A New Perspective on Heritage and Multi-dimensional Representation with H-BIM

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The paper investigates the state of the art of “Heritage-Building Information Modeling” (H-BIM) vis-à-vis its specific challenges, envisaging possible new uses of current tools. It also devises new features that could easily improve current modelling/BIM packages.

“Building Information Modelling” (BIM) can be seen as a multi-dimensional modelling technique for “Architecture, Engineering and Construction” (AEC), where a database of different data-sets is linked to geometries, containing valuable information about physical and rendering features, among others. In case of heritage-buildings many specific challenges arise, since many more parameters (hence dimensions) must be considered, including forms of decay, historical and technical layers, degrees of exploration.

Moreover, two aspects characterize the use of H-BIM: the uncertainty about the surveyed elements – especially as to their hidden parts which, in a BIM logic, must nevertheless be accounted for – and the need to include overlapping geometries insisting on the same space relating to different aspects of the surveyed reality, e.g. stone elements and their deterioration patterns, as well as structures and their sub-elements.

As to the first aspect, while in BIM reality follows the model, in H-BIM the model must correspond to the surveyed data and possibly include different hypothesis as to the uncertain ones, along with certainty gradients. As to the second, the co-existence within the same model of the overall shape and of its constituents, so that the latter add up to a perfectly overlapping unity, closely matching the former, would allow for the full exploitation of current technology. Careful use of existing tools and suggested improvements thereto are set forth in this paper, in view of delivering BIM tools and practices that can better represent and describe heritage-buildings, extrapolate new data, as well as allow for simulations of various kind, thus also helping in their preservation and maintenance through optioneering based on reliable data.

Keywords:
H-BIM, Simulation, Multidimensionality.

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BIM: THE “TRADITIONAL” BUNDLE.

Before dealing with the specific aspects of “Heritage-Building Information Modeling” (H-BIM), it is worth recalling some aspects that characterize “Building Information Modelling” (BIM), since they are the building blocks of H-BIM, and their correct implementation may stretch H-BIM usefulness and employability even further.

Multidimensionality

BIM models do not store only geometrical dimensions (3D), but also time dimension, such as phases and design alternatives (4D), cost data (5D), project lifecycle information (6D), and more. “Cultural Heritage” (CH) projects can clearly highly benefit from storing and using a high number of data dimensions.

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Sharing

Also due to the multidimensionality features – which allow data that are relevant to different disciplines to be stored and exploited by different teams and professionals – BIM packages have been developed to be used cooperatively, also in a network. This feature is clearly even more relevant to CH projects, where multidisciplinarity is even more crucial.

Object-oriented/parametric approach

For the multidimensional pieces of information to be related to each other, geometrical elements need to be divided by semantic elements, such as walls, windows, pillars. They are instances of larger categories – the families – which, in turn, may be constituted by other sub-families. A specific instance then inherits its family features but differentiates itself from other instances through specific parameters. The approach mimics Object Oriented Programming and seems a major strength but also a major issue when dealing with CH projects, which tend to be dealing with non-standardized elements.

LOD/LOG per object/family

The object-based structure of BIM models allows for storing multiple datasets for the same object, which could be even added over-time and could represent the same "dimensions" at different detailing levels. Without entering the specificities of Level of Detail, Level of Development and alike, the main relevant characteristic is the co-existence of alternative data – also geometrical – insisting on the same object. As we will see, this feature can be particularly useful for H-BIM.

H-BIM: STATE OF THE ART.

Over the last decade the adoption of BIM for heritage buildings has been a promising research topic intersecting various fields of study. In fact, BIM models are multidimensional models storing not only 3D geometrical data, but also a much wider range of information that suits particularly well the CH sector, where a multitude of historical layers as well as of applicable disciplines – historiography, architecture, decay analysis, etc. – pertain to a single piece of architecture, hence (potentially) to a single model. Moreover, BIM packages are inherently conceived as a cooperative team working environment, greatly facilitating the sharing of information and the creation thereof among teams and disciplines.

While the potential of BIM for CH is clear, the development of specific Heritage-BIM (H-BIM) packages or even accepted workflow best practices has not been reached yet. Some major technical challenges, as well as lack of agreement on procedural standards, have hitherto hindered a wider adoption of H-BIM in the field, which advocates for a new approach to the very essence of it, at least in view of the future development of more specific software packages and best practices.

H-BIM: KEY CURRENT CHALLENGES.

Key open challenges that are preventing H-BIM from becoming a widespread tool for CH projects seem to all relate to the difficulty of reverse-engineer reality into an information-rich, semantic-aware, object-oriented model with a measurable degree of reliability. In fact, BIM software has been developed as a tool to engineer future buildings, a process where – in the industrialized architectural world of today – the correspondence between the abstract model and its realization is somewhat guaranteed by the industrial (tight) tolerances within the production of architectural elements, as well as by a set of consolidated best practices in the construction process. In other words, reality closely follows the model in case of new contemporary buildings.

As regards H-BIM, there is not yet a mature and reliable process to automatically "translate" the data from surveying techniques – especially laser scanning and photogrammetry – to a BIM model. In fact, even after error correction and appropriate segmentation, and even when referring to an appropriate semantic-aware database,

> *"… despite the fact that the semi-automatic process is a difficult, time-consuming task, it is currently considered to be the most effective process for documentation projects and the parametric modeling of architectural heritage …"*

[Facundo López et al. 2018]

For automatized scan-to-BIM processes, two main EU projects are somewhat promising, respectively as to point cloud segmentation and geometrical analysis, and as to shared ontologies and semantic-aware modelling[1].

As to geometrical dimensions, it is at least possible to measure the “Level of Accuracy” (LoA) by measuring the differences between the surveyed data (e.g. point cloud) and the BIM model, and to decide the “Level of Development” (LoD) of the model which, in turn, may be set as corresponding to a relevant LoA. Using open source software such as *Cloud Compare*[2] it is possible to get numerical and graphical data about the accuracy of the BIM geometries vis-à-vis the surveyed data [Quattrini et al. 2015]. However, there is no standardized way built in the BIM software packages to achieve this, nor any consolidated way to even represent such LoA across the model. Moreover, even by combining multiple survey techniques, including infrared photogrammetry and other techniques dealing with the hidden (not directly observable) parts of an architecture, the LoA in reconstructing the inner parts of any element is not usually even accounted for when representing the geometry of each BIM “object”. Most H-BIM models mix measurable data with hypothetical ones within each object – e.g. wall surfaces and wall cores – thus raising more than one concern about the real usefulness of such a model as a reliable basis for CH projects.

However, it is the semantic-aware reconstruction that poses the greatest challenges (Fig. 1. Ontologies in H-BIM). In fact, even if survey data were available for the inner parts of the architecture, it would still be highly subjective how to subdivide and classify those data. As of today, even the recognition of “coarse” elements, such as the separation between walls/doors/windows is cutting edge, experimental technology[3].

A first aspect of such a challenge relates to the nature of the surveyed architecture itself, and to the theory of preservation: not all architectures were conceived as a set of geometrically coherent elements – as it might be the case with most classical, renaissance and gothic architecture – but heritage sites often show at least some layers of unplanned, informal and highly irregular elements. If for the former group of architecture a promising approach is the creation of shared repositories based on ontologies [Quattrini et al. 2015], where BIM “families” related to comparable architectures (by typology, place, time, etc.) are a toolbox applicable to the architectures at stake either by the expert or potentially even through AI, as to the latter it seems hard to even categorize all the possible situations and best practices.

[1] http://duraark.eu/and https://www.inception-project.eu/en
[2] https://www.danielgm.net/cc/
[3] http://duraark.eu/duraark-results-presented-in-cad-q-seminar/

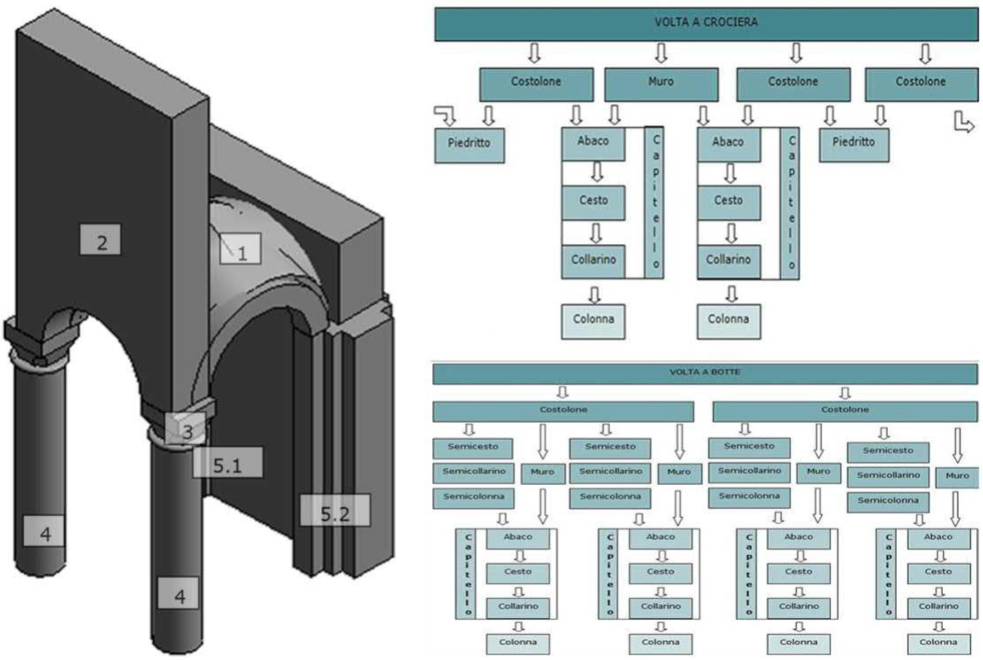

Fig. 1. Ontologies in H-BIM

In fact

> *"BIM approach includes information directly related to the object or its parts (both tangible and intangible such as material, dating, deterioration), yet it lacks a large amount of semantics about different context aspects (for example historical context, social information, environmental resources, other heritage artefacts information, etc.)[Simeone et al. 2014] In the field of built heritage, BIM model is integrated with ontology semantic relational system to enhance the representation of heritage knowledge and semantic reasoning. The integration can be an ad-hoc development based on BIM software [Acierno et al. 2017]. and a two-step modelling process by migrating IFC (Industry Foundation Classes) files to ontology environment for semantics richness [Quattrini et al. 2017; Bonduel et al. 2017]. The combined entity thus includes both object-oriented information, typically found in BIM platform, and semantic information, usually found in ontology modelling systems [Kalay et al. 2014]."*

[Yang et al. 2018] (Fig. 2)

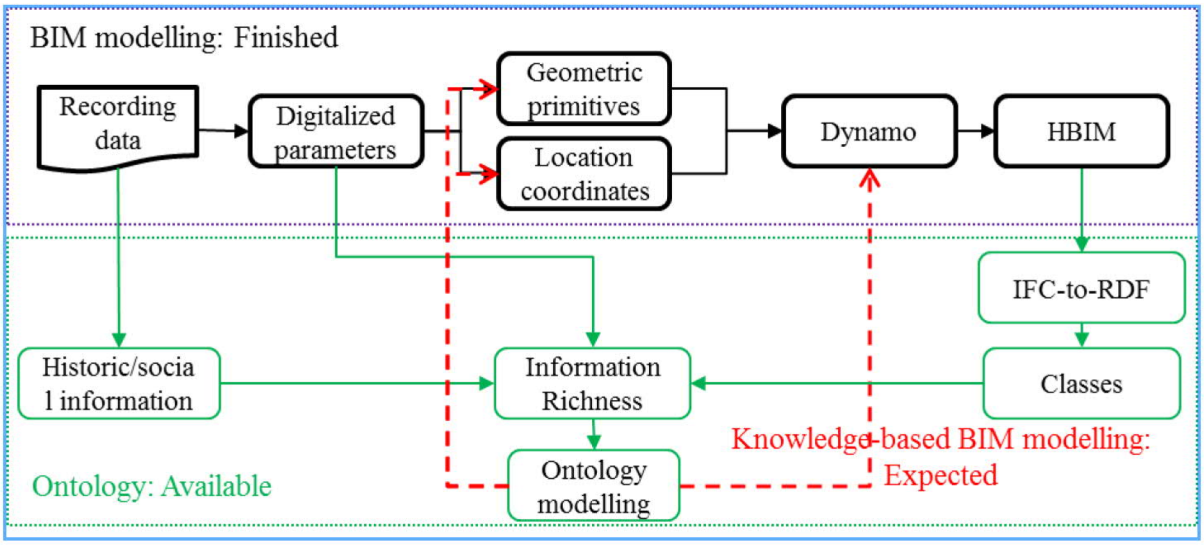

Fig. 2. H-BIM process and ontologies

Actually, the "normalization" of the surveyed architecture into more regular, standard elements, would risk resembling a Viollet-le-Duc approach to preservation, missing out the as-built dimension. Moreover, "regularization" might even make the BIM model not usable for some purposes, such as physical simulations, since the specificities and irregularities in shapes and materials must be accounted for in view of a reliable model.

For instance, while a contemporary wall made of very regular, industrially produced bricks can be easily described by an overall object encompassing the whole wall – where the internal partitions are accounted for by a sort of parametric 3D texture, and the physical characteristics are correctly approximated by a homogeneous average value across the wall – in case of an historically layered, decayed wall, the task at hand is even more daunting: should an overall wall geometry be identified as an "object" – a minimum geometrical unity as well as a basic "ontology", connotated by sub-elements and inner "layers" – or should each and every stone/brick be the minimum element, given their un-homogeneity? What about their physical attributes? And what size-limit to such a segmentation should we imagine? According to some scholars

> *"… the subdivision in small elements of the main architecture has to be connected with the aim of the BIM. The subdivision that takes into account the structural, architectural and decorative elements seems to be very reasonable, as it is also suitable for tridimensional analysis and not only 2D. Moreover, it represents the way all data will be accessed during the management of the architecture, so it helps the further steps of the BIM process (data entry, updates, etc.)."*

[Adami et al. 2017].

Possibly, since (H-)BIM models are supposed to serve multiple purposes, so should the model be rich, containing multiple, concurrent subdivision alternatives and LoDs.

In fact, a final problematic issue that seems deeply characterizing H-BIM today and hindering its efficacy as a preservation tool is the difficulty of accounting for the overlapping of geometrical data and even ontologies within one unique space. In fact, not necessarily do we need to choose among different spatial classification criteria. For instance, within the same spatial framework there can be "architectural elements" that can be recognized as pertaining to pillars, ribs and vaults, but also sub-elements, such as bricks, stones and mortar layers, and other overlapping geometries, such as incrustation and other decay elements often transversally affecting the architectural geometries, along intersecting shapes that follow physical rules, not architectural ones. Clearly, depending on the envisaged use of the model, different aspects would be relevant and thus preferred. Moreover, the cross-combination of those geometrically intersecting datasets could help extrapolating and inferring other datasets, and further contribute to achieve deeper understanding of the analyzed architecture.

This paper tries to imagine a new approach in the use of BIM technology for CH projects, where current software packages could be creatively used to include features not considered by developers, as well as to imagine future software improvements, whereby the foregoing challenges are dealt with by exploiting the potential model richness and computational power to the fullest, especially by allowing the storage of apparently “conflicting” geometrical information insisting on the same elements, and suggesting ways to represent such complexity and to use it for creating even richer models and simulations.

H-BIM: NEW APPROACH USING EXISTING TOOLS.

As seen, BIM technology bundles a series of features that were mostly thought in view of new constructions and were subsequently adapted also to CH projects. Since H-BIM is currently just the application, somehow the translation, of existing BIM technology to CH projects, many challenges have remained uncovered by commercial BIM packages. In this paragraph we will then dedicate a closer look to the available feature bundles to better evaluate which ones are most relevant to H-BIM, but also how each feature could be possibly adapted to H-BIM through use. In the next paragraph a series of new features are then devised and proposed to be possibly included in future releases of BIM/H-BIM packages to better suit CH projects.

We will analyze hereinafter some current BIM package features relating to key features/strengths of such technology and try to devise new uses better tuned to H-BIM.

Multidimensionality

As seen, BIM technology provides for the storage in one model of both geometrical and non-geometrical information, which fits CH projects well. In fact,

> *“… getting a rich HBIM model starting from accurate surveys is an unavoidable starting point to increase the conservation …”*

[Banfi et al. 2017]

However, the co-existence of different/alternative geometrical elements and pieces of information in the same space can be even more fruitful. Specifically:

- stretching the use of Project Phase also to include different historical phases – possibly including demolished or highly transformed architectures – may help grasping the historical evolution of the structure, and even interpolate missing data through a sort of ontogenetical simulation. This process could be compared to what historians do when trying to understand and describe historical phases: they usually refer to previous phases, so to understand the trends and the causal links, and even hypothesize future developments.

- stretching the use of Level of Detail. In BIM packages there are different Levels of Detail, and geometries are visualized based on a visibility parameter. Hence, by changing the LoD, different shapes and geometries are visualized for the same architectural objects. While the use of LoD is usually used to distinguish drawing styles by representation purposes – e.g. concept vs. construction – it could be profitably used to represent different geometrical datasets that, for instance, relate respectively to the architectural design (post/lintels/…), the building structure (bricks/stones/mortar layers), the decay elements (incrustations, etc.). Importantly, such geometries can compenetrate themselves, going beyond some BIM limitations that do not fit CH. However, one major limitation is that the selection of LoDs is model-wide, while CH projects may require a mixed representation thereof based on the objects to be highlighted. Another severe limitation in current BIM software packages is that only a limited number of Level of Detail are allowed, thus limiting the alternative datasets to be shown (e.g. in *Revit*[4] they are only three).

- stretching the use of linked models. Again, different disciplines and aspects could be included in one single main model by means of linked models. While this feature is usually exploited to store the parts of the model referring to a single discipline, such as architectural and structural geometries, it may be extended to different kind of even conflicting reconstruction hypotheses (e.g. more “abstract” – à la Viollet-le-Duc – vs. more “as built”). Similarly, the design option tool could be stretched to encompass even more data, not only for the future design, but also as to hypothesized data, such as, again, different historic reconstruction hypotheses.

[4] https://www.autodesk.com/products/revit/overview

Sharing

As to information sharing, there is nothing totally unique to H-BIM vis-a-vis "normal" BIM projects. However, while in such latter projects the usual flow between professional teams tends to be one-way – e.g. the engineers usually specify architectural design decisions as set forth in the BIM model, but often don't have an impact on the concept design phase – in creating a H-BIM model it seems crucial that technical knowledge helps architects reconstruct, i.e. reverse-engineer, the surveyed architecture and its decay, so to best approximate the status quo, greatly benefitting from a continuous exchange of knowledge and information among teams and disciplines. This holds true also as to design decisions, because often they would greatly benefit from physical/statical simulations to be performed before any intervention is made. In particular, if H-BIM includes different "types" of models, possibly with conflicting information, parallel work and coordination on each of such information "layer" speeds up process and facilitates cross-fertilization of expertise and knowledge, e.g. the simulation team guiding the survey team. It is worth noting that in CH projects could greatly benefit from information sharing not only among the teams participating to a specific project, but also among researchers in the field as to semantic parametric families related to the places and ages of the architectures at stake. An open repository paradigm would seem particularly suited for this and has been explored also in the framework of EU research projects[5].

Object-oriented/parametric approach

As already pointed out, Object-Oriented (OO) logic is possible also with totally irregular elements of heritage architectures, save for the wide degree of discretionality in segmentation/subdivision. Besides, each object can include geometrical elements with different degree of certainty, such as the directly observable surfaces of a wall and its internal structure. The creation of object/families that divide architectural elements by degree of certainty or by heritage ontologies/classifications is a possible way to better adapt BIM to CH projects. Again, a shared repository, possibly in the framework of an independent organization funded by academic institutions, is probably the way to go, even though IP rights and research funding might be issues to deal with to further implement such solutions.

As to parametrization, not necessarily does built heritage follow a stringent parametric logic. A case-specific approach seems necessary. Specifically, it would be advisable to ascertain "parametrizable" architectures (e.g. Greek, Renaissance), specific to the case at hand and discipline-based (stereotomy, historical research), as a pre-condition for applying parameters, at least the geometrical ones. As seen, repositories of families including relationships and proportions among parameters should be built and shared, possibly within the research community at large. Along with geometrical parameters, a set of CH-specific parameters would be purposefully agreed upon, for instance with respect to level of certainty and level of accuracy of the reconstructed model vs. the scanned data.

It is worth noting here that, besides the parametric features of BIM objects within BIM packages, there is another set of "parametric" tools – usually referred to as computational design tools – that are, and could be even more used profitably within or in connection to BIM software: it is the case of NURBS ("Non-Uniform Rational B-Spline")-based modelling tools, such as *GH for Rhinoceros*[6], an external NURBS modeler package, and *Dynamo for Revit*[7], a node-based programming tool for *Revit*. The interesting features of such type of software is the opportunity to create geometries that are only based on control points and mathematical functions and relationships, so that the resulting shapes are calculated in real time for representation and have an abstract geometrical nature, not linked to the specific scale or space references, apart from the starting control points. It then allows reconstructing a scale-less, mathematically describable drawing that can approximate the surveyed data by "interpolating" them. This process has been often used to "bridge" the discrete, scattered data from laser-scan and photogrammetry to continuous and mathematically describable shapes, ready for being classified by ontologies and "parametrized" with BIM information parameters. For instance, some scholars have been exploring a workflow to semi-automatize the creation of a H-BIM model starting from raw mesh data using *Dynamo for Revit* [Yang et al. 2018]. In addition, some external pieces of software, such as *Leica Infinity*[8], aimed at extrapolating shapes from the surveys could help bridging some of the gaps that are present at the moment, as well as serve as a good reference for devising future (H-)BIM features and seamless workflows.

[5] https://www.inception-project.eu/en
[6] Grasshopper (GH) for Rhinoceros (Rhino): https://www.grasshopper3d.com/page/download-1
[7] https://dynamobim.org/
[8] https://leica-geosystems.com/products/gnss-systems/software/leica-infinity

H-BIM: NEW APPROACH FOR DEVELOPING NEW TOOLS.

If adapting existing commercial BIM packages to CH projects seems the quickest and resource-aware approach to H-BIM development in the near future, more attention by the industry for developing specific H-BIM tools is clearly a realistic hope, also given the sheer market size of architectural projects dealing with some kind of CH settings. In view of such specific development, it is important to ask ourselves what challenges could be best tackled, and what features would be most needed in view of H-BIM specific software development.

Multidimensionality

In general, lack of information (e.g. as to the non-observable parts) and lack of geometrical regularity and consistence would greatly benefit from specific parameters within (H-)BIM software, possibly linked to visualization options, as follows.

Certainty/Accuracy: specific 3D-markers that encode (and represent) at least the level of accuracy and the level of certainty might be a great step forward – also in view of standardized procedures – with respect to attaching customized parameters to BIM families. It could be linked to a new system of model “Levels” (see further). Data may stem from the following point.

Categorization and storing of more types of data/models, potentially "conflicting": historical drawings, "rectified" drawings, survey activities, shape grammars and stereotomic knowledge, shared ontologies and reconstruction alternatives. All such datasets could beneficially be included – at least as data category – within (H-)BIM packages, so that standard plugins could be developed for matching and connecting those data and extract further insight on the architectures at stake. Here again, the creation of a standard data structure and labelling – possibly to be included within the “Industry Foundation Classes” (IFCs) – would help recognize and create best practices, and help sharing comparable data.

Sharing

While the de facto sharing of H-BIM families and other information is already feasible, it would be greatly more interesting to have (H-)BIM packages automatically linked to on-line repositories where families are uploaded and updated following a Wikipedia or Github[9] style, so to ensure at the same time a faster and more standardized data sharing and model building, as well as a sufficient degree of reliability.

Object-Oriented/Parametric Approach

First of all, while in standard BIM packages object-oriented and parametric features are united in describing every architectural element – such as a wall, defined by some basic geometrical starting data and “modified” through specific parameters – such an approach might not be the most appropriate for irregular elements that would still be objects, but would not be describable through simple measures. Therefore, while today external software packages are usually adopted for more complex and irregular elements to be imported and “objectified” within the BIM environment, it would be probably more efficient to have such modelling tools inside BIM packages and to be able to create different objects out of each of such shapes, and from a combination thereof. For instance, a standard family of irregular wall stones could be included in a wall family following the relevant ontologies, without any direct connection to a specific numeric parameter to create the shape. At most, semi-automatized shape creating tools may help smart-guess the real geometries starting from the available survey data, especially point clouds. Software like Revit can already be used to achieve these features – through customized families and possibly through node-based programming Dynamo [Yang et al. 2018] – but the process has not been standardized, nor is it user friendly: in fact, while standard families make it hard to even create a tilted wall, the conceptual mass tool is not intuitive, nor is it easy to achieve a fast and accurate result in this field.

Second, IFC classes could be fruitfully adopted for describing some other aspects of CH. For instance, a widened set of IFCs encompassing decay pattern families - e.g. ICOMOS (International Council on Monuments and Sites) - would allow for the creation of clearly defined BIM geometries representing decay in 3D, thus creating a far richer HBIM model. Likewise,

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[9] https://github.com/

> *"Given that the IFD (International Framework for Dictionaries) defined inside the BIM software are not exhaustive for the Historical Building domain, the definition of dictionaries inside the "Historical Building Framework" (H-IFD) aims to contribute in creating an open DB, updatable, dynamically adaptive to the real context and multi-faced contents of the historical architectures"*
>
> [Oreni et al. 2014)]

Further analysis and simulation tools could then be developed within the model, combining datasets about various aspects of the surveyed geometry, maintaining a high degree of interoperability and standardization at the same time.

Moreover, physical simulation parameters and tools could be introduced within (H-)BIM packages and help smart-guessing 3D semantic elements, including non-directly observable parts, e.g. star-cracks, moist areas, but even internal brick subdivisions. "Synthetic data" could be parametrically produced and be extremely useful for matching data sets using AI. In fact, AI could then help matching those simulations to the specific case, also based on a growing *corpus* of tested cases shared among the researchers in the field. In some cases, CH interventions dis-assemble architectural elements and can therefore provide a reality check. For instance, huge stone pillars within the Basilica di Santa Maria in Collemaggio in L'Aquila, Italy, was disassembled and provided great insight on the real structure thereof, versus the previously imagined one [Reni et al. 2014].

Of course, an enriched model would require the co-existence of overlapping and interacting data belonging to different classes (e.g. decay vs. architectural elements), interacting and specifying each other, also geometrically.

Finally, some kind of structured relationship between objects that are not exactly bordering one another, as it is usually the case in BIM packages, but rather overlap in some areas – such as an overall mesh representing the scanned wall surface intersecting or neighboring BIM wall objects and/or wall-stones – would be much needed to allow for specifying each other, transferring and "stamping" relevant information from one another. In the example, the wall objects could have a specific texture applied to its surveyed faces coming from the overall mesh, applied as a *pro-quota* wrap.

Model levels (LoD, LoG, LoI, LoA, etc.)

Without entering the specific taxonomy between these dimensions, it seems that new (H-)BIM packages should include a wider variety thereof, offering standardized options to visualize and combine them also according to CH best practices. Among others, we can envisage the following improvements:

- object-specific LoD "switch": it seems that a general, model-wide switch for LoD is not answering to the real needs of a model potentially encompassing heterogeneous elements, where each "cluster" of homogeneous layers/datasets might be usefully represented using a respectively different LoD (this is now somewhat achievable by tweaking LoD visualization in the object visualization settings). In fact, even just for representation purposes, it seems useful to have the opportunity to selectively focus of details that might be relevant to the specific purpose at stake. If, for instance, the drawing wants to convey the status of decay, it would be not only redundant, but even distracting, adding additional "graphic noise" stemming from other aspects such as surface textures, and switching levels just by selecting the elements/categories would be at least a time-saver.

- range-based Level of Certainty and time-frame for analysis, including forecasted trends. More in general, adding some range-based system to represent non-binary data. Similar gradient analysis and representation is already carried forward in FEM software packages, for representing – by discrete approximation – systems where data values change in space along a continuum: typical is the simulation of *Von-Mises Stresses*[10]. Similarly, a gradient representation of deviation between modelled geometries and surveyed point cloud is often used for assessing H-BIM reliability based on the chosen LoA, usually using an external software package such as Cloud Compare, an open source software solution [Bonduel et al. 2017], with the implication of not being able to automatically feed-back the obtained data into the BIM model for further data combination and visualization (Fig. 3).

[10] https://upload.wikimedia.org/wikipedia/commons/9/9e/NonlinearStaticAnalysisSnapFit.png

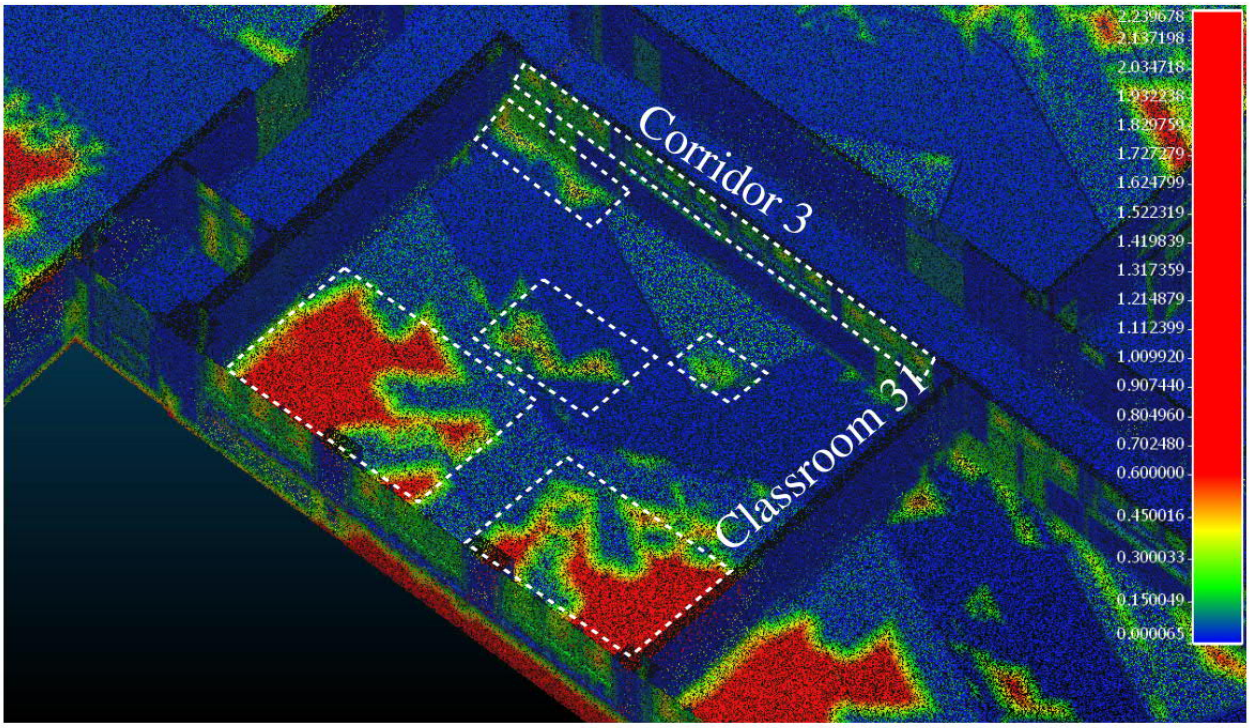

Fig. 3. Scan-to-BIM Output Validation

- new data type and combination thereof. For instance, new "synthetic" LODs, such as enhanced surface representation after scanning though displacement maps, or by texturization of single object through the combination and projection of other objects – also differing in spatial features – such as point clouds, meshes and alike representing scanned surfaces through normal and IR photogrammetry and laser scans vs. BIM walls vs. BIM wall stones and other wall layers objects.

- new graphic codes to represent different levels and data types. BIM packages are of course very customizable systems, very appropriate for creating a personal representation style. However, since in preservation there are a series of agreed upon standard graphic conventions, it seems that a robust set of pre-fab representation styles attuned to H-BIM projects would greatly improve the degree of universal “readability” of the models and a better starting point for a purposeful sharing within the research community.

Again, all such parameters should be available per object and per object group, not only model-wide, also because survey, model reconstruction and preservation project phases may not be carried forward and completed within the same time-frame, and some portions may even need a more in-depth survey than others: imagine heritage architectures where some portions were added in contemporary times using uniform materials and techniques, while other portions show a significant amount of historical layers and complexity. It should then be possible and even a standard procedure for H-BIM to be able to start off with survey data and a few generic and approximated “coarse” geometries, to be specified over-time as the surveying activities proceed, storing such subsequent detailing and reconstruction phases per-object – even with different-shaped objects insisting on the same space – so that different clusters of information could be utilized for representation, analysis and simulation as the case may be. This Mixed LoD approach [Banfi et al. 2017, p.11] has already been proposed for 3D city representation using GIS software in order to face challenges such as different dataset available for different buildings, etc. [Biljecki et al. 2013].

COMPUTATIONAL DESIGN, CH PLUGINS AND BIM

While, as mentioned, some BIM packages already provide computation design tools (e.g. *Dynamo for Revit*, a working workflow *GH-Archicad for Archicad*[11]), and some plugins for segmenting and dealing with point clouds – such as *Volvox for GH*[12] – are already available for helping develop NURBS modelling of surveyed data, there is still a lack of specific tools to help create a (H-)BIM model starting from surveyed data, especially point clouds and meshes stemming therefrom, if we want to go beyond the mere boundary recognition. Moreover, the transition from external parametric NURBS modeler, such as *Rhino*[13]*/GH* to BIM platforms is not always easy, as well as BIM plugins for such modelers are not yet as effective as proper BIM packages as a one-stop-shop solution. Therefore, we imagine a near future in which these set of features are – if not reunited in a unique software package – at least better coordinated with (H-)BIM, and specific automatized tools to help extrapolating BIM models from the available data are included. Physics simulation engines – now present in numerous software packages, especially the ones dedicated to creating gaming and realistic virtual worlds: see for instance *Houdini*[14] – could be purposefully exploited to create Synthetic Data about decay patterns, structural shifts and other phenomena impacting CH, and tested – also by AI [Tremblay et al. 2018] – in order to better approximate the real data gathered in the survey activities. See for instance Fig.4, comparing simulated and real dried mud images, as well as a "procedural crack" on a wall created using *Houdini*[15] as well as comparisons between artificially computed cracks and the ones happening in reality [Iben and O'Brien 2009].

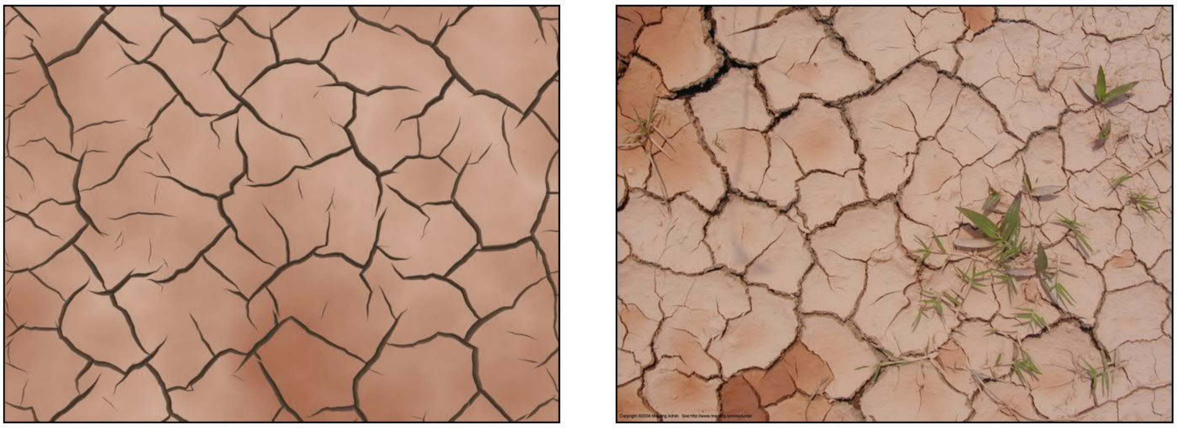

Fig. 4. A comparison between rendered dried mud (left) and a photograph (right)

The process could start from known data (e.g. observable wall surfaces) and a set of hypotheses to test (internal structure of the wall, material composition), and the simulated results could be then compared with the observed characteristics of the geometry at stake (e.g. the observable wall cracks, humidity traces, etc.). Basically, the same process of abstraction now carried forward by approximating real architectural geometries by means of BREPS (or B-reps – Boundary Representation) – save for later LoA checks – to be lately converted into BIM objects, could be performed with respect to the physical processes occurring on the architectures, in order to get a sufficiently accurate abstract-physical modelling of such processes. A similar approach is carried forward in the automotive industry as regards the mechanical robustness of prospected design solutions, as in Fig. 5. [Chanho 2018] and, more specifically, in "Finite Element Method" (FEM) analysis for AEC, as in Fig. 6. [Almeida et al. 2016] where, nonetheless, the approach is simplified, as the wall constituents are taken as a whole.

[11] GH-Archicad for Archicad is a software tool to bridge ARCHICAD (https://www.graphisoft.com/archicad/) to Rhino/Grasshopper (https://www.graphisoft.com/archicad/rhino-grasshopper/)
[12] https://www.food4rhino.com/app/volvox
[13] https://www.rhino3d.com/download/rhino/5/latest
[14] https://www.sidefx.com/products/houdini/
[15] https://goo.gl/images/R3Ejyr and https://vimeo.com/channels/529907/65805544

Fig. 5. Mechanical robustness analysis

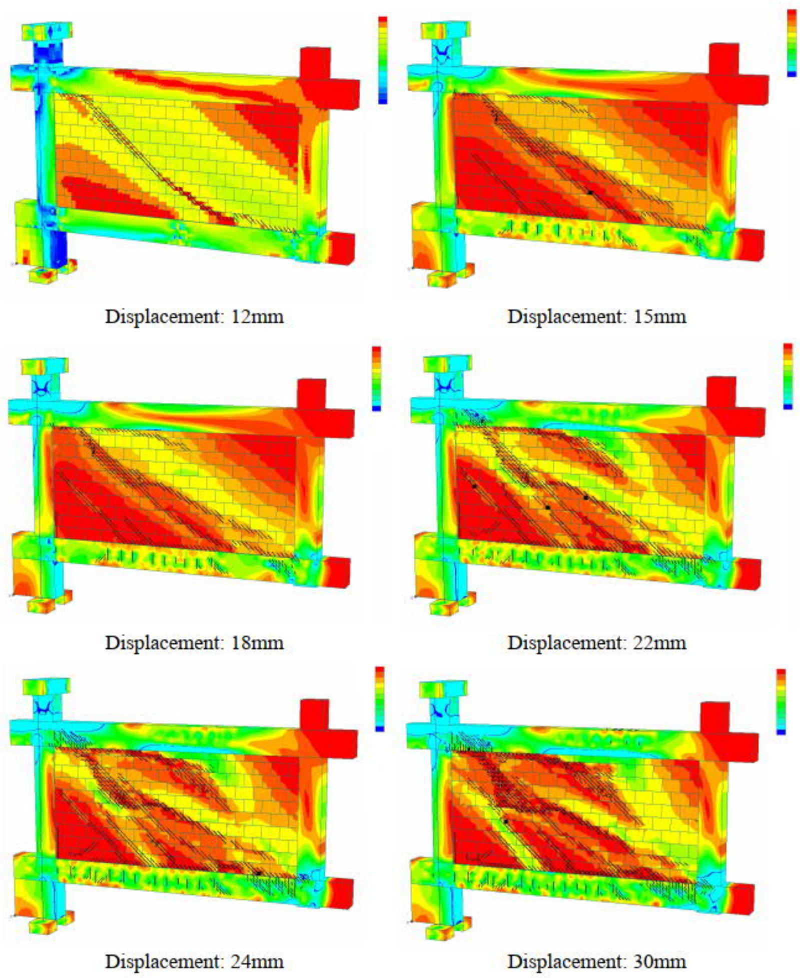

Fig. 6. RC frame and masonry Von Mises stresses and cracking pattern for several load steps

This extra layer of information could be useful for at least two main purposes. First, helping to figure out the missing data (e.g. hidden geometries); second, providing a powerful tool to simulate the prospected preservation plans and to tweak them to reach the required results.

As a last remark, the nature of BIM software packages may have to be questioned, possibly de-bundling aspects that are now seen as a necessary corollary of the BIM architecture, such as the "Object Oriented" (OO) and the parametric features. In fact, the shape creation/reconstruction and the "objectification" thereof through the categorization into IFC classes – possibly including relevant ontology structures and other data dimensions – could potentially be added and modified later in time, and not be necessarily included contextually with the creation of the geometries. Plugins for Grasshopper and Rhino to transform NURBS geometry into BIM geometry seem a good example of such an approach. See for instance *Grevit*[16].

As a final illustration of the foregoing analysis, the following set of images (Fig. 7) has been created to iconically illustrate the huge difference that exists at the moment between a standard BIM wall made of a uniform texturized material in Revit and a wall made of single textured stones using a modelling software like *Rhino/Grasshopper*. As the second image clearly shows, only the second wall would allow for even the easiest of physical operations, such as an "exploded" displacement of its constituent stones, which in turn would allow for a wider set of analysis and simulation processes. At the moment, it is possible to transfer such geometries in Revit (and other BIM packages), but the process is not a standard one, nor efficient, with some issues related to textures and other loss of information.

Even if we are aware of the many challenges at stake, as accounted for in this paper, we deem it crucial that H-BIM eventually start to follow a different and more specific approach to CH – building new agreed logics, features and practices – rather than just consisting in the use of standard BIM packages and practices awkwardly stretched and applied to heritage buildings. A combination of technical knowledge both in computational tools and in CH, along with a "political" will to foster the creation of new standards and practices, seems then an unavoidable building block for a better future H-BIM.

H-BIM: THE NEAR FUTURE.

To sum up, in order for H-BIM to become the flexible and powerful tool for CH projects that we all wish for, it will be key that a consistent and agreed upon methodology is developed – so to make sharing and comparing research results feasible – particularly as to the creation of a well-thought set of ontologies, as well as to allowing the coexistence of spatially overlapping multiple (and multi-disciplinary) data-sets.

A great achievement would be the creation of a reliable, multi-purpose unified model, where multiple data and dimensions – historical, physical, economical, etc. – not only can allow for various effective representation outputs, but could even help the very same model construction process, also through the use of AI algorithms creating and combining ontologies and physical phenomena, reciprocally reinforcing the degree of certainty of directly observable and inferred data. In other words, it is the "big data" within the H-BIM model and in the networked research community that could further strengthen the H-BIM model reliability and make the automatization of model creation less difficult to achieve.

Such an enhanced H-BIM technique could then finally help not only representing CH projects, but also help inferring new information and allow for a more grounded hypothesis testing in CH projects. If new packages dedicated to H-BIM would then constitute a great support of such new approach, it seems meanwhile feasible to creatively use the existing tools to make some steps forward.

[16] https://www.food4rhino.com/app/grevit-grasshopper-native-bim

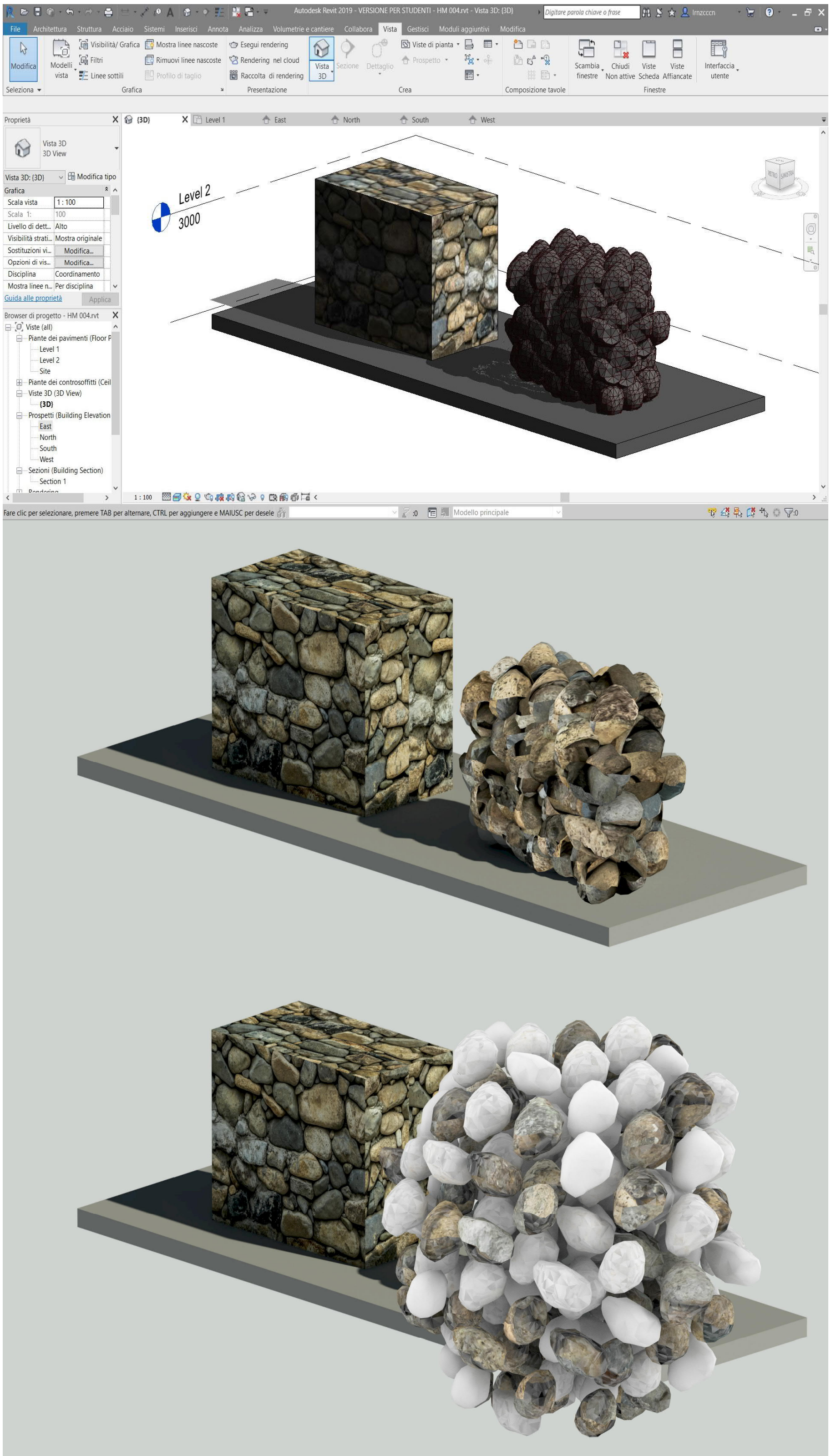

Fig. 7. Difference between "texturized" BIM wall (based on a parametric box geometry) and "simulated" conglomerate wall made of smaller objects, hence "explodable", thus allowing for various types of simulation and greater accuracy

REFERENCES

M. Acierno, S. Cursi, D. Simeone, and D. Fiorani. 2017. Architectural heritage knowledge modelling: An ontology-based framework for conservation process. Journal of Cultural Heritage, 24, 124-133.

A. Adami, B. Scala, and A. Spezzoni. 2017. "Modelling and accuracy in a bim environment for planned con-servation: the apartment of Troia of Giulio Romano." *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W3*, 17-23.

André Almeida, Eduardo Cavaco, Luís Neves, and Eduardo Júlio. 2016. "Non-linear analysis of rc frames with masonry infills subjected to column failure." Porto, Portugal: INEGI/FEUP.

F. Banfi, R. Brumana, S. Della Torre, D. Oreni, M. Previtali, L. Cantini, L. Barazzetti, and A. Franchi. 2017. "HBIM challenge among the paradigm of complexity, tools and preservation: the basilica di Collemaggio 8 years after the earthquake (l'Aquila)." *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W5*, 97-104.

Filip Biljecki, J. Zhao, Jantien Stoter, and H. Ledoux. 2013. "Revisiting the concept of level of detail in 3D city modelling." *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences. II-2/W1.*

Mathias Bonduel, Maarten Bassier, Maarten Vergauwen, Pieter Pauwels, and Ralf Klein. 2017. "Scan-to-BIM Output Validation: Towards a Standardized Geometric Quality Assessment of Building Information Models Based on Point Clouds." *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. XLII-2/W8*, 45-52.

José Facundo López, Pedro M. Lerones, José Llamas, Jaime Gómez-García-Bermejo, and Eduardo Zalama. 2018. "A Review of Heritage Building Information Modeling (H-BIM)." *Multimodal Technologies Interact. 2018*, 2(2), 21.

Hayley N. Iben and James F. O'Brien. 2009. "Generating surface crack patterns." *Graph. Models 71, 6 (November 2009)*, 198-208.

Y.E. Kalay, D. Schaumann, S.W. Hong, and D. Simeone. 2014. Beyond BIM: Next generation building information modeling to support form, function, and use of buildings. Building Information Modeling: BIM in Current and Future Practice, 321-335.

Chanho Lee. 2018. AutoForm Technical Manager Korea. *The Pictures Say it All: No More Splits at Royal EG after Robustness Analysis in Korea*.

D. Oreni, R. Brumana, A. Georgopoulos, and B. Cuca. 2014. "HBIM Library Objects for Conservation and Management of Built Heritage. International Journal of Heritage in the Digital Era, 3(2)." 321–334.

Ramona Quattrini, Eva Malinverni, Paolo Clini, Romina Nespeca, and E. Orlietti. 2015. "From TLS to HBIM: high quality semantically-aware 3D modeling of complex architecture." *ISPRS - International Archives of the Photo-grammetry, Remote Sensing and Spatial Information Sciences. XL-5/W4.*, 367-374.

Daniela Reni, R. Brumana, Stefano Della Torre, F. Banfi, Luigi Barazzetti, and M. Previtali. 2014. "Survey turned into HBIM: The restoration and the work involved concerning the Basilica di Collemaggio after the earthquake (L'Aquila)." *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences. II-5.*, 267-273.

D. Simeone, S. Cursi, I. Toldo, and G. Carrara. 2014. B(H)IMbuilt heritage information modelling-extending BIM approach to historical and archaeological heritage representation. In Fusion Proceedings of the 32nd eCAADe Conference,1, 613-622.

Jonathan Tremblay, Aayush Prakash, David Acuna, Mark Brophy, Varun Jampani, Cem Anil, Thang To, Eric Cameracci, Shaad Boochoon, and Stan Birchfield. 2018. "Training Deep Networks with Synthetic Data: Bridging the Reality Gap by Domain Randomization." *2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW).* Salt Lake City, UT, USA.

X. Yang, M. Koehl, and P. Grussenmeyer. 2018. "Mesh-to-BIM: from segmented mesh elements to BIM model with limited parameters." ISPRS TC II Mid-term Symposium "Towards Photogrammetry 2020, Jun 2018, Riva del Garda, Italy. pp.1213-1218, ff10.5194/isprsarchives-XLII-2-1213-2018ff. ffhal-02126147f, https://hal.archives-ouvertes.fr/hal-02126147

PICTURE CREDITS

Fig. 1. [Quattrini et al. 2015]
Fig. 2. [Yang et al. 2018]
Fig. 3. [Bonduel et al. 2017]
Fig. 4. 2004, Mayang Adnin in [Iben and O'Brien 2009]
Fig. 5. [Lee 2018] http://formingworld.com/robustness-korean-tier1/
Fig. 6. [Almeida et al. 2016, p.1373]
Fig. 7. 2019, Lorenzo Ceccon

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