The Integration of Virtual Design and Construction (VDC) With the Fourth Dimension of Building Information Modeling (4D BIM)

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Abstract

The aim of the research is to shed light on the relationship between the concepts of Virtual design and construction (VDC) and building information modeling (BIM), and in particular to identify and evaluate the potential benefits of using a methodology based on the integration of the fourth dimension of (4D BIM) with virtual design and construction (VDC) and its impact on the preparation of the schedule and project planning and construction simulation. The research reviews a case study of "Pharmacists Syndicate building - Tartous branch", the building model (3D BIM) was created in Autodesk Revit 2020 ®, then the model clash was detected, reviewed and resolved, and the quantities were calculated on the Autodesk Navisworks Manage 2020 ® program, and the time periods for each activity were estimated according to the quantities, workshop performance rates and teams. Finally, time schedule was created in Bentley Synchro PRO 2020® software, the elements of the schedule was linked to the (3D BIM) model and the resources needed to implement each activity, then the construction simulation of the model was performed. The results showed the importance of (4D BIM) and the use of software in accurate modeling of all building elements and solving design problems before construction, which in turn has a significant impact on reducing time and cost of the project implementation. Model-based calculation of quantities helps to accurately estimate resources and times for activities. The importance of scheduling within a virtual environment based on the (3D BIM) model lies in the ability to digitally plan all aspects of a construction project, create and discuss different work sequences, in addition to managing cost, schedule, earned value, risk management, site integrity, logistical planning and mega-project management before and during implementation. However, we cannot only rely on software and technologies, but there must be an integrated methodology that organizes construction operations, and here comes the role of (VDC) Virtual design and construction as an innovative implementation strategy that adopts (BIM) building information modeling. As the success of any project depends greatly on the efficiency of the management and organization of its operations to achieve its desired goals.

Keywords: Building Information Modeling (BIM); Virtual Design and Construction (VDC); Fourth Dimension of Building Information Modeling (4D BIM); Scheduling.

1. Introduction

The construction industry is one of the most important economic sectors in any country in the world. [1, 2] The construction project goes through several stages, with various people involved in these stages, each person has a specific role, and their goals often conflict. The final product in the construction industry is usually obtained through several contracting and sourcing strategies that differ from each other in their suitability for each type of project. All of the above made the construction industry suffer from increased costs, delays in project delivery and low quality all around the world.

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The construction industry in Syria suffers more than others in terms of economic growth rate and technological advancements as it faces difficulties in completing projects in accordance with their desired objectives (schedule, cost and quality) and restrictions [3, 4, 5].
understanding the complexities and challenges in the construction industry requires adopting a new work mechanism that keeps pace with the technological development in the world or developing the followed mechanism ,in order to increase the efficiency of the sector and facilitate the exchange of information and provide it in the correct and required form and term.

The use of Building Information Modelling (BIM) has become significant in the last few years [6, 7,8]. The concept of Building Information Modeling (BIM) is a technological revolution in the construction sector [9] as it rapidly changed the way buildings are conceptualised, designed, constructed, operated and how parties involved in a project (owner ,designer, contractor, suppliers, project manager) communicate between each other and over the entire project life cycle .which, increases the quality, and profitability and improves projects' performance and efficiency and not only solving the massive AEC project's problems and reaping the benefits of its implementation [10,11,12].The term virtual design and construction (VDC) is often used alongside building information modeling (BIM). virtual design and construction (VDC) is the use of advanced technology to assist in both the design and construction phases, as defined by the National Institute of Building Sciences (NIBS) Virtual Design and construction (VDC) is a process that uses advanced (BIM) technologies to collaboratively design, plan and manage projects before they are built.

There are a lot of studies that have highlighted the benefits of implementing BIM and VDC In the construction industry, as their application enhances the integration of the roles of all stakeholders in the project, which leads to greater efficiency and effectiveness in the completion of the project. It also facilitates communication and coordination between project parties, and faster access and exchange of required information. In addition to many other benefits ,it can also help reduce the cost and time required to complete the project, reduce design errors and change requests, and help document project information and data at all stages.

2. Literature Review:

2.1. Building Information Modeling (BIM):

“Building Information Modeling (BIM) is a process of establishing manageable and sharable representations of physical and functional data that define buildings throughout their life cycles in digital format” [13] but there is no precise BIM definition Different interpretations and definitions of BIM have emerged [14, 15, 16]. [17] defines BIM As “a modeling technique and set of associated processes for producing, communicating and analysing building models” while [18] proposes a different definition as “a methodology for managing basic building design and project data in a digital format throughout the building lifecycle.” [19]

BIM technology is continually being improved and developed, providing more detailed information and models not only in cost and time, but also in energy consumption and collision detection” [20]. The reason behind that is traditional 2D and 3D CAD diagrams have become insufficient as they are not designed to handle the amount of information required in recent construction Projects. Traditional CAD drawing tools does not include very important information such as tender, schedule, materials, etc. BIM can collect, share and deposit information from all stakeholders creating a more efficient way of working when compared to the traditional ways. BIM is not a computer program it is an integrated process combined with technologies where different beneficiaries of different professions work together in a multidisciplinary environment, share information and collaborate with each other to accomplish a common project with fewer errors and cheaper and faster process. BIM is not only a tool that can be used to create models but a process that involves the integration and collaboration of all stakeholders in all phases throughout the entire life cycle [21, 22].

2.1.1. BIM Dimensions:

BIM dimensions refer to a specific way in which different types of data are linked to the information model. Each dimension and the data attached to it gives a broader understanding of the project, ie: how it will be built, when it will be built, what it will cost, etc. (Trimble, Inc).
According to various articles, BIM dimensions can be defined as:

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3D BIM - 3D Modeling, **4D BIM** - Construction Planning and Scheduling**, 5D BIM** - Monitored and Controlled Cost Planning.**6D BIM** -sustainability and **7D BIM** is defined by operational management and maintenance [23]. There is not much controversy surrounding **8D BIM**, scientific articles and other sources linking this dimension to safety and accident prevention. Opinions differ on the definition of 9D BIM\ 10D BIM, [24] defines 9D BIM as scanning existing buildings and converting scanned data into models, while 10D BIM is defined as the use of augmented reality (AR) in construction. Chinese company (Gammon Construction Ltd). 9D BIM connects to the control of drones and production machinery, while 10D BIM connects to the integration of AI in construction. (CentreLine Studio Llp, Utilizando BIM, LinkedIn Corp) believes that **9D BIM** is related to introducing LEAN management philosophy in the construction sector, and **10D BIM** is related to industrial construction and manufacturing and making the civil construction sector more productive by incorporating the latest technologies [25].

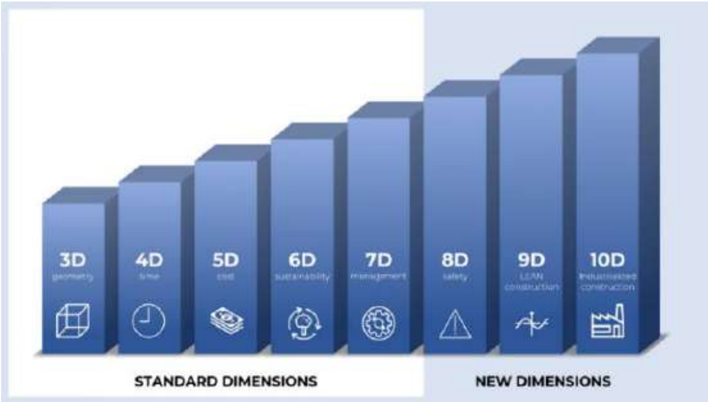

Figure 1: BIM Dimensions source (BuildEXT)

2.1.2. Fourth Dimension of Building Information Modeling (4D BIM):

"The fourth dimension of BIM in the literature is mostly related to time, planning, and safety management" [26], the fourth dimension of BIM adds a time or schedule element to the model; labour time data can be related to the number of materials already in the 3D BIM model. The model may therefore include data on delivery or installation periods, construction times, commissioning, consolidation, repair times, or time dependencies in other areas of the project. It provides a seamless construction agenda and a good strategic basis for managing Construction, as well as a visual understanding of a project, helps clarify communication between designers, contractors, and suppliers and provides information on logistics and efficient placement of materials on site.

4D BIM becomes very useful for avoiding misunderstandings and disputes for complex projects. "The 4D BIM model information can be used in the demolition phase. This use requires an additional dataset to be used to make decisions about component selection during the design phase, facilitating the demolition process in the future" [26]. information in this dimension can also be used to plan construction waste reuse and recycling [25].

2.1.3. Uses and Benefits of 4D BIM:

Research has shown that 4D BIM can be a solution to many shortcomings in current planning practices. Enriching the 3D BIM model with scheduling data has increasingly improved the quality of the construction planning process through the development and integration of several uses. For example, simulating work progress over time is an effective communication tool for explaining project progress and construction methods used to a client. In fact, visualizations built on 4D BIM provide an intuitive understanding of the construction process, enabling more effective communication and therefore better collaboration among all project stakeholders. The use of 4D BIM has made many applications possible, some of its uses and benefits are given below:

- ❖ Improve visual communication
- ❖ Schedule verification.
- ❖ Digital construction exercises.
- ❖ Detect spatial conflicts and avoid workplace congestion.
- ❖ Monitor construction progress on-site with site layout designs.
- ❖ Buildability analysis.

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- Site analysis including temporary components
- Production of action plans.
- Spatial and temporal analysis of health and safety management.
- Logistics management. [27] [28]

2.2. Virtual Design and Construction (VDC):

Unlike BIM which was developed and introduced by different researchers and different perspectives, VDC has a more concrete history as a product of CIFE at Stanford University as the term Virtual Design and Build was developed by John Kuns and Martin Fischer at Stanford University - Center for Integrated Facilities Engineering CIFE in 2001. They define the term as follows:

"The use of multi-disciplinary performance models of design-construction projects, including the Product (i.e., facilities), Work Processes and Organization of the design - construction - operation team in order to support business objectives" [29].

VDC is defined as a multidisciplinary implementation strategy supported by existing methods for planning, designing and implementing projects using virtual computer models. VDC aims to bring together BIM and PPM technology and practices to simplify project planning and execution, as well as increase quality and value for the client. For VDC to reach its full potential, it is necessary to create a unified framework that can combine existing methods and tools. A project cannot produce a satisfactory result if the information and workflow are unpredictable and unreliable. VDC contributes to more accurate engineering Modeling, analysis, and visualization, and the VDC process can also include business metrics, strategic management, and economic impact analysis on the cost and value of capital investment. Project visualization can be used to simulate the complexity of the construction process, understand problems and challenges that may occur, and address them virtually before construction begins. To rule out problems before they happen [30, 31].

CIFE has also developed an educational program for VDC that grants certification in this field. The goal of the program is to train participants in the principles and use of VDC, and to help them develop an implementation strategy for VDC in accordance with the objectives of the companies they work for [31, 32].

2.2.1. VDC framework:

VDC is a combination of new technologies (BIM) with an appropriate work and management (PPM) scheme, to support people working together on a project, in an integrated and synchronized manner (ICE). The planner focuses on achieving project goals, which will help the client achieve its goals while collecting data and tracking work progress.

From the intersection of the VDC framework and the POP model, the following correlations can be obtained: product design (P) is created using BIM, organization (O) is developed through integrated concurrent engineering practice (ICE), and process (P) are developed based on project production management (PPM). with having the same goals in both frameworks.

Since every framework and element in the hierarchy is equivalent, the user is can properly visualize, integrate, simulate, plan, implement and operate the project. However, the framework is not necessarily subject to the same elements (ICE, BIM, PPM) but adapts to existing technologies, methods and tools. To allow the project team to exceed the client's expectations in an integrated, synchronized and collaborative work environment [33].

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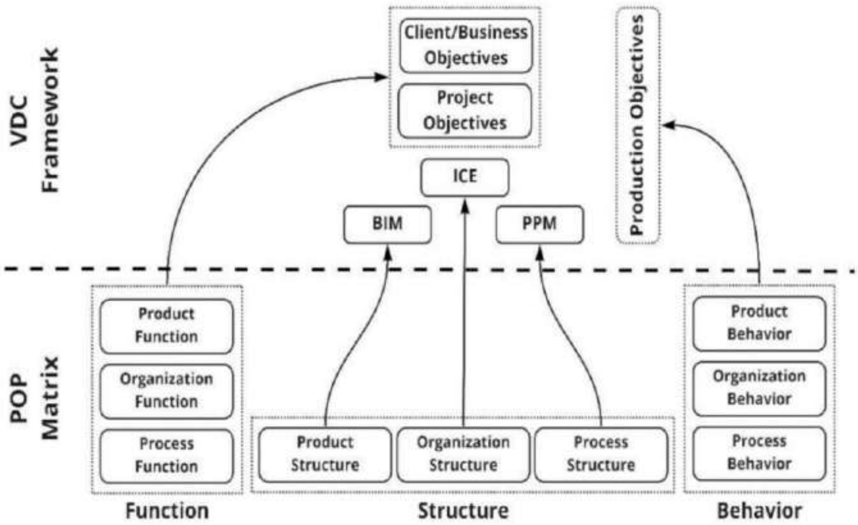

Figure 2: the relationship between VDC framework and POP model [33]

2.2.2. POP Model (Product-Organization-Process):

According to [29] there are three factors that the project manager can control in a project:

- ❖ The product to be manufactured.
- ❖ Organizing the workforce.
- ❖ The process behind the work.

These three factors form the basis of the POP model, which are an important aid to the development of virtual models used in VDC. The product is defined as the physical part of the construction process, for example a 3D model or specific building elements. The organizational model defines all the people and actors involved in the project, and how they communicate with each other. The process defines the activities and milestones associated with the project. The purpose of the POP model is to monitor and simulate the progress and performance of a project in order to evaluate the project's productivity and value. The POP model describes the three most important factors of VDC that support the implementation of technological tools and methodologies. The POP model is used in many ways by different actors [31, 32].

	Function: Objectives	Form/Scope: Design choices	Behavior: predictions
Product	spaces, elements and systems	Designed spaces, elements and systems	Predicted cost ($)
	Measurable Objectives	Values	Predictions; Assessed values
Organization	Actors	Selected actors	Predicted cost (hours or $)
	Measurable Objectives	Values	Predictions; Assessed values
Process	Tasks	Designed tasks	Predicted cost (days or $)
	Measurable Objectives	Values	Predictions; Assessed values

Figure 3: an example of POP model [32]

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2.3. Building Information Modeling (BIM) & Virtual Design and Construction (VDC):

The terms VDC and BIM are sometimes used interchangeably, as they are used as synonyms in several references such as [34] and [35]. Other references define VDC as a different term than BIM. For [32], BIM is represented as part of the overall VDC model which includes BIM as part of the product definition within the POP model. [36] consider BIM to a 3D or 4D visualization tool at best while VDC is an integrated business approach that goes beyond BIM as a tool [19, 37].

When VDC emerged, it did not use the BIM model, but instead used a different set of technological tools to create the product model. But later VDC practices became very closely associated with BIM models. The most comprehensive definition of VDC is as a way of working to embrace digitization as VDC embraces and integrates the use of other digital tools such as collaboration platforms and project management platforms [19].

BIM in the VDC framework is focused on supporting product design. It is not only limited to creating the virtual model of the building and resolving incompatibilities, the implementation of BIM includes the ability to effectively communicate project information through 4D/3D models, train designers and advise the client, and measure resource cost and impact on the project. The term "BIM+" in the VDC framework refers to advanced BIM applications, such as implementing 4D planning and scheduling or cost estimation based on BIM. However, the concept can be extended to new and more complex uses, such as virtual reality/augmented reality [33,38].

Although BIM represents the scope of a product, it does not encompass the entire project. BIM focuses on the concrete elements of the VDC framework, which are valuable but limited because management issues depend on a complete interaction between product, organization, and process [32]. Effective communication and collaboration between designers is critical to project success, something that cannot be achieved through coordination meetings or BIM coordinators alone. Therefore, using BIM as part of a VDC is only practical if combined with ICE sessions and using PPM.

BIM addresses information management challenges, while VDC addresses all project management issues. BIM enables a better understanding of project information (for design, construction, and operation) through powerful visualization, information integration, and automation. In addition, the application of BIM can be extended to support the manufacturing process in the AEC industry. Where BIM in the VDC framework takes on a broader meaning is Building Information Management which can include Building Information Modelling [33].

Finally, the model is what BIM and VDC have in common. Increasing the level of maturity of BIM means that the VDC phases need to be improved. Improving the quality of the BIM model provides VDC with a powerful tool, and upgrading the dimensions of the BIM model means increasing the number of services that the VDC can provide. Implementation of VDC requires capacity building within the organization using BIM. Thus, VDC and BIM are closely related terms, optimizing one can greatly influence the improvement of the other [19].

3. Research mythology

A mixed methodological approach was selected for conducting this research, The first method utilised an extensive literature review to build a deep understanding of the concepts of the research and the relationship that combines them. And an experimental approach represented by a case study of "Pharmacists Syndicate building - Tartous branch" it included 5 stages:

Stage I: planning and preparing the research POP model.
Stage II: the 3D modeling of the building using Autodesk Revit 2020® and rendering using EvolveLAB Veras® 2023.
Stage III: detecting clashes and estimating quantities on Autodesk Navisworks Manage 2020®.
Stage IV: WBS and estimating the time required for each activity based on the previous stages and resources productions, then creating a time schedule, and linking the schedule to project elements on Bentley Synchro PRO 2020®.
Stage V: construction simulation using Bentley Synchro PRO 2020®.

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The as-built plans of the project, documentation and the information about the project and its implementation period were provided by the studying engineers and the site manager.

4. Case Study:

4.1. Project overview:

The studied case is the Pharmacists Syndicate branch building built on property No. / 9496 / of the Tartous real estate area. It is a commercial and administrative building. Its implementation extended from July 2005 to June 2006. The building consists of a basement, a ground floor, and three floors above it. The three floors belong to the Pharmacists Syndicate. It consists of offices, administrative rooms, and meeting rooms with an estimated area of \187\ square meters for each floor, while the ground floor consists of a roofed hallway and five shops with an area of \305.5\ square meters and a service basement and warehouses with an area of \228\ square meters, so the total area of the building is \1242\ square meters, and the full height of the building is \1840 meters\.

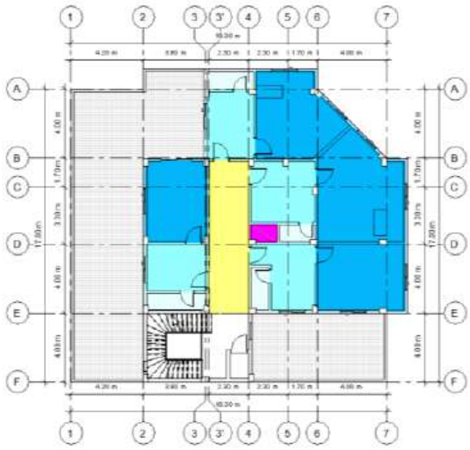

Figure 4: first floor plan

4.2. Proposed Workflow

4.3. The Research POP Model

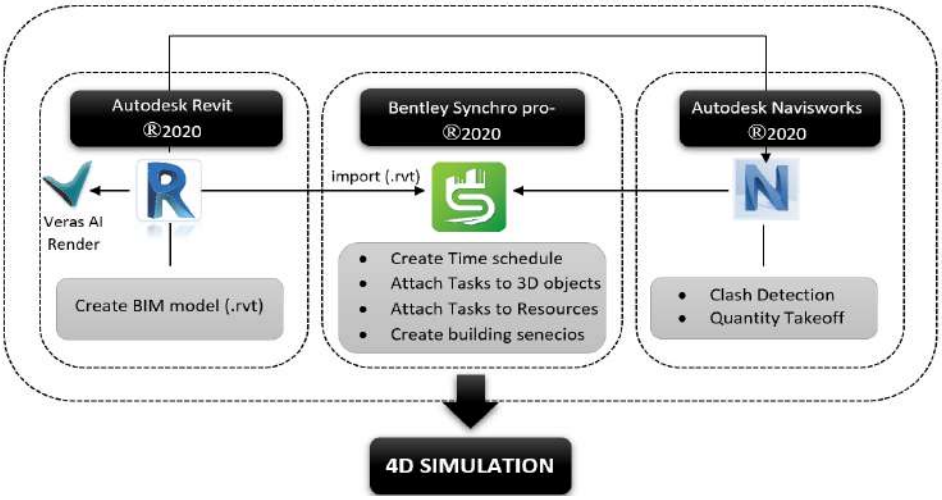

Figure 5: proposed workflow

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Table 1: the research POP model based on [33]

	Function			Form\Scope	Behavior predictions	
	Attribute	Relation-ship	Functional requirement	Scope\system	Predeicted	assessd
Product						
Product	3D Model	include		Pharmacists Syndicate building		
	Clash Report	include		Structural vs Architectural model		
	Quantities schedule	include		3D Model		
	Time schedule and 4D Simulation	include		For the construction sequence		
	Objectives					
	In accordance with LOD 200	>=	90		100	95
	Organization scope	Relation-ship	Functional requirement	Actor	Predeicted	assessd
Organization						
Organization	Researcher	include	Master student	Architect Nagham Salman		
	Supervisor	include	PhD	Dr. Muna Hamadeh		
	Objectives					
	stakeholder participation (synchronous sessions)	=	8		8	5
	Task(action\object)	Actor	Responsible Actor	Process form	Predeicted	assessd
Process						
Process	Approval of the Research topic and work plan	Supervisor	Dr. Muna Hamadeh	Approval of the general framework of the research	15 days	15 days
	Completion of the theoretical framework	Researcher	Nagham	Study and analyze references	25 days	27 days
	3D modeling	Researcher	Nagham	Autodesk Revit 2020	7 days	8 days
	Architectural rendering	Researcher	Nagham	EvolveLAB Veras 2023	2 days	2 days
	Clash detection	Researcher	Nagham	Autodesk Navisworks 2020	3 days	3 days
	Quantity Take-Off	Researcher	Nagham	Autodesk Navisworks 2020	2 days	1 days
	Scheduling and 4D Simulation	Researcher	Nagham	Bentley Synchro pro-2020	10 days	10 days
	Objectives					
	Conformance (Actual schedule to plan) (%)	>=	90		100	90

4.4. 3D Modeling (3D BIM):

4.4.1. Modeling with Autodesk Revit 2020®:

Autodesk Revit is one of the most used software in the BIM process. It allows users to create, review and edit 3D models. and access building information from the building model's database It provides highly accurate 3D models with almost negligible errors. The 3D BIM model is an important tool in the construction planning process. It is essential for clash detection, and accurate quantity estimation in the initial design stages, and is the corner stone for all other BIM dimensions.

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Revit was used to model the studied case (the building of the Pharmacists Syndicate branch in Tartous) according to the as-built project plans and documents that were provided by the studying engineers.

Figure 6: Structural model

Figure 7: Architectural model

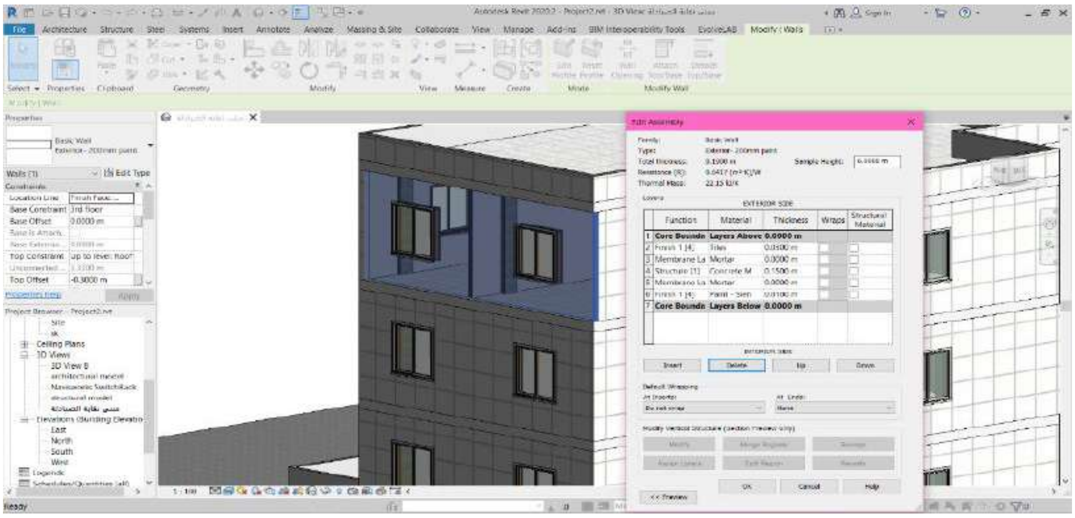

Figure 8: Characteristics of an external wall

Figure 9: Perspective view of the first-floor plan

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4.4.2. Rendering with EvolveLAB Veras 2023:

With the spread of artificial intelligence (AI), the field of architecture is witnessing a paradigm shift that transcends the traditional boundaries of design and innovation. Embedding AI technology within the architectural visualization process enables architects to push the boundaries of design and engineering in ways that were not possible before. And from the definition of VDC as a working method to embrace digitization, it was axiomatic to choose Veras AI software for rendering of the Pharmacists Syndicate branch building.

Figure 10: Veras rendering outcome

4.5. Autodesk Navisworks2020®:

4.5.1. Clash Detection:

Identifying and resolving clashes and overlaps before construction begins is an important step for all construction projects. BIM-based clash detection helps speed up construction projects by identifying clashes between multiple models during the early design phase, allowing architects and contractors to avoid design changes and errors.

After the 3D modeling on Revit, where the structural and architectural models were created and exported to Navisworks as nwc file format. The two models are opened in Navisworks to be matched together to detect clashes via the clash detection command.
By choosing the type of clash (Hard) and tolerance distance 1 cm, 39 clashes were detected within the model. To review these clashes, there are the following options:

- Approve: Accepted or has no effect.
- Mark as Reviewed: to then be reviewed by the person in charge of the model.
- Resolve: by exporting to the 3D software and resolving the clash.

To resolve the clashes, the Navisworks switchback 2020 feature is activated from the Add-ins list in the Revit interface. Then the clash to be resolved is exported to Revit, where it is resolved and the model is re-exported from Revit, and then updated in Navisworks.

For the rest of clashes (Approved/Reviewed) option was selected for each clash in the Navisworks clash detection window of the Status column. After completing the clash review and resolution the full clash report is issued.

AUTODESK NAVISWORKS Clash Report

	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
arch-struct	0.010m	39	0	0	10	15	14	Hard	OK

									Item 1				Item 2			
Image	Clash Name	Status	Distance	Description	Date Found	Date Approved	Approved By	Clash Point	Item ID	Layer	Item Name	Item Type	Item ID	Layer	Item Name	Item Type
	Clash9	Reviewed	-0.054	Hard	2023/6/4 03:08			x:-4.331, y:-5.113, z:18.364	Element ID: 441171	Roof	Default Wall	Solid	Element ID: 501537	Level 6	Clad - White	Solid
	Clash10	Reviewed	-0.054	Hard	2023/6/4 03:08			x:-4.136, y:-5.004, z:18.420	Element ID: 501537	Level 6	Clad - White	Solid	Element ID: 441113	Roof	Concrete, Cast-in-Place gray	Solid
	Clash22	Approved	-0.012	Hard	2023/6/4 03:08	2023/6/4 03:16	Naghem	x:-6.245, y:-4.004, z:14.830	Element ID: 451548	<No level>	Railing	Solid	Element ID: 450913	<No level>	Run(Internal)	Solid
	Clash24	Approved	-0.012	Hard	2023/6/4 03:08	2023/6/4 03:18	Naghem	x:-6.376, y:-2.614, z:13.966	Element ID: 451548	<No level>	Railing	Solid	Element ID: 450835	<No level>	Run(Internal)	Solid
	Clash1	Resolved	-0.150	Hard	2023/6/4 03:08			x:-1.278, y:-1.324, z:17.179	Element ID: 482082	Roof	Tiles	Solid	Element ID: 501229	Roof	Concrete, Cast-in-Place gray	Solid
	Clash2	Resolved	-0.149	Hard	2023/6/4 03:08			x:-1.141, y:-1.160, z:-3.000	Element ID: 391791	Basement	Paint - Sienna	Solid	Element ID: 378176	Basement	Concrete, Cast-in-Place gray	Solid

Figure 11: A sample of the clash report issued by Autodesk Navisworks2020®

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4.5.2. Quantity take-off:

The process of manually estimating quantities was time-consuming and error-prone. However, the digitization of quantities calculations has developed the process and made it more accurate. An example of this is BIM-based Quantity Take-Off (QTO), which help in achieving the most accurate results through detailed systems and models, as it relies on models and 3D objects to estimate building quantities.
In Autodesk Navisworks, quantities are tallied using the Quantification tool. It is based on making material estimates automatically from a 3D BIM model. What distinguishes Navisworks is that the quantities are calculated for the project as a whole and not for each item separately. The following figures are examples of architectural and structural quantities made by Navisworks.

WBS/RBS	Group1	Group2	Group3	Item	Ol	Mode	M	ModelN	M	Moc	Mo	Mod	M	ModelP	M	Model	M	Mode	Mo
1.2.2	**Foundation**	**Structural Foundatio**	**Foundation Slab**																
1.2.2.1	**Foundation**	**Structural Foundatio**	**Foundation Slab**	**150mm Foundation Slab**															
1.2.2.1.1	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	1	19.671 m		18.546 m		0.450 m		0.150 m		84.892 m		59.206 m²		26.643 m³	
1.2.2.1.2	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	2	0.850 m		2.300 m		0.450 m		0.150 m		6.300 m		1.955 m²		0.880 m³	
1.2.2.1.3	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	3	16.500 m		17.811 m		0.450 m		0.150 m		58.469 m		17.795 m²		8.008 m³	
1.2.2.1.4	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	4	2.354 m		2.388 m		0.450 m		0.150 m		8.167 m		2.006 m²		0.903 m³	
1.2.2.1.5	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	5	3.675 m		3.612 m		0.450 m		0.150 m		10.343 m		2.733 m²		1.230 m³	
1.2.2.1.6	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	6	17.548 m		12.696 m		0.200 m		0.150 m		160.049 m		22.114 m²		4.423 m³	
1.2.2.1.7	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	7	12.540 m		3.693 m		0.200 m		0.150 m		22.293 m		2.728 m²		0.546 m³	
1.2.2.1.8	Foundation	Structural Foundations	Foundation Slab	150mm Foundation Slab	8	3.708 m		0.298 m		0.200 m		0.150 m		8.012 m		1.105 m²		0.221 m³	

Figure 12: A sample of structural quantities

WBS/RBS	Group1	Group2	Group3	Item	Ol	Mode	M	ModelN	M		Mo	Mod	M		M	Model	M	Model	Mo
3.6	**ground floor**	**Walls**																	
3.6.1	**ground floor**	**Walls**	**Basic Wall**																
3.6.1.1	**ground floor**	**Walls**	**Basic Wall**	**Exterior - 200mm stone**															
3.6.1.1.1	ground floor	Walls	Basic Wall	Exterior - 200mm stone	1	2.302 m		0.200 m			m	2.750 m			m	6.331 m²		1.266 m³	
3.6.1.1.2	ground floor	Walls	Basic Wall	Exterior - 200mm stone	2	3.045 m		0.200 m			m	2.750 m			m	8.374 m²		1.675 m³	
3.6.1.1.3	ground floor	Walls	Basic Wall	Exterior - 200mm stone	3	3.200 m		0.200 m			m	2.450 m			m	7.840 m²		1.568 m³	
3.6.1.1.4	ground floor	Walls	Basic Wall	Exterior - 200mm stone	4	3.540 m		0.200 m			m	2.450 m			m	8.673 m²		1.735 m³	
3.6.1.1.5	ground floor	Walls	Basic Wall	Exterior - 200mm stone	5	1.700 m		0.200 m			m	2.750 m			m	4.675 m²		0.935 m³	
3.6.1.1.6	ground floor	Walls	Basic Wall	Exterior - 200mm stone	6	1.499 m		0.200 m			m	2.750 m			m	0.922 m²		0.184 m³	
3.6.1.1.7	ground floor	Walls	Basic Wall	Exterior - 200mm stone	7	1.350 m		0.200 m			m	4.650 m			m	6.742 m²		1.348 m³	
3.6.1.1.8	ground floor	Walls	Basic Wall	Exterior - 200mm stone	8	3.900 m		0.200 m			m	4.650 m			m	18.135 m²		3.627 m³	
3.6.1.1.9	ground floor	Walls	Basic Wall	Exterior - 200mm stone	9	3.546 m		0.200 m			m	4.650 m			m	16.489 m²		3.298 m³	
3.6.1.1.10	ground floor	Walls	Basic Wall	Exterior - 200mm stone	10	3.550 m		0.200 m			m	4.650 m			m	16.507 m²		3.301 m³	

Figure 13: A sample of architectural quantities

The objective of the quantity's calculation process is not only to know the quantities of materials required, but it is important to determine the scope of the project and helps to identify resources, know the financial costs and prepare the project schedule.

4.6. Scheduling:

4.6.1. Work Breakdown Structure WBS:

A WBS was used to analyse the overall scope of work for the project, including deliverables and specific activities. This helps estimate resources and costs, create a phasing schedule for tasks, and

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manage each phase. Dividing the team's work into smaller and well-defined elements is easier to manage and it assists in establishing the project schedule.

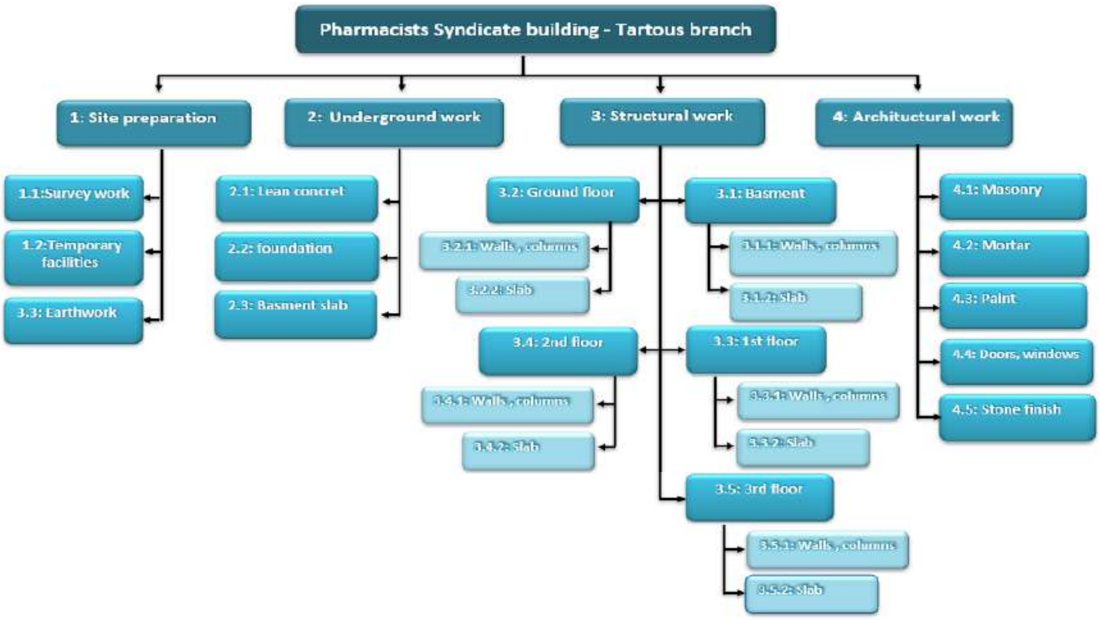

Figure 14: WBS

4.6.2. Estimating durations

Estimating the quantities of the 3D model and creating the WBS are important steps to create the time schedule, as the time required to implement each activity can be estimated based on the quantities and resources of each activity and the workshop productivity rates required for its execution.

Table 2: A sample of the time estimation for each activity

	Work			amount	Unit	Workshop	Productivity		Num	Time/ Days
							human	mechin		
Foundation	Structural Work	**Lean Concrete**	Pouring Concrete	15	m^3	Stationary mixer + 10 workers	_	40 m^3	1	1
		Footings	Formwork	65	m^3	1carpenter + 1 assistant + 1 worker	3 m^3	_	4	5
			Rebar	6.5	ton	1blacksmith + 2 assistants	0.28 ton	_	5	5
			Pouring Concrete	65	m^3	1mixing station + 2 angle grinder + 1 pump + 11 workers	_	100 m^3	1	1
		columns	Formwork	12	m^3	1carpenter + 1 assistant + 1 worker	1.65 m^3	_	4	2
			Rebar	1.8	ton	1blacksmith + 2 assistants	0.2 ton	_	4	2
			Pouring Concrete	12	m^3	1mixing station + 1 angle grinder + 1 pump + 5 workers	_	50 m^3	1	1
		Retaining walls	Formwork	45	m^3	1carpenter + 1 assistant + 1 worker	2.25 m^3	_	5	4
			Rebar	5	ton	1blacksmith + 2 assistants	0.2 ton	_	5	5
			Pouring Concrete	45	m^3	1mixing station + 2 angle grinder + 1 pump + 11 workers	_	100 m^3	1	1
		Slab	Formwork	22	m^3	1carpenter + 1 assistant + 1 worker	3 m^2	_	4	2
			Rebar	5.4	ton	1blacksmith + 2 assistants	0.27 ton	_	5	4
			Pouring Concrete	90.1	m^3	1mixing station + 2 angle grinder + 1 pump + 11 workers	_	100 m^3	1	1

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4.6.3. Bentley Synchro PRO 2020®:

As a result of the sum of the previous steps and based on the activities specified from the WBS and the estimation of the time periods for each activity, the project variables were entered virtually within the Synchro Pro software, and according to the norms of the Syrian construction and building projects, the work calendar was determined in terms of working days, holidays and specific working hours.

The virtual start of the project was set on 6/15/2023. Figure (41) shows the preparation of the project calendar within the Synchro Pro.

Two construction scenarios were studied. The first scenario includes the implementation of the works in sequence, i.e., starting the architectural works after the completion of the construction works. The implementation period was 285 days.

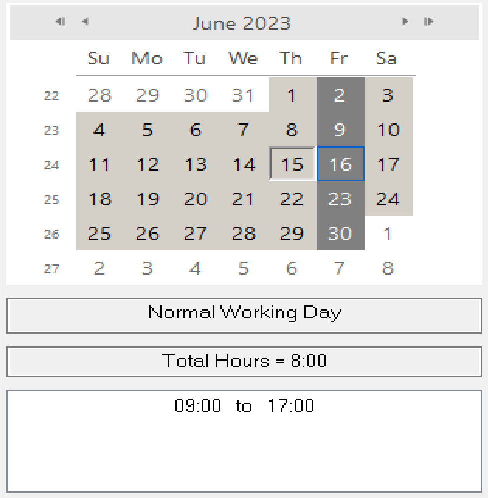

Figure 15: project calendar on synchro Pro

The second scenario which was adopted includes the start of the implementation of the architectural works after the completion of the construction of the first floor structurally. Accordingly, the nature of the relationships linking the project activities was determined, so the total duration of the project implementation was 222 days.

	ID	Name	Predecessor Details	Start	Finish	BL Start	BL Finish	Critical
1	ST00030	Pharmacists Syndicate building - Tartous branch		09:00 15/06/2023 ص	09:00 29/02/2024 ص	09:00 15/06/2023 ص	09:00 21/03/2024 ص	False
2	ST00040	Site preparation		09:00 15/06/2023 ص	05:00 05/08/2023 م	09:00 15/06/2023 ص	05:00 05/08/2023 م	False
7	ST00170	The end of site preparation works	ST00080: FF	09:00 06/08/2023 ص	09:00 06/08/2023 ص	09:00 06/08/2023 ص	09:00 06/08/2023 ص	False
8	ST00090	Underground work		09:00 26/06/2023 ص	05:00 22/08/2023 م	09:00 26/06/2023 ص	05:00 22/08/2023 م	False
25	ST00360	The end of underground work	ST00330: FF	09:00 23/08/2023 ص	09:00 23/08/2023 ص	09:00 23/08/2023 ص	09:00 23/08/2023 ص	False
26	ST00340	Structural work		09:00 23/08/2023 ص	05:00 11/02/2024 م	09:00 23/08/2023 ص	05:00 11/02/2024 م	False
62	ST00930	The end of structural work	ST00920: FF	09:00 12/02/2024 ص	09:00 12/02/2024 ص	09:00 12/02/2024 ص	09:00 12/02/2024 ص	False
63	ST00940	Architectural work		09:00 13/12/2023 ص	05:00 28/02/2024 م	09:00 13/12/2023 ص	05:00 20/03/2024 م	False
119	ST01400	The end of architectural work	ST01390: FF	09:00 29/02/2024 ص	09:00 29/02/2024 ص	09:00 21/03/2024 ص	09:00 21/03/2024 ص	True

Figure 16: Shows the start and end dates of each stage and the relationships between them

Whereas, the actual construction of the project required the equivalent of 420 days. One of the reasons for the delay was a downtime approximately 40 days due to weather conditions. There was also a delay due to problems in securing resources, lack of scheduling, design errors and re-work.

The 3D model was exported from Revit in IFC format and imported into Synchro Pro so that each element of the model is linked to the corresponding activity, and the activities are linked to the resources (materials, human and machinery) required to implement each activity.

Resources

	Name	Type	Task IDs	Tasks
166	2nd floor_(#155)	Material		
167	IfcBuildingElementProxy	Material		
168	M_Trim-Window-Exterior-Flat-Arch-Top-Tree_Centered:...	Material	ST01230	Doors, windows
169	M_Trim-Window-Exterior-Flat:with Sill:541153_(#63606)	Material	ST01230	Doors, windows
170	M_Trim-Window-Exterior-Flat:with Sill:541156_(#63700)	Material	ST01230	Doors, windows
171	M_Trim-Window-Exterior-Flat:with Sill:541159_(#63800)	Material	ST01230	Doors, windows
172	M_Trim-Window-Exterior-Flat:with Sill:541162_(#63904)	Material	ST01230	Doors, windows
173	M_Trim-Window-Exterior-Flat:with Sill:541168_(#64002)	Material	ST01230	Doors, windows

Figure 17: A sample of material resources

4.7. Simulation:

One of the main features of Synchro Pro is the ability to link each activity of the timeline to its corresponding element of the 3D model, thus performing highly accurate simulations, constructability

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analysis and analysis of different time scenarios, as the elements of the model are automatically updated without the need to modify each element separately.

The attached figures show the sequence of the construction process for the Pharmacists Syndicate branch building in Tartous, according to the schedule prepared within the Synchro Pro software.

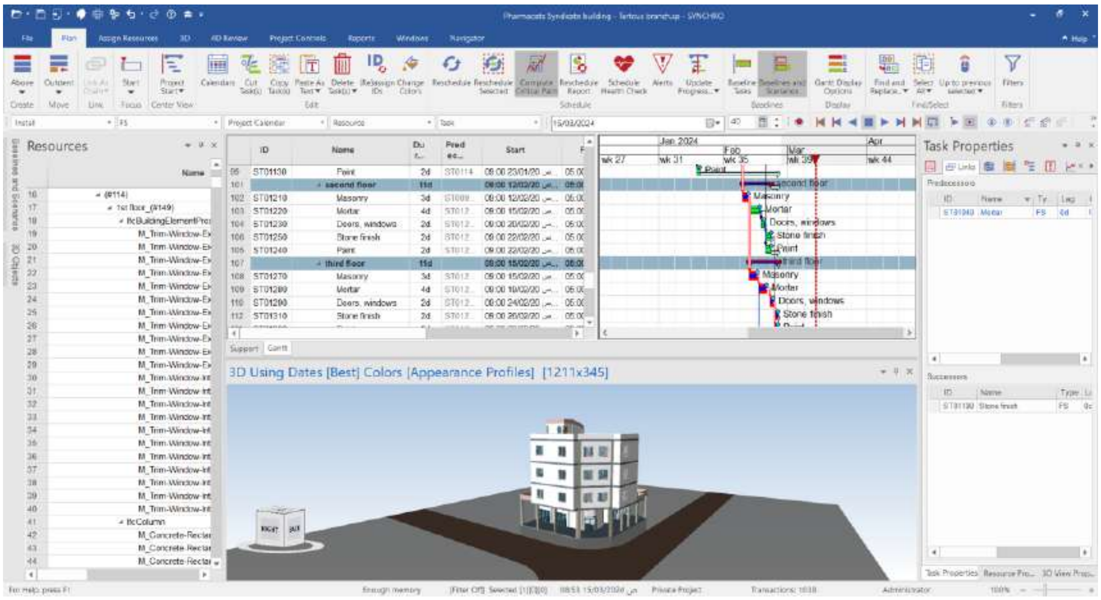

Figure 18: the software interface showing the time schedule and the 3D model

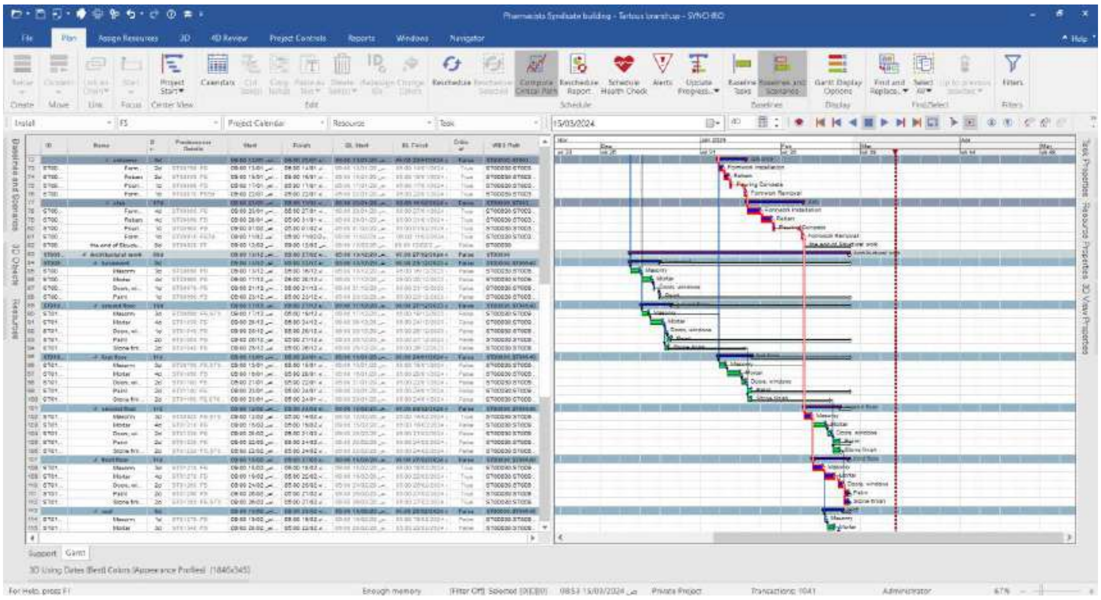

Figure 19: a sample of the timeline showing activities details and critical path relationships

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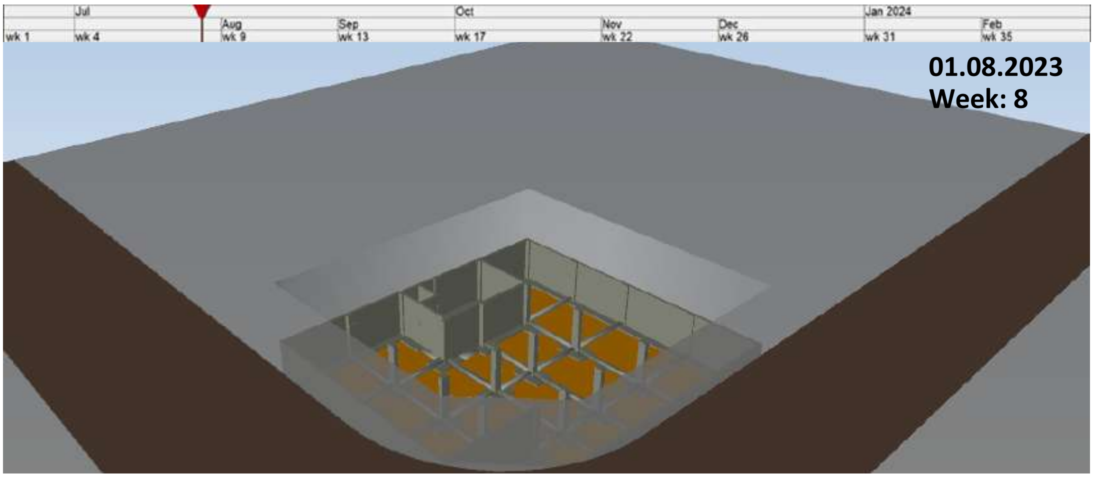

Figure 20: Foundation work

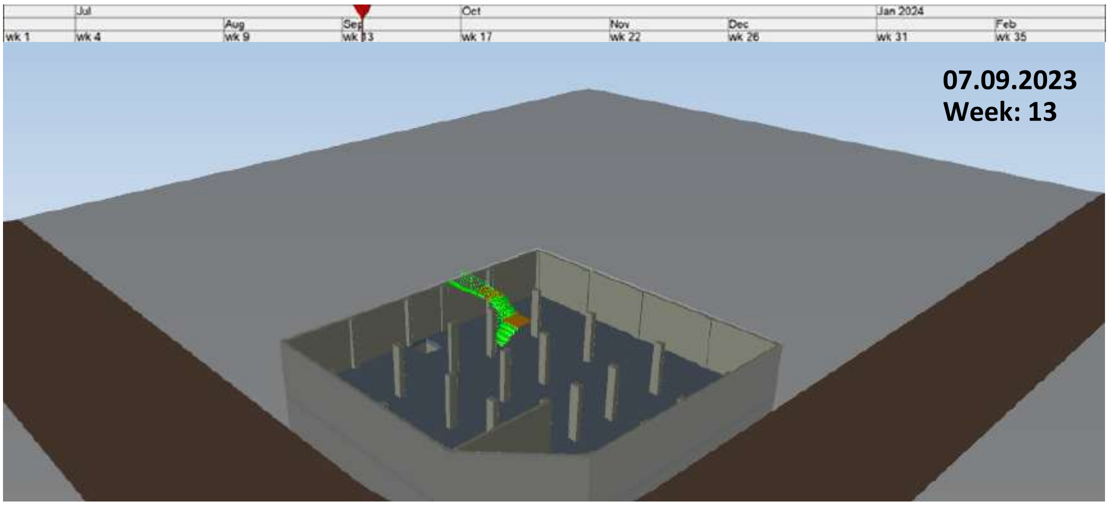

Figure 21: Basement's structural work

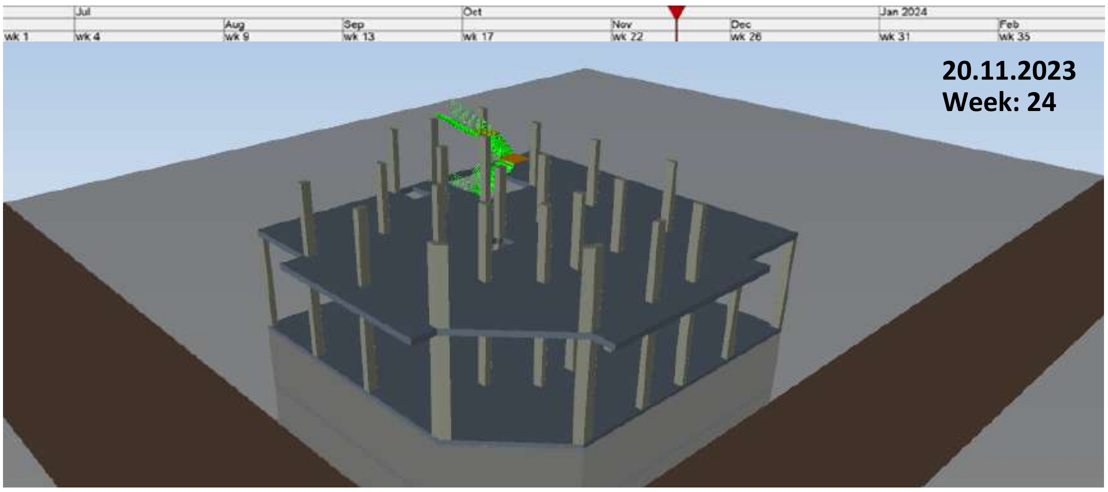

Figure 22: structural work for the 1st floor

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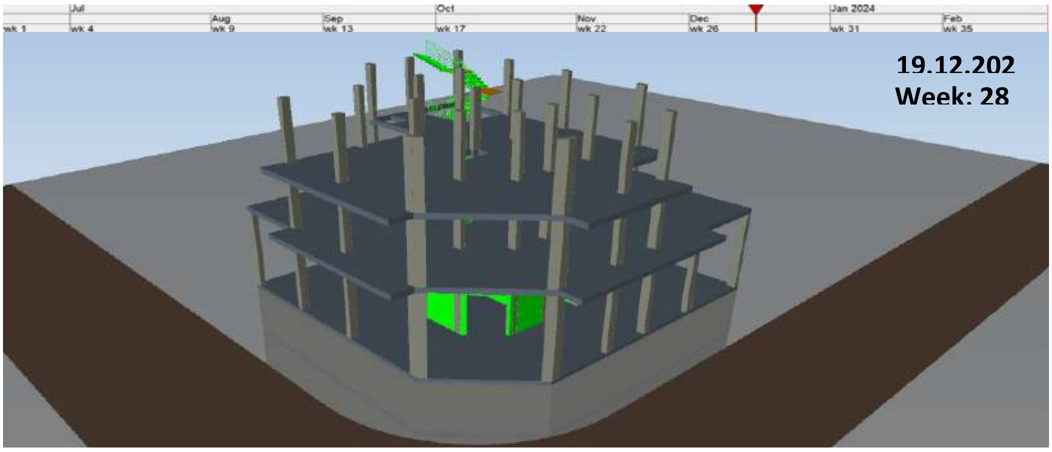

Figure 23: Columns and staircase work for the 2nd floor and masonry work for the ground floor

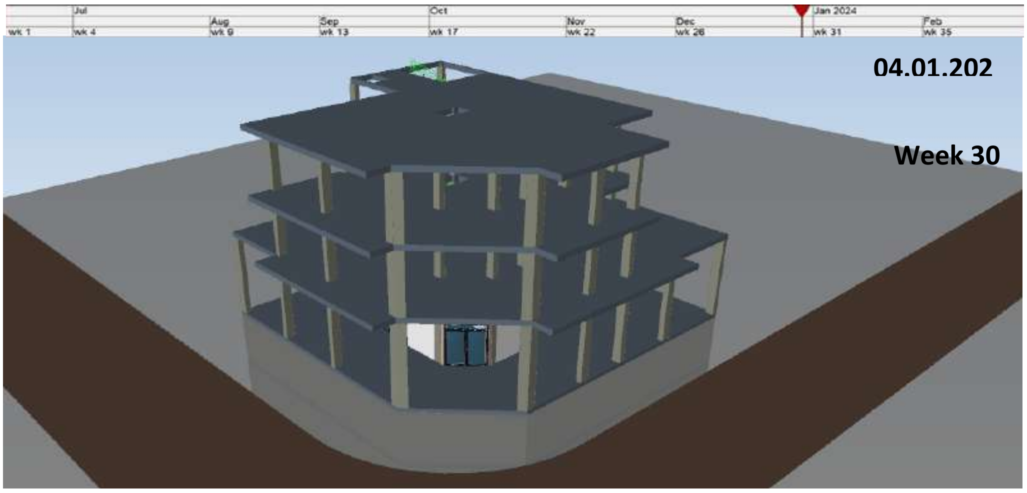

Figure 24: structural work for the 2nd floor and architectural work for the ground floor Completed

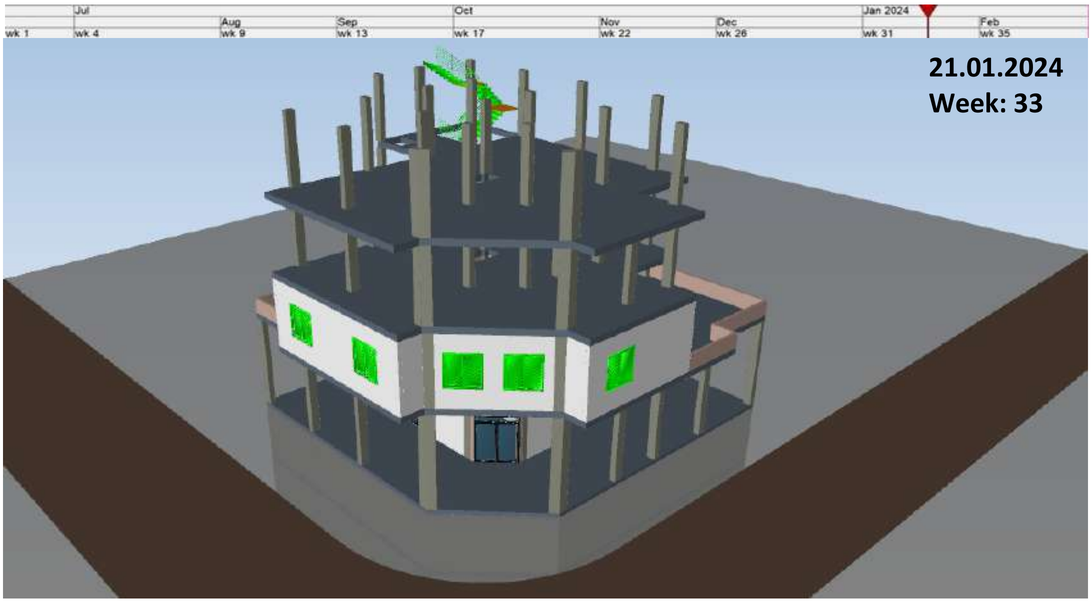

Figure 25: structural work for the 3rd floor and finishes for the 1st floor

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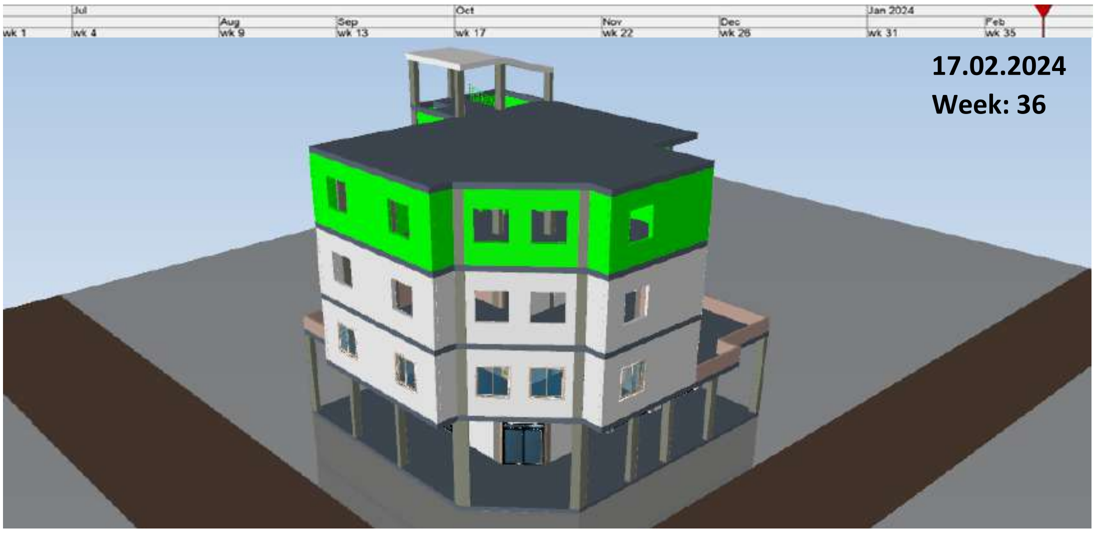

Figure 26: masonry work for the 3rd floor completed

Figure 27: The final model

4. Conclusion

By studying and reviewing the literature for the concepts of virtual design and construction (VDC) and building information modeling (BIM), the researcher found that the two terms are closely related, as virtual design and construction (VDC) is an innovative implementation strategy that adopts BIM to support product design.

Through the case study that was applied to further understand 4D BIM and VDC and their impact on the preparation of the time schedule, the following conclusions can be drawn:

1. The use of 4D BIM tools and software to detect clashes is very important in accurate modeling of all building elements, identifying design problems and reviewing and solving clashes in the early design stages, as 39 clashes were discovered within the 3D BIM model of the Pharmacists Syndicate branch building, and they were reviewed and resolved before moving on to the next stage, which reduces RFIs and re-work, which in turn has a significant impact on reducing project execution time and cost.

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2. Estimating quantities based on the 3D BIM model helps to produce a more accurate estimate as it helps to organize resources by knowing the amount\number of resources (human - machinery - materials) needed for each activity throughout the project stages. And it also helps in determining the exact times of the activities, which facilitates the process of preparing a time schedule that simulates the construction process without errors.

3. The importance of scheduling within a virtual environment based on a 3D BIM model is the ability to digitally plan all aspects of a construction project, create and discuss different work sequences and simulate their construction, which provides a better understanding of the project and it gives the ability to visualize the project's construction process for all stakeholders.

4. Bentley Synchro Pro is a relatively easy to use software which enables to create an accurate time schedule with the same accuracy of popular scheduling software such as Primavera P6, Microsoft Project or Excel, but has the advantage of being able to link schedule activities to 3D model elements and to resources specific to each activity. It also has the ability to simulate the construction process within the software without exporting it for other programs such as Autodesk Navisworks, especially that the Timeliner tool works on simulation in general, unlike Bentley Synchro Pro, which allows the creation of multiple simulation scenarios with extreme accuracy based on both the model and the detailed schedule of the project's progress and automatically adjusting the elements according to the chosen scenario. It also has the ability to integrate other multiple characteristics such as cost management, earned value, risk management, site safety, logistical planning and mega project management before and during implementation, as it has the ability to track on-site progress and identify activities ahead or behind schedule by comparing the planned schedule to the actual construction progress. in fact. This facilitates the construction process, increases time efficiency, and provides a common virtual work environment that is easily accessible to all participants in the construction process.

5. VDC provides an integrated implementation strategy that uses existing methods and tools in a more efficient and organized manner. The integration of Virtual Design and Construction (VDC) and Building Information Modeling (BIM) provides a manageable and easy to access virtual work environment that helps organize all construction processes. Its use improves communication and reduces time and money spent on the project. As the success of any project depends greatly on the efficiency of its management and the organization of its operations to achieve its desired goals.

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