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Conservation Digitalization through Heritage Building Information Modelling (HBIM): Online Database Theoretical Review

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ABSTRACT

It is essential in today's world to protect and maintain cultural heritage in the face of threats posed by modernity, development, and climate change, all of which have the potential to shorten the useful lifespan of cultural heritage. On the other hand, the effort involved in conservation is far more challenging since incomplete documentation frequently leads to misunderstandings and incorrect interpretations. Heritage Building Information Modelling (HBIM) is a tool that came into latter part of the 2000s with the intention of assisting in the management of the conservation, rehabilitation, and retrofitting of heritage structures. When it comes to the management and digitization of documents associated with historical buildings and artefacts, HBIM is often regarded as the most trustworthy tools available. The main objective of this paper is to identify theories concerning HBIM based on theoretical review conducted via online database. On 9th October 2022, the search had been made using Scopus online database, 1346 articles and conferences paper were selected in this research, after screening phases, only 65 high quality articles were included. As a result, HBIM digitalization model is proposed

1. Introduction

Complex activity such as cultural and architectural heritage management require humanities and informatics skills, in recent decades, enormous digitization methods have emerged to preserve, enhance, and transmit cultural heritage (CH). This phenomenon creates opportunities for digital heritage study. The growing number and quality of geometrical and aware 3D models require accessibility, information reliability, and multidisciplinary collaboration within the same environment. Heritage Building Information Modelling (HBIM) platforms are currently regarded as the most effective tools for managing historical architecture [1] HBIM is currently and widely used since it has high potential for representing cultural heritage through managing and documenting

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historical buildings as well as the numerous restoration efforts carried out by allowing information to be correlated with all the elements of the structure [2].

1.1 Digitalization through HBIM in Conservation and Heritage Industry

The term Historic Building Information Modeling (HBIM) was established in 2009, it can be defined as an application of technology to the construction, depiction, and management of existing buildings. HBIM differs from BIM in its information and modelling approach. HBIM emphasizes the value of information regarding the conservation status of locations and materials, enabling designers, managers, conservators, etc. a resource to aid in diagnostic research and management and support. In addition, HBIM's two main fundamentals are surveying and modelling [3] and the implementation of HBIM can be categorized into three major components: data collecting, database design, and three-dimensional modelling. [4]

Therefore, HBIM makes it possible to portray historical buildings in a digital setting, by providing all of the updatable documentation in addition to the geometric information, as well as the numerous restoration activities that have been carried out. The inventorying of the existing cultural heritage demands an initial stage for the collection of geometric data that can be used to plan the restoration work (through photogrammetry or terrestrial laser scanner) [2] Numerous studies has indicated the efficacy of HBIM as the initial phase in the life cycle of historic buildings. Research also shows that graphic and semantically unified information synced across all disciplines benefits management in later phases: intervention, execution, maintenance, and dissemination. [5]

Modelling the existing building with the new digital survey approach led to a greater understanding of cultural heritage, particularly in terms of predicted output. HBIM is a great solution for documenting these existing buildings and thereby preserving heritage, and it has huge potential to become an effective tool for preserving architectural and cultural heritage. [6] Consequently, this research will identify theories of digitalization through HBIM tools, and then comprehend these ideas in order to propose an HBIM digitalization model.

2. Methods

The main objective of this research is to identify theories of digitalization in HBIM which can influence conservation industry in Malaysia. Thus, systematic literature review is made based on search of articles across online databases such as Scopus by using keywords “Heritage Building Information Modelling” or “HBIM” and “Conservation” and “Documentation and Recording” or “Digitalization”. These searches only focus for 5 years latest period starting from year 2018 until year 2022.

These key concepts from the research protocol composed from TITLE-ABS-KEY and string together with Boolean operators AND/OR. The exact research string used is (“Heritage Building Information Modelling”) OR (“Historical Building Information Modelling”) OR (“HBIM”) AND (“Conservation”) OR (“Documentation”) OR ("Recording") OR ("Digitalization") OR ("Digitization"). The primary search turned into huge numbers of articles. The articles were filtered numerous times according to research protocol.

Table 1
Research Protocol

Item	Content
Research Aim / Objective	To identify theories of heritage building information modelling (HBIM) based on articles published by Scopus between 2018 to 2022
Research Question	What is the theories of heritage building information modelling (HBIM) for conservation?
Keywords	(“Heritage Building Information Modelling”) OR (“Historical Building Information Modelling”) OR (“HBIM”) AND (“Conservation”) OR (“Documentation”) OR ("Recording") OR ("Digitalization") OR ("Digitization")
Research Databases (Online)	Scopus
Year of Publication	2018 to 2022
Type of Publication	Articles and conference papers
Language	English
Exclusion Criteria	• Outside 5 years latest period • Abstract and document not available to download • Not written in language: English • Not related to HBIM and digitalization for conservation
Data Extraction	Excel spreadsheets to track paper and status based on the protocol.
Narrative Synthesis	Bibliometric Analysis (through Vos viewer) • Location/country of authors • Publications distribution based on journals • Publication over time (year) • Thematic analysis based on abstract, research focus, outcome, and relationship of the research

The research protocol uses exclusion and inclusion criteria in order to find out the most highly related and useful research content based on Scopus online database. All of the articles extracted were published in between the last five years (2018 to 2022). Besides, this protocol only received conference papers and articles that were in final stage of publication as shown in table 1 above.

This search was conducted on 9th October 2022 in resulting 1346 articles. Then the screening was made in three phases as shown in table 2. 1st phase screening was made to choosing 5 years latest publication which only focus on article and conference paper in final stage and in English medium, this screening resulting exclusion of 430 articles. Next, 2nd phase screening were made based keywords that related to the research, through this phase, 539 numbers of documents were excluded. Then, 3rd phase screening was conducted by dismissing documents which are unrelated based on topics keywords as well as unavailable documents to be download. As a result, thematic reviews only include 65 numbers of documents (article and conference paper) that are considered as high-quality.

Table 2
Flow of HBIM Digitalization

Identification	Record Identification through SCOPUS Online Database (n=1346)
Screening	1st phase screening: • 5 years latest publication (2018 to 2022) • types of publication: articles and conference paper • publication stage: final • language medium: English Record excluded after 1st phase screening (n = 430) Record screened, (n = 916) 2nd phase screening: • related keywords: HBIM, Historical Building, Heritage Building Information Modelling Heritage Conservation, Heritage Documentation Record excluded after 2nd phase screening (n = 539) Record screened, (n=377) 3rd phase screening: • unrelated or unavailable keywords on abstract • documents are not availed for download • content of the articles and conferences paper are not related with the searching topic Record excluded after 3rd phase screening (n=281) Record screened, (n=96)
Included	Included in the thematic reviews (n=65)

3. Results and Discussion

In bibliometric analysis, a quantitative approach was implemented for the purpose of describing, analyzing, and keeping track of the research that was published. Through this method, it can produce a comprehensive and thorough review process. As an outcome, the reviews have become systematic and high quality. The pattern of produced publications during the past five years, beginning in 2018 and continuing through 2020, is represented in Figure 1. In 2018, 9 numbers of articles were published, and it grew rapidly in 2019. In comparison between these five years, the number of articles published in 2019 which is 30 is the largest among all. Nevertheless, there were only 7 numbers of articles in 2020, a reduction from the previous year. In 2021 and 2022, the numbers went up slowly, and a total of 9 and 11 articles were recorded. The number of articles published is likely to increase by the end of the year and in the years to come.

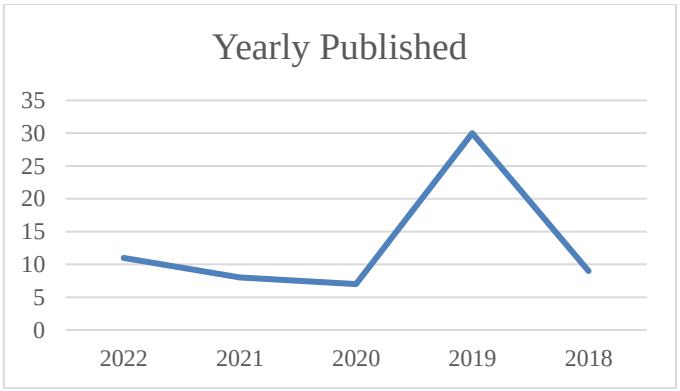

Fig. 1. Publication on HBIM by year

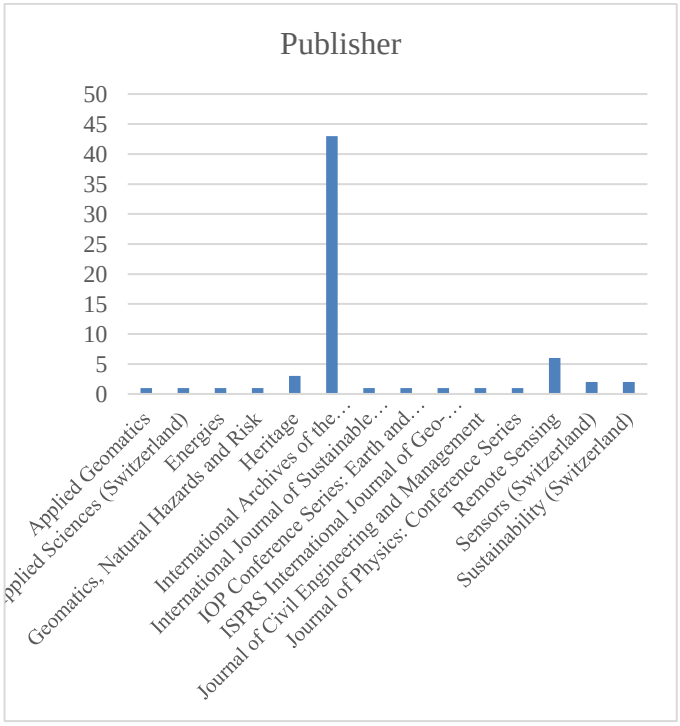

Fig. 2. Publisher per publication

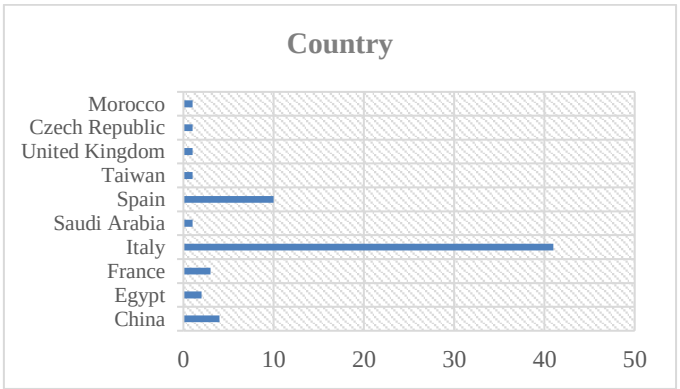

Fig. 3. Authors by country per publication

The detailed distribution of the articles within journals are shown in Figure 2 above, according to the distributions, the highest source of the articles and conference paper were from International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS) which is

43 numbers. Meanwhile, the second highest source was from Remote Sensing which is 6 numbers, and the other sources were only below than 3 numbers published.

Figure 3 above shows publication based of author's countries. Through the data below, it can be seen that Italy is the country that highest rates in publishing articles and conference paper regarding HBIM which were 41 numbers respectively. The second highest among all countries was Spain, which were 10 numbers. Other countries also involved were China, Egypt, France, Saudi Arabia, Taiwan, United Kingdom, Czech Republic and Morocco were only publishing not more than 4 numbers. It can be seen that European authors are ahead of Middle Eastern and Asian countries in publishing articles and conference papers in HBIM topic.

Table 3
Research Themes

Keywords (research themes)																			
NOS	HBIM	3D-M	IM	SS	CH	PGY	PCL	LS	PM	VR	BIM	GIS	StB	UAV	DL	LoD	TLS	S	DD
[7]	X	X	X		X	X	X		X	X	X	X							
[1]	X	X	X		X	X	X	X	X		X		X		X	X	X		
[8]	X	X			X	X	X	X	X	X	X			X		X			
[9]	X	X		X	X	X	X	X			X		X	X	X	X	X	X	
[10]	X	X			X	X	X	X	X		X		X	X		X	X		
[11]	X	X				X	X	X			X								
[3]	X	X	X		X	X	X	X	X		X	X	X	X	X			X	
[2]	X	X	X		X	X	X	X	X		X		X	X	X			X	
[12]	X			X	X	X	X	X	X				X		X				
[13]	X				X		X		X		X		X	X		X		X	
[14]	X		X		X	X	X	X						X		X			X
[15]	X	X			X	X	X	X	X			X							
[16]	X	X							X			X	X			X		X	
[17]		X			X	X	X	X			X	X							
[18]	X	X			X	X	X	X	X		X		X	X					
[19]	X	X	X		X	X	X	X	X		X	X							
[20]	X	X			X	X	X	X	X		X		X	X			X	X	
[21]	X	X	X	X	X	X	X	X						X			X		
[22]	X	X		X	X	X	X	X	X				X	X	X		X		
[23]	X	X			X	X	X	X			X						X		
[24]	X	X			X	X	X		X		X			X		X		X	
[25]	X	X	X		X	X	X	X	X			X	X						X
[26]	X	X	X		X		X	X	X		X		X			X		X	
[27]	X	X		X	X	X	X	X	X		X	X			X	X	X		
[28]	X	X	X	X	X	X	X	X			X		X		X		X		
[29]	X	X				X	X	X	X		X	X		X			X		X
[6]	X	X			X		X	X	X		X		X				X		X
[30]	X	X			X	X	X	X	X		X								
[31]	X	X				X	X	X	X		X					X			
[32]	X	X			X	X	X	X		X	X					X			
[33]	X	X		X	X	X	X	X	X			X	X		X				
[34]	X	X			X		X	X	X		X		X	X		X	X		
[35]	X	X			X	X	X	X			X					X			
[36]	X	X	X		X	X	X										X		
[37]		X		X	X		X	X	X		X	X		X	X	X	X		X
[38]	X	X			X	X	X		X		X						X		
[39]	X	X	X	X	X	X		X	X		X					X		X	
[40]	X	X		X	X		X						X	X		X			
[41]	X	X				X	X	X			X			X		X			
[42]	X				X						X	X							
[43]	X				X		X		X		X	X				X		X	
[44]		X			X		X					X							X

[45]	X	X			X		X				X	X		X		X	X		X
[46]	X				X	X	X	X	X		X		X			X	X	X	X
[47]	X	X			X	X	X	X			X		X					X	
[48]	X	X			X	X	X	X			X								
[49]	X	X				X	X	X	X		X	X	X			X	X	X	
[50]	X	X			X		X	X				X	X			X		X	
[51]	X	X			X		X	X			X	X				X			
[52]	X	X			X		X	X	X		X		X	X		X		X	
[53]	X	X			X		X				X			X		X	X		X
[54]	X	X			X		X		X		X		X				X		
[55]	X	X			X	X	X	X	X		X		X						
[56]	X	X			X		X		X		X	X				X		X	
[57]	X	X			X		X	X			X					X			
[58]	X	X			X	X	X		X		X								
[59]	X	X			X	X	X	X				X		X		X	X		
[60]	X	X			X		X		X		X	X		X				X	
[61]	X	X					X		X		X	X	X			X			
[62]	X	X			X	X	X	X	X		X		X				X		
[4]	X	X			X		X	X	X		X	X					X		
[63]	X	X				X	X	X			X	X				X			
[64]	X	X	X		X		X	X	X							X	X		
[65]	X	X				X	X				X	X				X		X	
[5]	X	X			X	X	X		X		X	X				X		X	

HBIM (Heritage Building Information Modelling)/**3DM** (3D-Modelling)/**IM** (Information Management)/**SS** (Semantic Segmentation)/**CH** (Cultural Heritage)/**PGY** (Photogrammetry)/**PCL** (Point Cloud)/**LS** (Laser Scanning/Laser Scanner)/**PM** (Parametric Model)/**VR** (Virtual Reality)/**BIM** (Building Information Modelling)/**GIS** (Geographic Information Systems)/**StB** (Scan-to-BIM)/**UAV** (Unmanned Aerial Vehicles)/**DL** (Deep Learning)/**LoD** (Level of Detail)/**TLS** (Terrestrial Laser Scanning)/**S** (Stratigraphy)/**DD** (Digital Documentation)

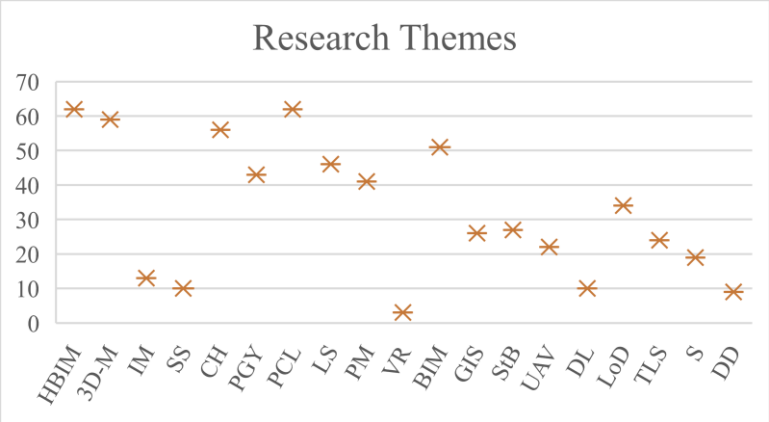

Fig. 4. Research themes according to publication

The classification of research themes is shown in Table 3 and Figure 4 above. As a result, the primary determinants of HBIM are developed and these determinants contributes towards development of digitalization component in conservation.

- **Heritage Building Information Modelling (HBIM)**: Historic Building Information Modeling (HBIM) entails automating the process of data collecting for historic buildings and sites, then mapping parametric and information-rich objects onto a geometric framework derived from survey data. Digital objects are transformed from static representations to dynamic, interactive, and "smart" models when information and knowledge are added as semantic

features to remotely sensed survey data. The resulting Historic BIM can be seen, as well as used for data extraction and analysis. Researchers from the fields of computing, architecture, archaeology, engineering, and other heritage sectors are working to improve the process for efficiency and to create more open systems as part of a multi-disciplinary and ever-evolving system. [51]

- **3D-Modelling (3DM)**: 3D modelling is getting more popular to document and explain archaeological and cultural heritage, especially in the past few years. Due to the high complexity and heterogeneity of 3D data and the variety of heritage resources, many segmentation and classification methods are being searched into. [39] The purpose of 3D BIM models is to collect digital information that can improve building management in ways that are consistent with the structure of the object being modelled, the institution's projected timeline for the project's completion, and the software's geometric construction constraints [31]

- **Information Management (IM)**: With the help of modern information management systems, it is now possible to create digital copies of cultural artefacts and use them in a planned and systematic manner. Reality-based survey approaches provide metric representation of reality as it is, returning the current object by photographs, range data, computer-aided design (CAD) drawings, and maps, or even by integrating these methods [21] An effective information management approach incorporates segmentation, hierarchical structure, and semantic enrichment [28]

- **Semantic Segmentation (SS)**: Semantic segmentation of point clouds is a key phase in the process, it decomposes complicated architectures into single parts that are subsequently enhanced with significant information in BIM software. Moreover, semantic segmentation able to classifies each 3D point into predetermined categories. These classes are architectural aspects (e.g. walls, doors, columns, stairs, etc.). Segmentation groups point clouds into specified subgroups based on geometric, radiometric, etc. The segmentation process divides point clouds into homogeneous regions with similar features, while the classification step identifies the groups [37] This semantic segmentation that considers structural, architectural, and decorative features may also be used for 3D research [24] Although obtaining an accurate 3D geometry model is no longer an issue, semantic segmentation and labelling of elements, as well as improving the representation of the linkages between physical and intangible historical information, are still highly anticipated [40]

- **Cultural Heritage (CH)**: UNESCO defines Cultural Heritage as the tangible (such as monuments, structures, landscapes, natural sites) and intangible (such as traditions, languages, traditions, knowledge) legacy of past generations. Cultural Heritage places, monuments, and artefacts must be appropriately managed to be protected. Institutions and corporations responsible for managing cultural heritage should manage its conservation, distribution, and attainment [32] In Cultural Heritage (CH) documentation, technological advances have enhanced the range and complexity of information sources. The capabilities of today's tools and methods for digital representation and information management bring up new possibilities for data collecting [36]

- **Photogrammetry (PGY)**: Graphic documentation approach has changed over time. Nowadays. photogrammetry is being used to collect data, which encompasses each stratigraphic unit into

three dimensions, making this method the most rigorous and efficient [8]. Photogrammetry is a popular technique for acquiring geometric/spatial data in the field of Cultural Heritage [38] it was used to undertake the survey of external sides of the building or monuments, as an example the side of the roofs to highlight the preservation status of tiles and roof structure in general [48]

- **Point Cloud (PCL)**: Surface meshing from the point cloud provides a framework for mapping HBIM objects. HBIM objects record regularity, while the point cloud surface model mesh records differentiation [14] 3D point clouds are accurate representations of real-world objects and include shape, size, position, and radiometry. Photogrammetry and laser scanning generate 3D point clouds to characterise an object's or scene's surface. Such representations are technically expressed as matrices of unorganised points; the rows correspond to the total number of points in the 3D cloud while the columns contain point-level information such coordinates, normal direction, colour, intensity, etc [12]

- **Laser Scanning/ Laser Scanner (LS)**: Laser scanner detection methods are utilised to collect information in the HBIM, which also makes it feasible to obtain geometric information by associating it with photographs [11]. The laser scanner point clouds were segmented in order to identify data and extrapolate "the components" that make up the model. The "parts" were loaded into the HBIM for connectivity and subsequent material and physical parameter matching to create a virtual model that was realistic. Laser scanners have shown to be highly important tools in the field of Cultural Heritage since it is non-invasive equipment that enable users to conduct extensive inspections of places without affecting their historical, cultural, and economic significance [3].

- **Parametric Modelling (PM)**: Each object in a parametric model can be interpreted and approximated depending on objective and subjective (critic) views. After collecting metric data, a parametric HBIM model can be created. Cultural Heritage items require a high level of detail in geometry and embellishments, hence free form modelling may be appropriate [34]. Parametric model construction, based on geometric rules in Treatises, is the initial stage in building a library of ideal models that may be overlapped on point clouds to assess geometric configuration. Complex parametric models based on reality-based surveys (including geometric annotations); Using principles and dimensions, architectural orders can be simply turned into parametric models [55].

- **Virtual Reality (VR)**: Through inversion virtual reality (VR) technologies, viewers may explore these structures from anywhere in the world and perhaps even access locations that are inaccessible due to conservation or accessibility concerns. In this approach, it can sustainably disseminate cultural heritage. Using the virtual models created for the goal of studying and recording heritage, virtual reality inverse technologies can be used to tour heritage sites. Three-dimensional modelling offers a new way to show information about things and conduct virtual tours of historic sites [8].

- **BIM (Building Information Modelling)**: Building Information Modelling (BIM) enhances the capabilities of classical CAD by establishing geometric and semantic relationships between 3D objects (surveyed as they are) and external data. BIM technology may merge geometric information with other data types. As-built BIM is challenging due to the complexity of geometric and non-geometric data and its interpretation on a BIM platform. Using commercial

BIM software for a historical building or archaeology project could lead to methodological compromises [60]. Building Information Modelling (BIM) is commonly used in heritage documentation (HBIM). The process includes solid element modelling based on documentation data in Autodesk Revit, a typical BIM platform, and successive modelling from these geometric primitives in Autodesk Dynamo, a Revit plugin for visual programming. BIM-based reconstruction adds measurement, semantic, and other information to the standard computer graphics model [61]

- **Geographic Information System (GIS)**: Geographic information systems (GIS) are used to store, visualise, and analyse geographic data. Geometry is used to store spatial features, which are then referenced with map projections and coordinates. Table attributes are then paired with spatial features to enable for data analysis. 2D GIS is being phased out in favour of 3D geographic data, which allows for more comprehensive analysis. 3D GIS can define and show buildings, urban rural centres, and other features based on their geometry, topology, semantics, and visualisation. With the addition of semantic attributes, extensive analysis and 3D spatial searches for modelling city and urban aspects are now possible. This examination comprises building fabric and structural elements, relief, vegetation, transportation, water bodies, city furniture, and land usage [51].

- **Scan-to-BIM (StB)**: The term Scan-to-BIM (or Point-to-BIM) was coined to describe the workflow that begins with the generation of a point cloud and then is translated (usually with time-consuming human intervention) into "in-place" geometric objects (i.e. not relying on libraries) in order to exchange building data among practitioners and designers via abstract 3D representation [62].The scan-to-BIM procedure is largely used in the current HBIM project to manually generate the geometric model from the point cloud [61]. The modelling of the architectural and structural features, which were unique in their kind, necessitated the use of various grades of generation (GOG) in order to generate a model capable of transforming point clouds into parametric objects (Scan-to-BIM process) [46].

- **Unmaned Aerial Vehicle (UAV)**: The UAV survey was conducted to obtain all the exterior elements of the building/sites/artifacts that were too high for the TLS survey to reach [10]. The usage of the UAV eliminated the difficulties of reaching areas of the building/sites/artifacts that are difficult to approach and detect—specifically, the inside spaces that are not secure due to roof faults that are only visible from above [13]. In order to prevent stitching issues during the process of UAV acquisition, it was necessary to guarantee the system's stability throughout exposure [14].

- **Deep Learning (DL)**: Deep learning refers to a subclass of end-to-end machine learning techniques including Deep Neural Networks (e.g. CNN, deep reinforcement learning, GAN, etc.). Its incorporation in computer vision applications began only a few years ago. Deep learning allows machines to learn from pixels to classifiers. Each layered layer with a similar structure performing different transformation functions pulls features from layers below and above in a directly connected way [33]. In Digital Cultural Heritage (DCH), semantic segmentation of 3D Point Clouds with Deep Learning (DL) techniques can help recognise historical architectural elements at an adequate level of detail, speeding up the process of modelling historical buildings for developing BIM models from survey data, called HBIM (Historical Building Information Modeling) [28].

- **Level of Detail (LoD)**: The Level of Detail (LOD) specifies the amount and type of building information that must be included in a BIM model. This encompasses not only graphical objects or physical properties, but also the data connected with the items. In a nutshell, Level of Detail (LOD) is a framework for specifying the development of the BIM Model, which aids communication and cooperation with all project teams. LOD was founded by the American Institute of Architects (AIA) in 2008 when it first presented five "levels of development" for describing the degree of detail in a BIM model. However, in order to assist the building trades in better adopting and implementing them, BIMForum interpreted those levels for specific building components and released them in 2013 as Six Levels of Development (LOD) [66].

- **Terrestrial Level Scanning (TLS)**: Terrestrial Laser Scanning (TLS) allows automatic, rapid, and efficient 3D coordinate collecting of cultural heritage artefacts. For most applications, this data gathering method is an acceptable alternative to digital photogrammetry [37]. This survey served as main reference and for correcting two-dimensional surveys (A. Moreira, 2018) In addition, TLS's millimeter-level accuracy, resolution, and three-dimensional geometry enabled researchers reexamine flaws and omissions made by hand measurements in previous surveys [59]. TLS were employed to meet the architectural scale graphic detail requirements [53].

- **Stratigraphy (S)**: HBIM can connect the complex geometry of stratigraphic units with photogrammetric texturing and the constructed material database [9]. Stratigraphic units of historical architecture might be handled in a BIM platform, where each could be digitally linked to its history phases and augmented with fresh structural knowledge. The application of stratigraphic analysis and the detection of all interventions on a historical building in a specific period on HBIM projects contributes significantly to the evaluation of risk and vulnerability elements, because constructive and destructive actions would be connected as architectural components to parametric model. In architectural terminology, USM and USR concern masonry, wall cavities, render/plaster, decoration, and other aspects [43].

- **Digital Documentation (DD)**: Digital documentation is needed to come up with informative conservation and maintenance plans, as well as to learn about the decorative devices, space design, and materials used, as well as the innovative building solution chosen [46]. Heritage digital documentation is made up of three steps: 1) getting the raw LiDAR data; 2) processing the point cloud; and 3) making the model. Because each tier depends on the output of the one before it, the output and benefits of each tier are passed on to the next. [29].

4. Conclusion

This study has contributed to knowledge of conducting a review through online database such as Scopus, it will eventually establish a baseline for upcoming research in the future. As a result, the study reveals that HBIM digitalization trends from previous five years, a conceptual model that focusing on HBIM digitalization are provided as below, it can be referred as HBIMDM – HBIM Digitalization Model as proposed in figure 5 below:

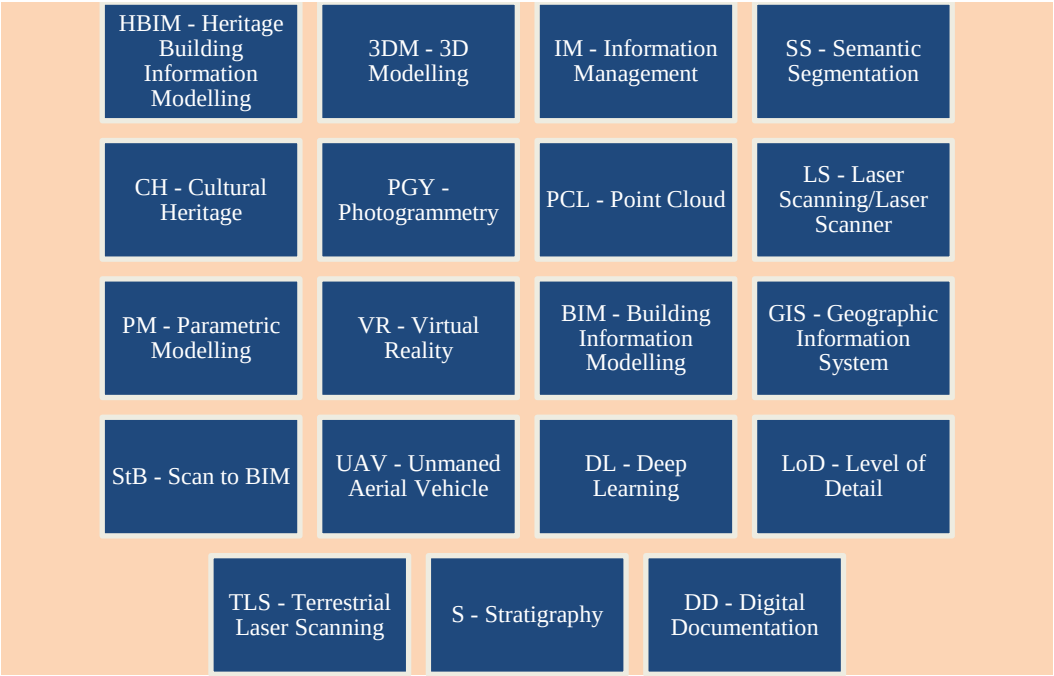

Fig. 5. HBIM Digitalization Model (HBIMDM)

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