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HBIM and matching techniques: considerations for late nineteenth- and early twentieth-century buildings

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Historic Building Information Modelling (HBIM) is limited by the irrelevance of object libraries and the inability of 3D scans to determine structures in buildings of dissimilar age and construction. The potential for energy conscious initiatives to make informed judgments regarding the 'deep renovation' of traditional buildings requires development of better non-invasive appraisal methods. Presumptions are dangerous for the majority of forms of historic building construction, yet older buildings benefit from better statutory control against alteration in any event. Here it is proposed that the pre-existing standard methods of nineteenth- and early twentieth-century construction could improve capacity to build data for a significant number of buildings of that era. The matching of images to develop place recognition algorithms has been deployed in a number of contexts. Standards, Patents and Specifications provide the means for developing new object libraries nested and shared from the surface to the structure. The example of decorative finishes, commonly used in public buildings at the turn of the twentieth century, demonstrates a traceable route whereby classifications could be determined using historic specifications and product data. The wider potential for such groundwork to enhance capacity to model energy performance of these less well protected buildings is suggested.

Keywords: matching; HBIM; nineteenth and twentieth century; specification; standards; deep-renovation

Introduction

Relevance and method

Historic Building Information Modelling (HBIM), aiming to meet government demands for auditing the building industry has to date struggled to gain traction beyond quantified outcomes such as cost or structural performance.[1] In theory, for historic buildings, the presence of long term records, and their measurability should make them better sources of data than those that are proposed on the basis of projected performance standards yet their idiosyncrasies defy pigeonholing and blanket statements. The contribution of increasingly usable scanning techniques whether by 3D laser scan or structure-from-motion methods are limited to providing data which records the surface finish and dimensional characteristics of a space or a building exterior. Here, it is proposed that advantage is taken of the data generated through the increasingly mechanised building industry and professionalisation of designers around the turn of the last century in order to inform measured data. For this significant proportion of the UK 'traditional' building stock, standards and specification can be of use to supplement geometric survey data. Since the 1840s,

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specifications were determined as a sequence leading from Structure to Finishes.[2] It is proposed that this archaic workflow sequence may be an advantage in augmenting the information relayed by surface scanning techniques.

For scan data to be of more immediate use in HBIM applications, not only do greater libraries of standardised components need to be sought where possible but also groundwork to establish wider contextual parameters should be used. Murphy et al. established a workflow to add photogrammetric survey data and parametric constraints to inform HBIM.[3] To date the key role of HBIM remains one of quantification,[4] for the sharing of economic consequences of a proposed plan, whether they be in quantities of material required or to enable structural calculations. Here it is suggested that it also contributes to a more accurate calibration of building performance modelling. HBIM should be developed to address specifically increasing pressure for the deep energy retrofitting of historic and traditional buildings.

There is a significant risk to judgments made for the treatment of marginal historic buildings when oversimplification or inaccurate generalisations of material qualities are presumed for calculation purposes. For this reason, improving the accuracy and deterministic capabilities of HBIM is a desirable and in many cases an urgent requirement. At present, demands for energy and conservation dominate the economic and low carbon agenda and increasingly research is directed towards improving the energy performance of existing building stock since in 2010, 41% of energy use in Europe was said to come from buildings.[5] Whereas ancient buildings may be relatively well protected by legislation, 'traditional' buildings and also innovative buildings of the time lie at the margins of protection. The many thousands of buildings built at the turn of the last century are at risk of significant alteration in advance of a proper assessment of their quality in terms of a legacy for future generations.

The increasingly mechanised era of building from 1880 onwards is however, significantly better documented in technical terms than previous periods through records of product literature, standardised procedures and material classifications. The practice of specification which grew from a consolidation of professional expertise was established in the UK and in the US along similar lines, and could, if sufficiently well organised, be determined to provide the prompts for the rapid and increasingly accurate interpretation of surface measurements.

Modelling of environmental conditions is limited by risks of over-supposition, as are deeper analyses of material composition. Laser scans and photogrammetric surveys are limited in their ability to record only visible surfaces. Here the potential for the correlation of historic product literature, standardised trade practices and product patents are investigated as potential sources of repeatable data which might make developments in 'place recognition' techniques play a critical role in this process. This has scope for improving accuracy for building performance analysis, heritage documentation and also for more accurate valorisation. By definition, The work is generally limited to buildings built after the development of the architectural and engineering professions from the 1840s onwards, however there are a huge number of these, termed 'traditional' whilst not yet considered 'historic', and they are often at the greatest risk of unsympathetic modification.

Outlining the potential for existing data and processes to be advanced, this article then illustrates how a particular common feature of late nineteenth- and early twentieth-century building is recognisable as a key component in three different contexts under differing conditions of decay. The study seeks to lay the groundwork for taking such work forward.

HBIM and object libraries

Autodesk's Revit BIM software enables the formulation of object libraries and families with parametric constraints and properties. The capacity for HBIM to be applied meaningfully or efficiently to support the evaluation of performance of historic buildings is severely hampered by the inability

to rely upon standardised objects. Murphy et al. have established the potential for pattern books and principles of proportion to set parametric constraints for the reconstruction of typical eighteenth-century buildings in Dublin and Prague.[6] Oreni et al. have used 3D scanning techniques to develop structural object libraries for brick vaults and timber floors in Italian buildings.[7] Barazzetti et al. have gone on to explore the capacity for HBIM to be incorporated into mobile apps.[8]

Whilst unique attributes will remain a limiting issue for the swift evaluation of a large number of heritage buildings, it is entirely plausible that the post-industrial revolution built stock in the UK and US could benefit from greater recognition of their standardised typologies, workmanship, materials, specifications and building products.

Place recognition principles

Historic buildings are commonly categorised by construction type and often provide accurate dimensional datasets between them, yet the translation of such information into shared formats is constrained by a lack of commercial incentive. Research has already demonstrated the capacity for place recognition to be automated,[9] based upon Random Sample Consensus (RANSAC) algorithms initially developed in the early 1980s.[10] More recently, Johns and Yang have developed *Pairwise Probabilistic Voting* (PPV) whereby lower computational demands enable more rapid matching between images of objects.[11] Amato et al. have applied landmark recognition techniques to k-Nearest Neighbours algorithm classification principles in order to develop monument recognition processes.[12] The principle of matching is an enduring one: Johnston noted in his *History of Light and Colour Measurement* the acceleration of techniques at the turn of the last century, including those of *Matching* or *Nulling* for photometry and colorimetry for commercial purposes. The observer compares intensity directly with a standard (for example a star, planet or standard candle) and then adjusts the standard until the light is nulled. Colorimetry, a term coined by chemists for determining quanitities dissolved in a solution, was also based on *Matching*. Joseph Lovibond, an English brewer made a very successful matching device called a 'Tintometer' which compared a graded set of glass filters to beer.[13]

Increasingly, research today in computer vision is driven to create matching algorithms to cater for challenging contrasts such as those generated by images taken in varying weather conditions.[14] This is perhaps the most useful development with regard to the potential for HBIM libraries to play a role. The question of whether such methods could be brought forward to tackle comparisons between illustrations and photographs arises here. Advertisements and product literature in the UK publication *Architectural Review* began to shift from engraved images to photographic ones around 1900. Greyscale photographic advertisements notionally have the advantage of being more readily paired. By contrast, a black and white engraving provides a highly descriptive depiction but may not so readily be matched with the observed object in a scan. There are means to increase the speed of this apprehension by simply cataloguing and categorising these elements according to function, but further work is required to determine if this could be automated further. Johns and Yang's recent work reverts to using RANSAC methods to match 2D image 'cliques'.[16] This may have potential to be applied to the correlation of illustration and photograph.

Very often the functioning aspects of decorative schemes, the way in which they covered structural joints or incorporated heating or ventilation equipment are deemed redundant because of ignorance of how these mechanisms were set up to function. Given that such features were standard elements of so many buildings, even where they have been altered for good reason, there is potential to make significant gains from identifying such patterns and enabling future projects to contribute further to such knowledge bases.

Figure 1.   Advertisement for Roof Ventilators from the *Architect's Compendium* 1893.[15]

Figure 2.   Roof Ventilator: Cradely Heath Library Wills and Anderson, 1909.

Organising a parametric library

Murphy et al. established the means to identify construction methods through the use of pattern books correlated with 3D Survey data.[17] It is critical that platforms are designed to enable the addition of knowledge as it is created. To this end, further shareable platforms need to be

provided. The Association of Preservation Technology International have compiled a rich data-base of trade literature which is accessible to all.[18] The Royal Institute of British Architects (RIBA) in the UK as well as many Schools of Architecture contain within their libraries huge quantities of technical history, which is, by virtue of its relative closeness, deemed of marginal interest and thereby also risks being overlooked. It was common practice for journals to be bound by academic institutions without their advertisements, a habit which has severely diminished the value of many collections.

The metadata for materials, their structural and environmental performance, their period and region of manufacture have however, long been classified in Technical Indexes using transatlantic standards for their ordering. It appears logical to adopt these regimes and build parametric constraints according to the information supplied rather than applying the given information to a new script.

Scale application

Oreni et al.'s work has already established the practice of taking the room or base plan to establish the span of a vault.[19] Murphy has used constraints determined form pattern books.[20] These insights are critical in stitching the logic of the surface discovered to the dimensional potential for its application. The deeper cataloguing and intelligent ordering of available resources and technical guidance become the principles behind which the semantics of the object library should be constructed. The number of traditional or historic buildings in England alone demonstrates the potential scalability of the proposal; twenty per cent of English housing was built pre-1919 and 17% between 1919 and 1947.[21]

The National Building Specification in the UK (NBS), in association with key Computer Aided Design (CAD) developers, has already established standards for workflows to incorporate contemporary products and to build shareable BIM libraries. The commercial incentive to do so is self-evident, to do it for traditional buildings requires a deeper commitment.

Historic resources

Specification: structure and finishes

The first published format for architectural specifications in the UK was developed from practice itself. Organised by building type and then by trade; roofer, plasterer, etc.[22] Updated by Rogers in 1872,[23] and again by Donaldson,[24] it was adopted by the architectural press in 1900 and printed annually until 1970 when the NBS was launched, which continues today. The process and format was closely paralleled in America by Bower.[25] Published initially almost as self-help guides, specification remains a self-taught skill, yet it most closely describes the materials, workmanship and performance to which design drawings relate. As Bower noted, the categorisation model grew from practice, as did Donaldson's use of prime example specifications.[26]

The key correlation between specification practices and those of laser scanning and structure from motion is that of a classification of finishes separated from structure. In today's specification software, just as the specification of a structure and skin will prompt the specification of a finish, the designation of a finish will prompt the definition of the supporting framework, superstructure and substructure. By selecting emulsion paint, the background layer, its adhesion to the layer behind the composition and reference for the plasterboard will cross-reference to the supporting studwork, the fixing of the studwork to the head and sill, the head and sill to the external construction and finish, etc. It is this method of deduction which is tested here, as applied to the interpretation of scanned data which records finishes.
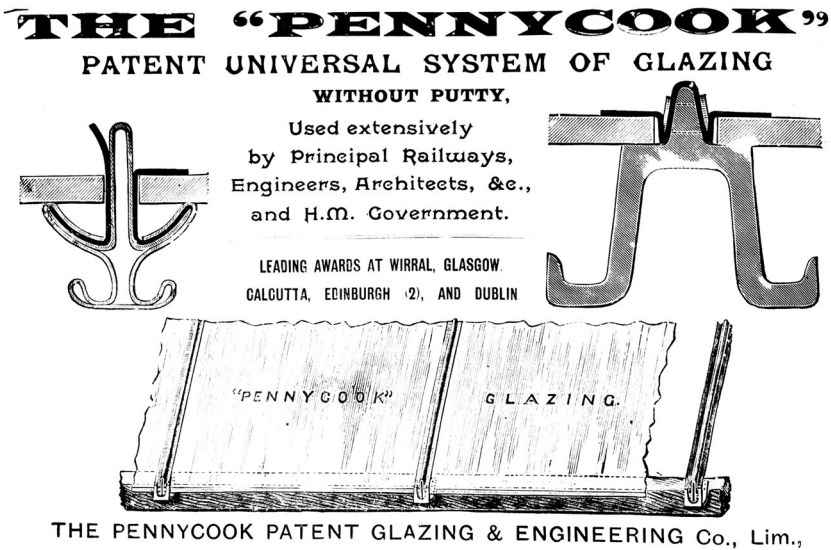
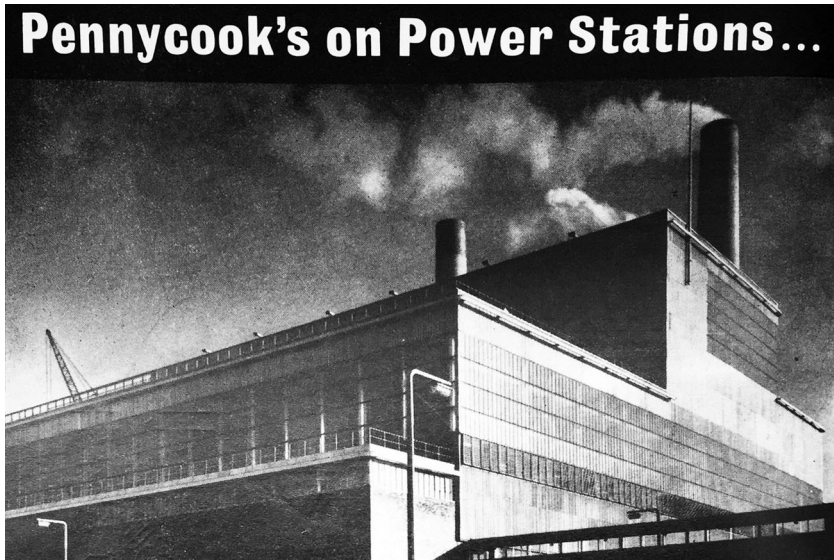Figure 3.   Advertisement for Pennycook Patent Glazing from the *Architect's Compendium* 1893.[27]

Figure 4.   Pennycook's Patent Glazing Adverisement in *Specification* 1966.[28]

Standardisation and patents

The impetus for the definitive classification of building products and materials stemmed from the need to establish patents for commercial purposes. These methods of calibration were necessarily exhaustively researched, renewed and updated in order to be resilient in an increasingly competitive and international legal environment. Whilst claims as to the accuracy of product performance might have proved misleading, the actual classification of products is often very precise.

Advertisements in historic building journals and product literature where available provide patent references but also, crucially, illustrated resources that may be matched to observed examples. In the case of more significant buildings, significant hints were often given through advertisements in the journal in which the finished building was published.

Case study: decorative fibrous plaster ceilings

Prevalence:

Curved and decorative ceilings were made possible by the use of pre-stressed concrete, but also using steel trusses beneath timber roof structures. They were highly popular within public buildings; swimming pools, libraries, courts, schools, etc. because not only did they enable wide spans to cover larger spaces, they also had environmental benefits, enabling ventilation as well as the economical incorporation of top lighting.[30] Architectural competitions for public buildings published in *The Builder* between 1890 and 1930 and later, reveal the incorporation of curved ceilings in the shared spaces of public buildings in the UK to be almost universal. The associated use of decorative fibrous plaster mouldings to adorn these ceilings also became a standard finish. Numerous companies initially provided such services. G. Jackson & Sons remain in existence with catalogues that span a 235-year history.

Identification methods

By collating the 3D data from interior site surveys with a laser scanner or with structure-from-motion pointclouds, it is possible to associate elements from commercial catalogues and to

Figure 5.   Dining Room, Dartmouth College.[29]

gain further data from standard specifications for materials and workmanship of the time. Buildings can then be better understood in terms of their material performance and their durability to date. Adding data with respect to environmental performance (thermal and in terms of moisture absorption), provenance (location and date), probable chemical composition of finishes and calculations of natural and artificial light reflectance all assist in building the data model of a building's provenance beyond the surface geometry. In addition, the alignment of contemporary specifications can be used to collate further data such as fixing methods, thickness and substrate construction standards. These data can be added to create asset information models (AIM) for historic buildings and contribute to Life Cycle Analysis (LCA) modelling with the benefit of actual historic data, both of which are stated aims of BIM for new buildings set out in ISO14000.

Three examples

The three case studies presented here reveal the use of historical data in conjunction with computer modelling to better comprehend the performance and value of three buildings which all have (or had) curved ceilings.

Cradley Heath Library, Birmingham

Cradely Heath library, built in 1909 by London Architects, Wills and Anderson, is a single storey building with a vaulted reading room. The key purpose of the high ceiling being the incorporation of dormer windows to provide brighter light from higher in the sky like cryptoportici and adequate ventilation to relieve staff and visitors from the overpowering smell of the anticipated unwashed public.

From a photographic survey and spot dimensions, a simple CAD model was created in order to model the effectiveness of the original design for natural light using RADIANCE software. Here, the mouldings remain in place and it is possible though historic records to determine the supplier of the ceiling plaster, the ventilation system and the windows.

Figure 6.   View of curved ceiling in reading room, Cradley Health Library.
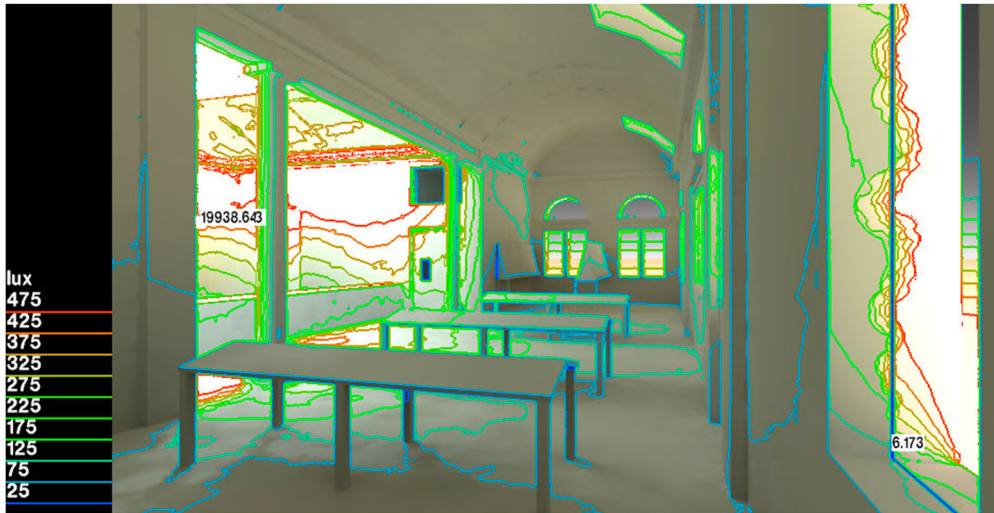
Figure 7.   RADIANCE rendered model depicting natural light distribution in reading room, Cradley Health Library.

The value of the quantification of natural light through this modelling is to highlight the design sophistication which developed within an era of constrained use of electricity. Whereas, in the coal rich field of the Black Country, fuel for heating was readily available, both the prevalence of smog and the immature technology of electrification demanded inventiveness with regard to the use of natural light, a resource that is commonly overlooked as artificial light became cheaper. These design principles were understood as standard methods for optimising scarce resources.

Lister Steps Library, Liverpool

The Carnegie Library at Lister Steps in Liverpool was built in 1905, designed by Thomas Shelmerdine. In its present state, the building is derelict and awaits the implementation of a funded re-purposing project. Emergency repair teams have removed considerable quantities of damp plaster and have stored sample profiles in anticipation of its reinstatement. The ceiling of the main reading room remains reasonably intact and a recent laser scan by one person taking less than half an hour reveals the surface profile but also the layers of construction supporting the surface by virtue of its decrepit state.

From the dimensional data revealed through the scan of the ceiling surface alone, the typical elements including the structural module, the roof light dimensions, the location of ventilation grilles as well as the specific plaster mouldings can be identified. Simultaneously, reference to the journal in which the finished building was published can supply data as to the suppliers of the roof lights, plaster finishes, electrical light fittings and ventilation patent systems through reference to associated advertisements.

The cornice, for example, can be identified as No. G103 from a G. Jackson & Sons Catalogue. All other profiles may be similarly identified. If the process of this identification was to become one that was semi-automated, through the sharing of databases and dimensional matching software such as that being developed by Johns and Yang to identify 'Geometric Cliques', the future proprietors of this building would be rich in data and understanding, improving their

Figure 8.   Lister Steps pointcloud of main reading room.

capacity to design and manage their use of the building, to recognise its values and the way in which it was originally designed to perform environmentally.

Using categorisation from collating contemporary specification documents together with the product literature, it is possible to input parameters defining the build up of the supporting structure and to take steps towards including other data such as the thickness and R-value contributing to more accurate estimations of heat loss.

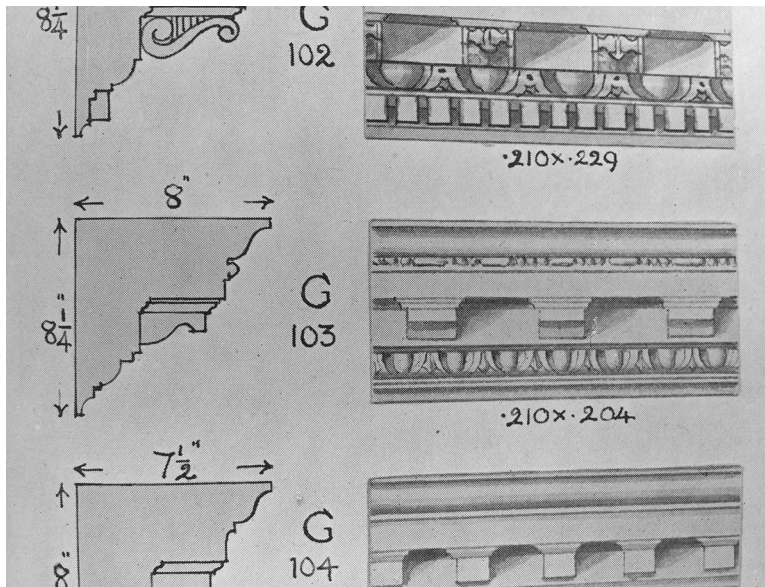Figure 9.   Lister Steps ceiling of main reading room.

Figure 10.   Cornice in G. Jackson and Sons Catalogue. Used with permission from G. Jackson.[31]

Coal Exchange, Cardiff

The trading hall of the once vibrant Coal Exchange in Cardiff, designed by James, Seward and Thomas c.1886, had a similarly vaulted and glazed roof supported by a set of steel trusses. Again, the single volume space was designed to profit from the benefit of direct top lighting

Figure 11.   Cut away of laser scan of main trading hall 2014, Cardiff Coal Exchange.[32]

and ventilation. The photograph reveals the way in which the space was originally used, a crowded and competitive trading floor, an interior in which people did not anticipate taking off their hats to improve their thermal comfort.

Typically for such early twentieth-century single glazed canopies, having become vulnerable to both the ingress of water and the egress of heat, the whole roof void is now concealed by a false ceiling, significantly diminishing the comprehension of the space as designed, removing its maximal source of natural light at the zenith.

In the case of the Coal Exchange, local archives contain original drawings of the space and it is possible, not only to survey the remaining structure behind the false ceiling, but also to marry the original specification and 2D dimensional data with the extant volume. In this instance, in order for the correlation of the original drawing to the 3D scan to become better matched, the use of place recognition algorithms would need to be further developed to adjust between 2D and 3D data but also between that which is projected as a rendered surface and that which is a line drawing. The use of historic photographs together with any fortunate remnant of a historic specification or bill would be the only means of providing a schedule for the re-instatement of ornamental cast plaster elements.

Conclusion

Whereas BIM aims to provide predictive models as to how a building should perform, HBIM has the potential to indicate to a broad audience how a building has actually performed. The need to establish quantifiable profiles for building performance becomes more urgent as pressures to refurbish them increase. Collating data into the twentieth-century canon of architecture using the method of tracing specification standards would make use of well-established and accessible pathways. The better we are able to trace the specific workflows of building designers in the past, the better we should be able to marry data to the models we create of their buildings. Yet it is evident that simple standard practices are readily abandoned, forgotten and lost within two generations. When components are no longer manufactured or advertised it is very possible to ignore or misinterpret them. Whilst they may not be reinvented, they may be rehabilitated or reinterpreted or even adapted in a better way if they have been properly identified in the first instance. The case studies here aim to show instances of how working to retrieve such knowledge would enable better, future decisions to be made, preventing the misunderstanding and consequently misinformed decisions which can cause irretrievable damage.

A well-constructed library of standards paired with a focused HBIM cataloguing initiative would enable deduction from the general to the particular, as well as the reverse for recognising the design intentions for buildings of this period. The key gain in collating such data is to build the capacity for HBIM to become more precise and relevant as a tool to be deployed in defence of a large number of traditional but standardised buildings. It is of paramount importance for those that inherit the stewardship of such spaces to understand them better. Methods that were a common currency in one generation may be completely misinterpreted by the one after the next. What we perceive as merely decorative can be determined as functional through modelled proofs of performance. The importance of comprehending the constructional intent of a building is not only driven by academic interest, it underpins economic survival by enabling buildings to perform as they were designed to. If our standards of performance expectation have altered because we have cheap artificial light and don't want to wear coats and hats inside, the steps taken to address modifications to such buildings should be very carefully appraised. Driving the efficiency of matching tools to enhance the development of an informed HBIM platform as a tool for supporting better decision-making in this arena is a critical step for a large quantity of our traditional building stock that falls within this period of construction. It is

highly desirable for governmental authorities to support the development of future contributions of this nature. Beyond the potential for recording, there is a real requirement for improved methods of interpretation. Studies such as these will enable the clustering of deep understanding of vernacular traits and localised traditional methods and improve the availability of such data. The purpose of which enables architectural history to contribute towards greater technical intelligence for today.

There is clearly a danger of providing too much capacity to automate information but if we neglect to engage with the potential of these tools at all, the risk is likely to become greater still. This work is limited in its application to buildings of a particular period, it does not propose a solution for historic buildings in general, rather a pathway towards addressing a large number of buildings of marginal significance which are, by definition, at the greatest risk of ill-informed alteration.

Note on contributor

Oriel Prizeman has been a senior lecturer at Cardiff University since 2012, she set up an MSc in Sustainable Building Conservation there in 2013. Previously she ran an architectural practice in Cambridge. Her PhD thesis, *Philanthropy and Light; Carnegie Libraries and the advent of Transatlantic Standards for Public Space* was published by Ashgate in 2012, and her edited book, *Sustainable Building Conservation; Theory and Practice of Responsive Design in the Heritage Environment* (RIBA Publications), was published in November 2015.

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