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Original Article

Mapping manufacturing data into the life cycle of building information modeling projects digitally

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Abstract

BIM megaprojects are expanding today all across the world. These projects have huge data sets, complex objects, and several stakeholders. The Architecture, Engineering, Construction, and Facility Management (AEC FM) industry is undertaking major responsibility for delivering quality services to meet clients' expectations. Additionally, one of the current research gaps with emerging trends in BIM is integrating conventional methods with BIM. One of the main challenges is that the product data is resistant to the digital transformation strategy that the AEC FM industry is pursuing. This causes breakpoints in the digital data workflow throughout the BIM project life cycle. The paper used a questionnaire to solicit the opinion of AEC FM experts on using BIM objects and delivery methods for product data and their impact on digital data workflow. Then, the paper establishes a digital data repository (DDR) for vital manufactured standard products. It digitalizes the product data on graphical and non-graphical levels. The graphic level is packed into formats that serve closed and open BIM directions. The non-graphical level is loaded into Open Database Connectivity (ODBC) using a SQL server to enable the AEC FM industry to restructure product data digitally according to each project phase's needs. DDR facilitates enhancing a digital workflow, reducing time, cost, and effort to manage product data, improving decision-making, and accelerating the performance of BIM projects. Furthermore, it enhances business opportunities for manufacturers in AEC FM markets. Finally, DDR is considered the digital identity of a product throughout the product life cycle.

1. INTRODUCTION

The journey of the AEC industry toward digital transformation includes a significant role in building information modeling. It is a virtual common data environment with graphically structured data on building physical characteristics. The development of BIM is related to setting up a digital data workflow to exchange information through the entire life cycle of a project, from design up to refurbishment. The BIM projects continue to face unique challenges involving utilizing advanced technologies, many stakeholders, and more and more data generation that needs to be organized and shared to achieve business objectives. Data is the driving force of the digital era; a research gap in the paper is essentially the unstructured manufacturing data that will lead to; breakpoints of digital workflow, poor data quality, misleading decision-makers, and confusing them. Therefore, the traditional documents and conventional delivery methods of the manufactured product data in files or formats that are not open to search, sort, extract, share, manage, or restructure, such as PDFs or printed catalogs, are not appropriate for the demands of the digital approach. So, the main goal of paper directed towards the enhancement of the data management process to improve data quality, decrease the breakpoints of digital workflow, accelerate project performance, and then fulfill the objectives of all stakeholders. There are several important stakeholders in the AEC sector. The power of stakeholders depends on the magnitude of their participation in the project life cycle. The manufacturing sector is regarded as the AEC sector's twin. A key to stakeholders' success is to incorporate their requirements early in the project. On the other hand, in comparison to many other industries, the AEC industry has lower productivity. So, to increase productivity in the AEC sector, other stakeholder sectors must be accountable for supplying the demands of the AEC sector in a manner consistent with its needs. As a result, it is crucial to interact with each other correctly. The manufacturing sector is the backbone of the AEC and FM industries. It is the initial milestone in the creation of the physical building components or assets. Depending on that, the role of the manufacturing industry needs to be more effective by packing the physical building components into credible digital repositories. So, the objectives of paper are suggestion a solution to digitalize product data as a digital identity for products. It is a solution to adapt the roles between the manufacturing sector and the AEC FM industry according to the attainment of data reliability and the attribution of functions to the relevant party without the need for more double effort from the other parties. Thus, this paper recommends the establishment of DDR, especially for vital manufactured products that are standardized, not customized. It takes into consideration the requirements of BIM technology, a targeted digital transportation approach throughout the product life cycle, and the ability of product data to be restructured according to the needs of each project phase. It will accelerate the performance of BIM projects and improve the quality of the data and the digital workflow. Additionally, it will enhance the business opportunities for manufacturers in the AEC FM markets.

2. Literature Review

The AEC sector involved a variety of categories of projects in Figure 1. It impacted on operational strategies and working procedures within the construction sector[1].

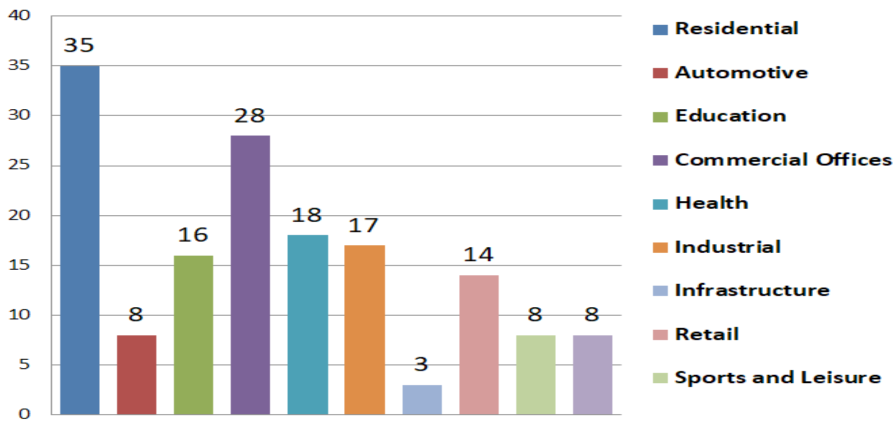
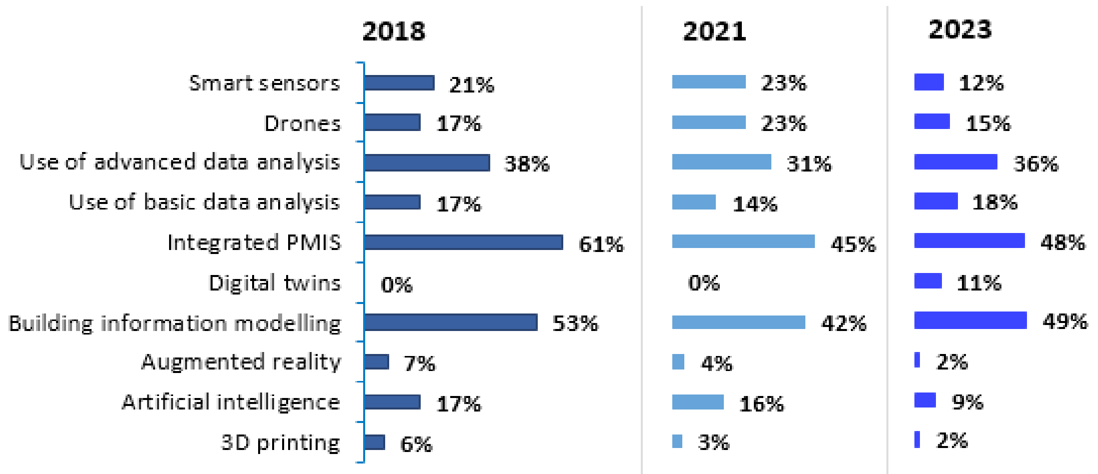


Fig. 1: The categories of projects, and key trends in construction[1].

According to the International Energy Agency (IEA), effective management of existing structures is crucial. It is an important step to enhance building operations, facilitate information access, and provide statistics that will aid in the improved decision-making of building managers[2]. As a result of changes like projects and unique clients' requirements, the need arose for the development of the AEC FM industry by directing to the digital transformation approach. The drivers of digital transformation were split into two main categories: inner motives and outside triggers[3]. The most important factor included in the outside triggers of digital transformation is the evolution of technology[4]. Critical success aspects of digital transformation are categorized into multiple dimensions, such as technology, context and contents of digital transformation, strategy, and organizational capacities [5]. During the digital transformation journey, the AEC sector must also deal with internal issues, including poor project monitoring. A related problem is the poor tracking of projects in comparison to other sectors. Across several manufacturing industries, operational activities are continuously monitored, and a lot of data is gathered[6]. On the other hand, the main risks impeding digital transportation is a lack of data control. A lot of companies are preoccupied with technology rather than the client because they lack the appropriate strategy. Organizational transition, data integration, and technology must be conducted equally to achieve an effective digital transition for businesses[4]. Despite all the previous efforts, the digital revolution over the past fifty years has impacted the considerable innovation occurring at the corporate or business level. However, the AEC industry has been slower to absorb and adapt to advanced technologies than other international industries. As an industry focused on effective procurement procedures, E&C has typically adopted a cautious approach to product design and delivery, resulting in project management silos and a relatively fragmented market[7]. Across manufacturing industries, operational activities are continuously monitored, and a lot of data is created and gathered. So, in the event of a problem, a manufacturer can swiftly pinpoint the root causes. So, a top-level implementation of digitalization by project stakeholders should result in improved information exchange between them[6]. This exchange should be based on multiple aspects, such as interoperability and information management processes throughout the product life cycle. Finally, it enhances the increased use of digital transportation approaches. So, this research looks at digitizing product data and how it will optimize the broader utilization of digital workflow for data and arrange the responsibilities between the manufacturers and the AEC FM. Many technologies have the potential to deliver the highest overall return on investment (ROI) in capital projects. BIM was the top three responses as shown in Figure 2[8].



BIM is one of the most revolutionary innovations in the AEC sector. The rate of BIM use has increased in the AEC sector[9]. The importance of adopting BIM is growing quickly and is being acknowledged in the AEC sector[10]. Professional functions use the fundamental BIM data to enable, expand, compute, or simulate certain business needs[11]. According to ISO 19650-1, BIM applies to the whole life cycle of a built asset, including strategic planning, initial design, engineering, development, documentation and construction, day-to-day operation, maintenance, refurbishment, repair, and end-of-life[12]. However, the modeling phase took the most time. This phase was segmented to enhance efficiency according to the level of detail required to achieve the final requirement[13]. So, libraries for building information modeling allow users to spend less time and cash, reduce the misleading or conflicting nature of documentation sets throughout the design life cycle, and update them in the construction phase[14]. Despite that, a lot of types of equipment, particularly technical equipment, are frequently not included in BIM libraries. A different choice could be to design a customized model. It requires a lot of effort, though, and the efficiency-to-time ratio[15]. So, it is required to find an effective way to speed up the creation of BIM models to accelerate the performance of BIM projects. On the other side, BIM can perform the functions of information sharing and exchange, but the compatibility of BIM software still needs improvement[16]. Additionally, the construction industry has multiple stakeholders in the same industry or in other sectors that use other platforms and applications. So the need to move from closed BIM to open BIM is essential to achieving data sharing between them. The in-house and closed BIM methodologies needed to be opened up for the whole value chain of the construction sector, from design to asset management[17]. According to the buildingSMART International, Industry Foundation Classes (IFC), is a standardized, digital representation of the built environment. It is an open, international standard[18]. Therefore, part of this research gives a solution that enables injecting a fabricated digital model as a credible source without needing to create it from scratch or search for it in BIM libraries, and validates its data. The digital assets should be presented in the most common format and IFC file to serve on both closed and open BIM directions. Furthermore, as buildings develop into strategic assets in addition to commercial assets, data retrieval to monitor expenditures and building effectiveness is becoming more crucial. BIM is positioned to enhance an additional level of functionality for controlling buildings and the physical assets within them, along with comparable advantages[19]. ISO_29481-1_2010 defines BIM as a shared digital representation of the physical and functional characteristics of any built object that forms a reliable basis for decisions[20]. The initial milestone in integrating BIM and facility management practices is to create realistic operations and maintenance activities in connection with the locations and equipment[15]. Although the facility management and Computer-aided facility management (CAFM) offer a comprehensive asset inventory and enable the planning of processes, procedures, and maintenance tasks. However, the interconnectedness of these tasks is required with a BIM model framework that enables improved visualization, validation, and availability[15]. The adaptability of the BIM model additionally offers the opportunity to combine the tracking equipment and maintenance activities with the operation periods depending on timing utilization or sporadic events[13]. A range of supporting technologies are needed to improve the virtual modules of Digital Twin (DT), such as real entities, virtual models, DT information, intelligent services, and interactions[21]. The definition of a digital twin is a digital version of a real asset that gathers and transmits real-time data. Its operation depends on the bi-directional synchronization of data between the real and digital worlds[22]. The initial stage of the digital model is offline since it is linked to the system manually. On the second stage, the digital model automatically collects information from the shop floor. The top stage of the digital twin is entirely synced by real-time interaction[23]. Additionally, it is possible to link BIM with the FM platform or database. A BIM model was established, containing all the parameters related to day-to-day process management duties. The BIM-based technique provides real-time data that is gathered by sensors and connected to SQL databases that are synced with the BIM model, supplying the end user with data allocated to a particular area[13]. The BIM-based technique proposed in this research brings additional revenue. Real-time data gathered by sensors is connected to SQL databases that are synced with the BIM model at the same time, giving the user access to all the data related to a certain location[24]. On the other hand, the difficulties of construction waste remanufacturing are the absence of enough data and the problems of sharing data among those involved in the remanufacturing chain. The implementation of digital twins in the remanufacturing of construction waste utilizes the monitoring, reuse, and control of construction waste[25]. So, additional recommendations are provided related to organizational transformation on the path towards a digital-driven construction industry, which includes but is not restricted to the regulation and law of the proprietary rights of digital assets[26]. The Specifiers' Properties information exchange (SPie) project has had multiple occurrences of interactions with the United States design and manufacturing industries. These efforts have not been effective in improving a national standard for minimum BIM object attributes. Although Construction Operation Building information exchange (COBie) enhances the format for facility asset information, it does not outline the specifications for certain product attributes. So, the previous attempts to involve facility managers in establishing an Operators Properties information exchange (Opie) failed due to an absence of reaction from the community[27]. Although the multilevel model of cyber-physical systems and digital twins for production contains the unit level, system level, and smart service platform[28]. The unit level refers to the tiny component taking part in manufacturing processes, such as a digital twin object (DTO) is constructed[29]. After that, several workable methods Suggested for the usage of manufacturing big data. However, it is concentrated more on the algorithm's performance and disregarded the data preparation[30]. To improve data exchange, it is essential to determine the destination responsible for creating data, the requirements and needs of each phase, and the relationship of data with each other. GSA has established three layers of data demands in BIM projects. To serve its business desires. The first is BIM for the spatial program, the second is equipment information, and the third is an as-designed BIM with energy analysis predictions[31]. According to ISO 19650-2, there are three common methods adopted to define the level of information needed for an asset. The first method is the descriptive method; the second method is the specification method; and the third method is the asset definition method. It focuses on determining the level of information needed for each asset separately and is the most comprehensive of all the methods[32]. Finally, The primary challenges in the AEC industry, especially BIM projects, are mainly sharing data and information, while there are limited research works on how to cope with the difficulties[25]. The following Figure 3 presents a paradigm that connects current research gaps with emerging trends in BIM and smart building areas[16]. The integration of traditional methods and technology with BIM is one of the research gaps. So, this paper will focus on the graphical and non-graphical levels for the data of the vital standard product to provide digital asset for it that enable the digital delivery methods of product data to the AEC FM industry and improved digital data workflow then facilitate decisions based on trusted real data.

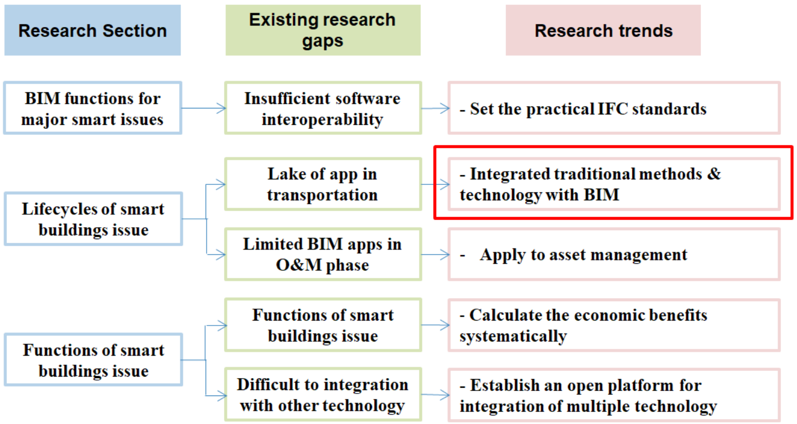


Fig. 3: Research framework linking existing study areas to future directions[16].

All around the literature reviews; it was found that there are several attempts to move the manufacturing sectors, AEC industry, and FM industry toward digital transportation. However, there is an absence of cooperation and an unadapting of responsibilities between the manufacturing sector and the AEC and FM industries. This leads to breakpoints in the digital workflow of data and then weakness in accelerating the performance of projects. So, this paper proposes to improve the quality of product data structure injected into BIM projects by establishing a Digital Data Repository passed through a digital workflow from the manufacturing sector to the AEC sector until it arrives at the FM industry. It accelerates the performance of BIM projects and saves cost, time, and effort by avoiding revising and reorganizing data at each phase. Additionally, it improves business opportunities for manufacturers in BIM markets.

3. Methedology

The concept of the digital data management process is one of the most important aspects of BIM projects success. Currently, the AEC and FM industries use multiple platforms and digital technology to manage and exchange data and keep updated about the progress of the whole project. However the management process for product data has not been fully facilitated to accelerate the achievement of stakeholders' requirements. This research used a questionnaire to solicit the opinion of AEC FM industry professionals and experts on using BIM objects and delivery methods for product data and their impact on digital data workflow. The primary objective of this step is to ensure the needs of the AEC FM sector to digitalize product data. The following formula was used to get the desired sample size for this investigation: n= N / (1+N (e) 2) as provided by Tara Yamane, 1967. Where n signifies the sample size, N signifies the population under study, and e signifies the margin error. A sample size of 95 was determined. Google Forms was used to collect online responses to the questionnaire, which was distributed to a sample of 300 specialists. The responses to the questionnaires obtained were 145, which is more than the calculated sample size.

The questionnaire responses were analyzed to determine the most common methods used to establish BIM objects and delivery methods for product data. It was discovered that more effort, cost, and time are expended on creating BIM objects from scratch or searching into BIM libraries, or from previous projects, and then adjusting the product data, both graphical and non-graphical, in each phase of the project life cycle. All the previous leads to no one trusted source for manufactured product data, poor data, breakpoints in digital workflow, and stumble data exchange among stakeholders. So, this paper recommends establishing a Digital Data Repository (DDR) for vital manufactured standard products in the AEC FM sector because their performance and roles are critical throughout the total project life cycle. It injects product data into the digital data workflow throughout the BIM project life cycle. The DDR functions through three elements. The first one is presenting a 3D asset for the product with the most common formats used in closed BIM programs. The second one is an IFC file that serves the open BIM approach. The final one is the database for product data to enable digital data management processes with no more time, cost, or effort. Figure 4 shows these elements. DDR is considered a digital identity attached to the product throughout its life cycle. It digitalizes the product data on graphical (horizontal direction) and non-graphical (vertical direction) levels. Thus, it decreases the breakpoints in digital data workflow throughout the BIM project life cycle, accelerates data sharing, and then improves decision-making and the performance of the project. On the other hand, it promotes business opportunities for the manufacturing sector by directing towards a digital approach that the AEC and FM sectors are pursuing.

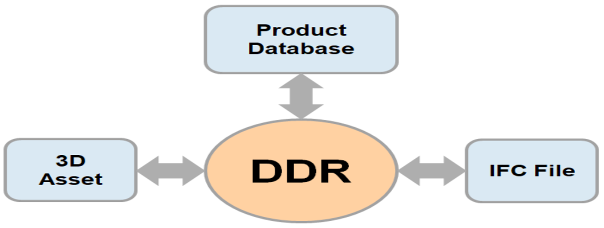


Fig. 4: The proposed solution DDR based on graphical and non-graphical levels.

3.1. 3D Asset

It used to be necessary to create BIM objects from scratch and add them to the in-house library while working on BIM projects. It takes more effort and prolongs the duration of the modeling phase. Subsequently, public BIM libraries emerged, offering the ability to peruse and download BIM objects from various libraries. However, more time is wasted searching for the required BIM objects in these libraries. It also takes longer to validate the data or attempt to alter some data to make it meet the specifications of the project. So, it's important to motivate team members to devote their whole attention to their job without straying into other tasks such as searching for required BIM objects and validating their data. Therefore, the proposed solution (DDR) obliges the manufacturers to offer a 3D asset attached to their product documentation to achieve the required specifications for each model of the product. This allows them to represent all real data in one credible source that is sent to the AEC FM industry. In the following, some criteria should be established for a 3D object to be considered a 3D asset. It is considered a manufacturer's responsibility. It is a little effort for manufacturers in comparison to the effort done in the AEC industry because each manufacturer applies to its standard products, but the project specifications in the AEC industry don’t have standards; they vary from one project to another:

- Creating an object with real information for each product type and model to be ready for injection into the project model.

- Creating an asset with real graphical data (using a 3D scanner) to help in the coordination phase where they occupy the real spaces and achieve Constructability. On the other side, it saves time, cost, and effort in the laser scanning phase, where the laser scanner on the real site captures the object location; there is no need for more resolution or more points to provide graphical features of objects. It is already achieved in the 3D asset.

- Achieving a level of detail (LOD) in geometric data using features such as detail level in Autodesk Revit software. It enables mitigation of the family size in the early stages (design stages) of the project and increase the accuracy of family details as the project progresses to optimize the use of 3D family in each stage.

- The 3D asset should be classified by Omniclass, Uniclass, and MasterFormat, where effective information organizing and retrieval are enhanced. Additionally, a 3D asset should be assigned by the ifcExportAs parameter to support COBie export. The standardization of objects facilitates the digitalization approach; there is no standardization without classification.

- All previous features reduce time, cost, and effort to convert PIM to AIM, where the critical manufactured standard products that require tracking their performance in the FM phase are already received at the beginning of the project as 3D assets.

3.2. IFC File

Much as there was a lack of flexibility in the management of roles to find the required BIM object, there was also a lack of flexibility in the integration of BIM programs. The DDR should contain an IFC file for each product model to serve the open BIM programs and enable the DDR to provide both directions, open BIM and closed BIM. The IFC file should also contain the criteria for the 3D asset, such as real graphical and non-graphical data, and classifications to achieve the same benefits.

3.3. Product Database

The majority of product data sent to the AEC and FM industries is not searchable and does not permit sorting, filtering, extracting, or restructuring data such as PDF or printed catalogs. It is a terrible, solid issue; there is no time to search manually or visually, and most projects become fast-track. On the other hand, designers used to select product specifications according to previous projects, but this caused many issues where some products developed their features, so the design calculations did not match the current products on the market. The contractors face big distinctions and have to request redesigns or purchase products with higher specifications, which results in more cost and increases inconsistent data in various project documents. Currently, some manufacturers provide configurators for designers as a good, fast solution. It is the arrangement software for products and their models that makes up the database, where it receives the required key inputs and then provides the targeted product models and their brochures. It has solved the disruption between design specifications and available market products. But still, the problem with the data structure that manufacturers produce does not match the digital workflow. So, the product database is an electronically stored collection of product data that is interrelated and connected. It enables users to access, retrieve, and manipulate data at any time. It should be established to be consistent with the required needs of stakeholders. One of the most useful database usages is a view level in the schema architecture of a database, which provides a flexible solution by hiding parts of the database from specific users to enable each team to pick up only the target information without stuffing a lot of data to no avail. Additionally, it also allows end users to restructure data in accordance with project-specific needs without the need for intensive manual procedures. It makes it easier to integrate product data automatically with the platforms and BIM software that the players in the AEC and FM sectors use. The schema architecture of a database is essential in creating a database that not only ensures its confidentiality and performance but also preserves the essence of the data. It separates the database into three layers. The physical layer is the first; this level establishes the database's actual physical storage configuration. The conceptual layer is the second; this level describes the overall database structure. The view layer is the last; this level describes the actual view of data that is relevant to the needs of users. The three-level scheme architecture of a database is shown in Figure 5. The physical layer depends on the operating system and the format of the bits on hard drives, and it is unimportant to end users. So, the case study in this paper will focus on the conceptual and view layers and ignore the physical layer.

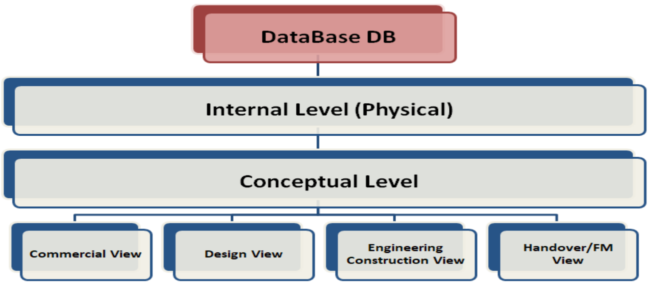


Fig. 5: The three-level schema architecture of the database for Digital Data Repository.

DDR is considered a credible source for manufactured standard product data. It can greatly mitigate data inconsistency as a result of different files of the same data appearing in different places or being manually restructured in each phase. It improves the requirements of digital construction in the AEC sector and digital twin in the FM sector. The workflow of the DDR throughout the life cycle of BIM projects will be demonstrated, as will its integration with digital methods used in the AEC FM sector recently by passing it to the AEC FM industry to achieve their needs, as shown in Figure 6.

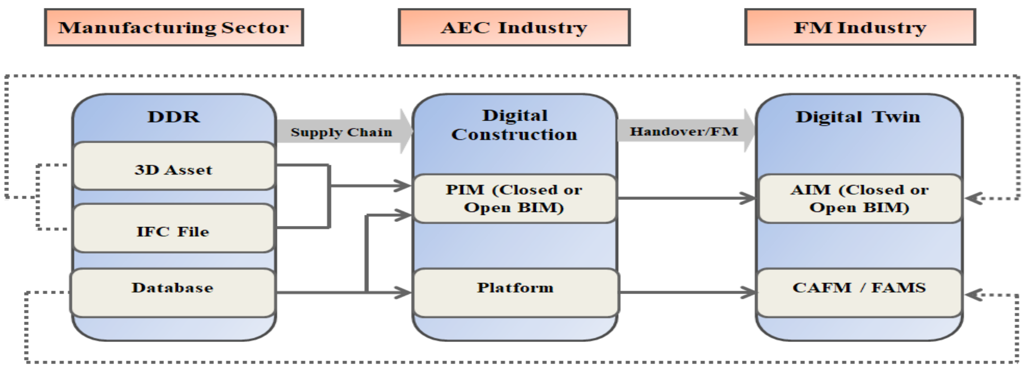


Fig. 6: The workflow of DDR throughout life cycle BIM projects to follow digital approach.

Workflow of DDR for new building →
Workflow of DDR for replacement ⇢

The implementation of processes for DDR is systematically represented step-by-step in the following flowchart in Figure 7 to enable injecting it into the workflow. The problem is depicted as an input, and then it performs essential processes that are ongoing to lead to the required conclusions. The traditional delivery method of product data was the problem, and the digitalization of product data, both graphical and non-graphical, is the target of all processes to enable the mapping of manufactured standard product data digitally into BIM projects by establishing DDR to improve the efficiency of the digital data workflow that illustrated in Figure 6.

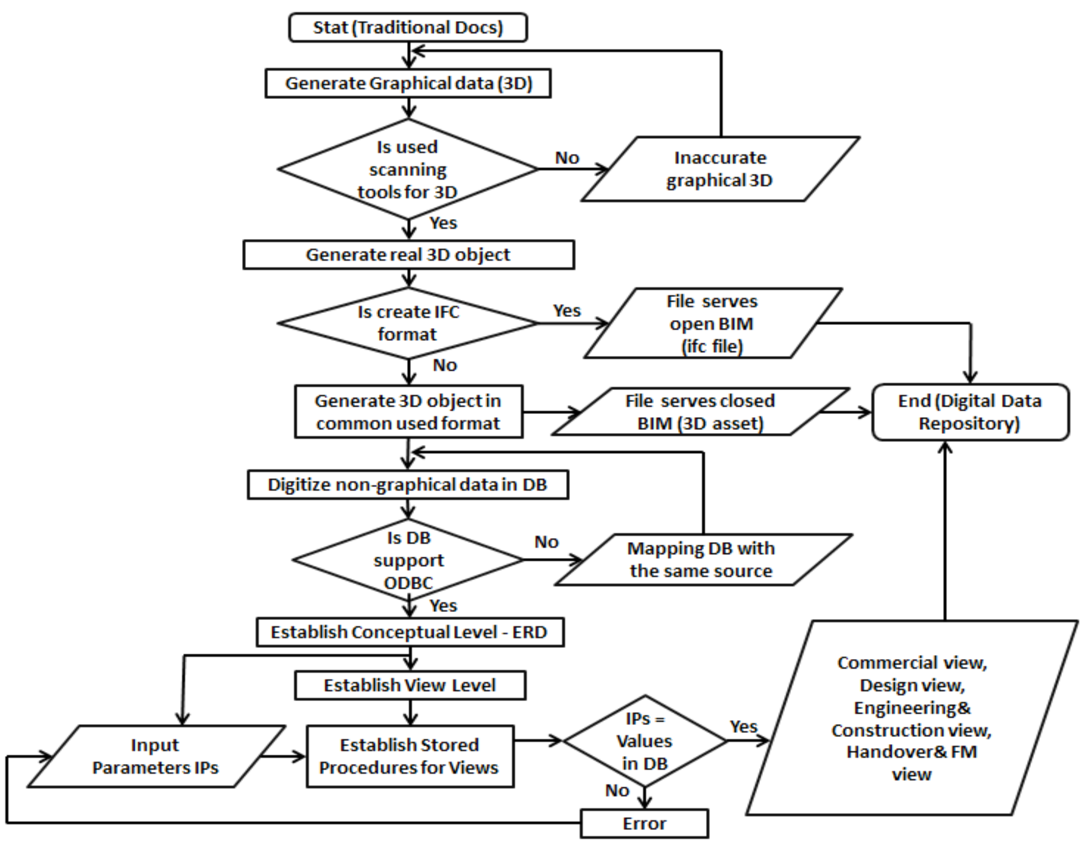


Fig. 7: The flowchart illustrates the processes establishment of DDR.

The next section will be focused on establishing a case study of an Uninterrupted Power Supply (UPS) product database using Microsoft SQL Server as a Database Management System (DBMS) that supports Open Database Connectivity (ODBC). UPS is selected because it is considered one of the vital manufactured standard products, it is a critical product in the AEC industry according to its cost and sensitivity throughout design, procurement, and construction, and its role and performance should be tracked into the FM stage. It is one of the products that this paper recommends applying DDR to.

4. Case Study

Databases are the backbone of modern information systems, which act as repositories for structured and ordered data. So, in the field of data management, creating a database system that meets the distinct requirements of stakeholders is a multifaceted task. A product database was to be applied to UPS products to validate the applicability of the proposed solution and verify its benefits for digitalizing product data to improve digital data workflow and accelerate project performance. The case study used Microsoft SQL Server as a DBMS that supported ODBC to design a product database. ODBC is a standard interface for accessing data from diverse sources. It provides a common API for developers to write applications that can access data from a variety of sources. It enables interaction with BIM programs and platforms. On the other side, there are two ways that DDR is transferred to the AEC or FM industries. The first is files in (CSV) format for views extracted using stored procedures in accordance with the required models. A script file .sql with data alone, or schema and data, is the second type of file.

4.1. The Schema Architecture of the Product Database

The schema architecture of the UPS product database displays the conceptual level and view level, as well as how the data is arranged and stored in schemas, tables, and the connections between them. A database scenario was established based on six schemes that are shown in the ERD; each one contains a set of tables related together. The schema label is shown in Figure 8.

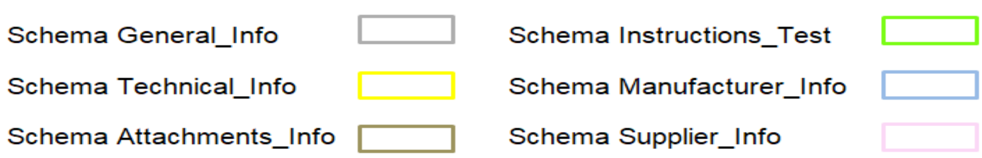


Fig. 8: The schemas label of the UPS database

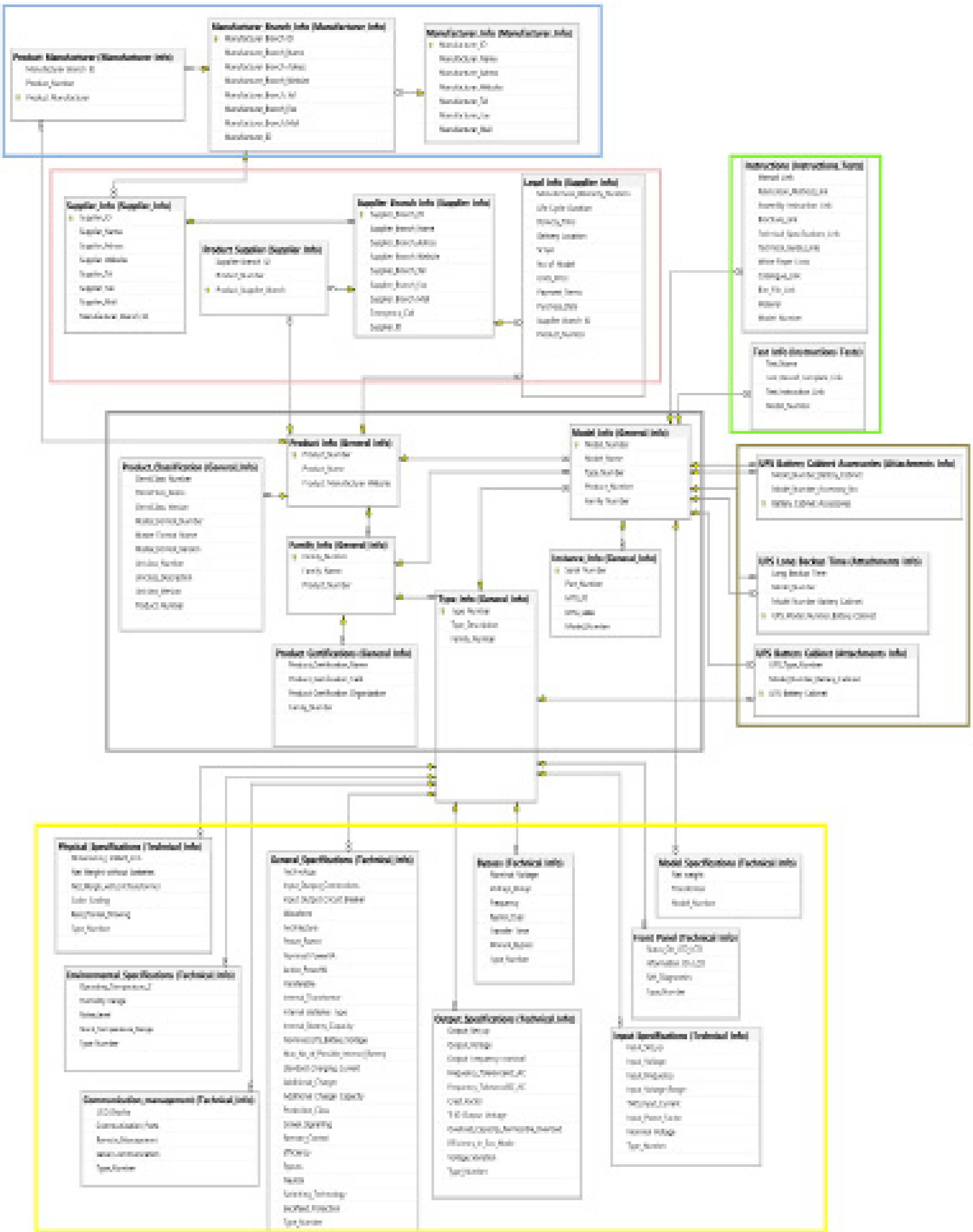


Fig. 9: The ERD represents of the UPS product data and its relationships.

4.1.2. View Level

The view level divided the database into four views that are relevant to the needs of users for each phase: commercial view, design view, engineering and construction view, and handover and FM view. Table 1 presents the information schema of Commercial View. It enables users to access the same data or parts of data in different structures according to their requirements. Also, it is available to end users to restructure the data tables into additional views to achieve any specific required representation for data.

Table 1: The information schema of commercial view

Column Name	Data Type	Schema / Table Name
Model_Number	int	General_Info / Model_Info
Model_Name	varchar	General_Info / Model_Info
Type_Number	int	General_Info / Type_Info
Type_Description	varchar	General_Info / Type_Info
Family_Name	varchar	General_Info / Family_Info
Product_Name	varchar	General_Info / Product_Info
Supplier_Branch_ID	int	Supplier_Info / Supplier_Branch_Info
Supplier_Branch_Name	varchar	Supplier_Info / Supplier_Branch_Info
Supplier_Branch_Adress	varchar	Supplier_Info / Supplier_Branch_Info
Supplier_Branch_Website	varchar	Supplier_Info / Supplier_Branch_Info
Supplier_Branch_Tel	int	Supplier_Info / Supplier_Branch_Info
Supplier_Branch_Fax	int	Supplier_Info / Supplier_Branch_Info
Supplier_Branch_Mail	varchar	Supplier_Info / Supplier_Branch_Info
Manufacturer_Warranty_Duration	varchar	Supplier_Info / Legal_Info
Life_Cycle_Duration	varchar	Supplier_Info / Legal_Info
Delivery_Time	varchar	Supplier_Info / Legal_Info
Delivery_Location	varchar	Supplier_Info / Legal_Info
Scope	varchar	Supplier_Info / Legal_Info
No_of_Model	int	Supplier_Info / Legal_Info
Unite_Price	varchar	Supplier_Info / Legal_Info
Payment_Terms	varchar	Supplier_Info / Legal_Info
Manufacturer_Branch_Name	date	Manufacturer_Info / Manufacturer_Branch_Info
Manufacturer_Branch_Adress	varchar	Manufacturer_Info / Manufacturer_Branch_Info
Manufacturer_Branch_Website	varchar	Manufacturer_Info / Manufacturer_Branch_Info
Manufacturer_Branch_Tel	int	Manufacturer_Info / Manufacturer_Branch_Info
Manufacturer_Branch_Fax	int	Manufacturer_Info / Manufacturer_Branch_Info
Manufacturer_Branch_Mail	varchar	Manufacturer_Info / Manufacturer_Branch_Info
Model_Number_Battery_Cabinet	int	Attachments_Info / UPS_Battery_Cabinet
Model_Number_Accessory_No	int	Attachments_Info / UPS_Battery_Cabinet_Accessories

4.2. Stored Procedures

It uses the stored procedures to perform some defined actions. It presents the required view in the database according to conditions based on specific input parameters. These conditions filter the database to capture the target models. The stored procedure for the Commercial view uses the conditions to pick up the specific model of the product according to Model_Number and Supplier_Branch_ID. It allows suppliers to offer commercial data with supplier's data. For the Design view and the Engineering_Construction view, it used the condition to pick up the specific model of the product according to Model_Number because they depend on the technical product data only. For the Handover_FM view, it used conditions to pick up the specific instance model of the product according to Model_Number, Serial_Number, and Supplier_Branch_ID because it allows facility teams to receive the instance data on the real site and the supplier data that provided this product. Figure 10 illustrates the stored procedure used to visualize the commercial view in the UPS product database.

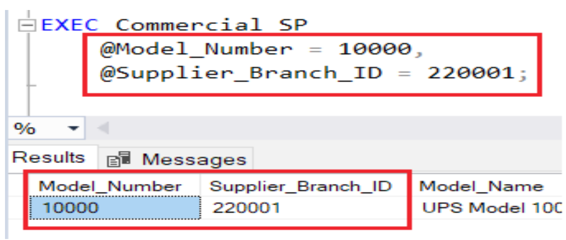


Fig. 10: The stored procedure for commercial view

The UPS product database is established based on the processes of the proposed solution. The schema architecture was the first process that included the conceptual and view levels of the database, followed by entering data for UPS product samples into the database. Finally, the store procedures are created for extracting the targeted views. The product database is a DDR when it includes a 3D asset and an IFC file as links in the BIM File attribute in the instructions table. Thus, DDR is considered a credible source for product data.

5. Conclusion and Future Work

The study contributes to science by offering novel philosophical thinking for practically an existing challenge where there is no clear process or methodology for concluding other than intuition and firsthand experience. So, this research used a questionnaire to get the feedback of professionals in the AEC FM sector on using BIM objects and delivery methods for product data to ensure the needs of the AEC FM sector to digitalize manufacturing product data. Thus, this research establishes the DDR to introduce a solution for the AEC FM sector to enhance digital data workflow, accelerate decision-making, and improve the performance of BIM projects. Furthermore, it provides the manufacturer with a strategy to stay on track with digital transportation. This strategy will enhance integration between the sectors throughout the product lifecycle. It ends up illustrating the beneficial results of establishing DDR for manufactured standard product data according to the required criteria in the AEC FM industry. DDR improves cooperation between the several actors in BIM projects by adopting their roles. So, the DDR adjusts the duties in accordance with the achievement of data dependability and the assignment of responsibilities to the appropriate party. It makes the process of tracking all product data easier according to one credible source. Then, it accelerates the creation of PIM and the preparation of AIM by utilizing a 3D asset and IFC file. Additionally, data inconsistencies between various sources are solved by using the product database. Furthermore, the view level of the database enables the restructuring of the data according to the needs of each stage, thus achieving data sharing with several stakeholders. All things considered, DDR has several benefits over printed catalogs, and conventional file-based systems, not only for the AEC FM industry but also for the manufacturing sector. It facilitates faster sales cycle. It makes it possible to integrate with digital marketplaces. Thus, it enhances business opportunities in the AEC FM markets. Furthermore, it can inject new product types without needing to renew the printed catalogs or replace PDF files. It provides flexibility in the storage and manipulation of the database content as needed. Finally, going paperless by using digital solutions can help reduce the ecological impact of paper and achieve a healthier and more sustainable environment.

This study bridges the research gap in the field it addresses; thus, other researchers may consider it a preliminary track or a starting point to improve the results. There are several potential improvements to the developed solution presented in this study. These include: developing a dynamic product database by utilizing real-time parameters that are customizable to receive actions from the real site and send reactions as a third part of controlling the product at the O&M phase. Also, establishing a live link between the 3D asset and the product database in DDR creates bi-directional relationships. Furthermore, mapping the 3D asset to the product database captures the coordinates of its location in spatial attributes. Finally, the proposed DDR can be further improved to make decisions to facilitate manufacturing product data digital workflow during the different phases of BIM projects.

6. Abbreviation:

(BIM) Building Information Modeling
(AEC FM) Architectural Engineering and Construction Facility Management
(IFC) Industry Foundation Classes
(DT) Digital Twin
(DTO) Digital Twin Object
(COBie) Construction Operations Building Information Exchange
(SPie) Specifiers' Properties information exchange
(OPie) Operators Properties Information Exchange
(PIM) Project Information Model
(AIM) Asset Information Model
(UPS) Uninterrupted power supply
(ERD) Entity-Relationship Diagrams
(DDR) Digital Data Repository

7. References

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