, to ensure that all visible surfaces had been recorded, from which wall and other thicknesses can be quickly derived.

The most obvious immediate uses for such scanned output are twofold. First, a far greater level of accuracy can be expected when taking measurements from the model than would ever be possible undertaking manual surveys on site and much more quickly. Second, and perhaps of most relevance to this study, is the potential for using such surveys to identify and record accurately to the existing structure. Although in the case of the Tivoli the auditorium is intact and remains in much the same condition as it has been for many decades, many other cinema buildings have been subdivided over time and details removed or altered. A potential use of this emerging technology should be to facilitate a virtual reconstruction of altered buildings, using measured 'clues' from the site.

USE OF SCAN DATA WITHIN FURTHER CAD DESIGN MODELLING

Although it is true that raw scan data have the ability to provide value to the building professional through the provision of highly accurate geometrical data, this has limited usability for the designers and surveyors without some form of post-processing. For example, the data could be used as the basis of two-dimensional sectional and elevation drawings, produced in typical CAD packages (Brown *et al*, 2009). However, it is important to note that widely accessible software can allow scan data to be post-processed for use as a surface mesh within new design models, and subsequently accurately modelled and rendered. An example shown in Figure 7, for example, illustrates such a mesh, produced through processing of data taken from the Tivoli scan. The mesh is of a moulding located well outside an area of the auditorium inaccessible using traditional surveying methods, and certainly not usually accessible without great expense (in terms of both time and the cost of scaffolding). Using the 3D high-definition scanner, accurate measurements were taken to millimetre detail of a complex shape in little over 20 min.

Showing a detail taken from above a balcony 'box seat' in the auditorium, the surface of a plaster moulding, in this case that of an angel figure, has been processed for use

Figure 7: Detail from 3D surface mesh.

within packages such as 3D Studio Max, or AutoCAD. The raw scan data were transformed from that of a ‘point cloud’ to a Poisson mesh using the third-party (freeware) Meshlab. The possibilities following such processing are immense, as they would allow for the data to now be used in, as stated, new design work, but also potentially within with rapid prototyping studies, and the like. Thus, the highly rich data set collected to record a building in its current state becomes useful as the starting point for future work.

DISCUSSION AND RECOMMENDATIONS

This article describes a field study that aimed to explore how a complex array of information pertaining to recording of the built heritage can be facilitated using

techniques from information visualisation. The case study considered in this article operated as a successful theatre and cinema for over 50 years, before partial closure and change of use in the 1960s. Its history as a 'variety' theatre, which is thought to have displayed only a limited range of early cinema and newsreels, is interesting in itself, in that changes in the expectations of an emerging consumer society contributed to its eventual demise, almost regardless of its architectural and functional qualities.

Emerging technologies, including both computer modelling and laser scanning, are clearly important tools in recording of the built heritage. However, it is equally important to ensure that the emerging data are related to other drivers, which will in many cases be far more influential within design, planning and eventual use of a building. The data capturing and recording using such devices should be seen as an ongoing process. It could, and perhaps should, allow for a greater flexibility in the change of use of historic buildings by recording details of features, forms and shapes accurately and for posterity much in the same way an archaeological dig is conducted. In many ways, this methodology ensures that a visual record is maintained despite a change of use (for wider study and dissemination in future years), yet ensures that buildings do not remain static and can dynamically change. In essence, if parts of a building are destroyed – there will, if recorded this way, always be a virtual record. This, arguably, will change the face and process of recording historic buildings and affect the strategies put in place for their protection.

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