

Article

Research on 3D Digital Technological Process of Construction Products with Model-Based Definition

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Abstract: To guide the site staff to produce complex construction products with high quality, this paper proposes a three-dimensional digital technological process method for construction products. Firstly, the process information of construction products is processed from the perspective of quality control and quality management. Then, the geometric entities in the product construction process are modeled based on the building information model (BIM). Then, the process information is expressed and integrated into geometric entities by the model-based definition (MBD) technology, and the interactive files guiding product construction are output. Finally, the technological process expression example of the infill wall masonry project shows that the proposed digital technological process method can fully utilize the advantages of three-dimensional space and desktop virtual reality, help to deepen process understanding, improve product construction quality, reduce project cost, and provide new ideas for digital research in the construction industry.

Keywords: model-based definition; building information modeling; technological process; process information expression; quality control; quality management



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1. Introduction

With the wide application of building information model (BIM)-related three-dimensional architectural design software, the digital design technology of the construction industry has become relatively mature. In contrast, the digital technology of construction products is still developing, which has become the bottleneck of building product design and construction integration. Therefore, it is significant to study the three-dimensional technological process method of construction products for digital and engineering applications.

Process refers to the knowledge and skills involved in the execution of the task or the quality of the given product. The quality of the process determines the quality, cost, and construction efficiency of construction products [1]. The process is affected by many factors, and the process quality is largely determined by skills, experience, ability, and understanding of the process, and the quality management level of the construction personnel [2,3]. Low-level process training methods and quality management methods make it difficult for construction workers to understand and realize the quality control of construction products, thus leading to poor-quality construction products.

A business process is a set of interrelated or interworked activities that translate input into output, i.e., a series of activities to achieve specific objectives [4]. Different from the business process, the technological process investigated in this paper is related to the construction process of construction products. This problem involves a series of activities that transform input into the output of construction products through the input of resource elements and the control of constraint elements.

Digitization refers to the process of converting analog information into a digital format [5,6]. Technological process digitization indicates the use of digital technology to manage and express the elements of the construction process (resource input, constraint control).

Model-based definition (MBD) is a product definition method that integrates product design information and manufacturing information into a three-dimensional model to comprehensively describe the product [7,8]. At present, MBD technology has been widely used in the manufacturing industry, and 3D digital models are taken as the only basis for product definition, production process, production planning, and quality inspection. The integration of design, manufacturing, and quality management is realized to avoid many defects caused by a manufacturing method based on traditional two-dimensional engineering drawings [9,10].

This paper investigates the three-dimensional digital technological process of construction products by comprehensively applying knowledge of computer science, management science, engineering management, civil engineering, and other disciplines. The process characteristics and quality control requirements of construction products are collected. In addition, the expression system of the digital construction process of construction products is constructed based on BIM technology, MBD technology, and information technology.

The rest of this paper is organized as follows: Section 2 summarizes the literature related to the research content and research methods of this paper; Section 3 introduces the construction process of the expression method; Section 4 provides a case analysis and discussion; finally, Section 5 concludes this paper.

2. Related Work

At present, there are many studies on the digitization of construction product quality control or quality management, while the digitization of the construction product technological process is less studied. The existing studies often regard the construction process as a part of quality control or quality management. Based on BIM technology and lean theory, Liu and Shi established a construction quality control system called KanBIM to visualize the construction process and acceptance standards, which improves the construction quality of construction enterprises and reduces the cost of project construction [11]. Lou et al. combined the BIM technology and AR technology in construction quality control, collected construction quality data through AR technology, and uploaded them to the BIM model for comparison, thus realizing the timely detection and feedback of construction quality problems. Looking at the defects in the current construction quality control method [12]. Wang et al. developed a construction quality control system by integrating the BIM model and laser radar to realize real-time quality control and construction defect identification for the construction site [13]. Based on the light detection and ranging (LiDAR) technology and AR technology, Karji et al., constructed a 3D quality-control model to improve the accuracy and efficiency of previous construction quality-control methods. By taking the five-story construction site in Huddersfield as an example [14], Al-Adhami et al. studied and discussed the implementation and feasibility of BIM-based extended reality (XR) technology in a quality control inspection of construction sites [15]. Mirshokraei et al. integrated the BIM and AR technology into the building component quality management system to input and test component quality data in real-time through a shared digital environment. Case studies showed that the system can enhance communication, improve quality, and optimize costs [16]. From the above literature research, research into advanced technologies such as BIM and AR in terms of quality control and quality management is more in-depth, and most research concentrated on the middle stage and the later stage of the construction process. However, there is no digital research on the process flow in the previous stage.

Model-based definition (MBD) is a new product definition method adopted by Boeing Corporation of the United States, which integrates geometric information and non-geometric information to describe products in three-dimensional models [17,18]. It is an important technology for the manufacturing process and quality management. Based on the MBD technology, Zhou et al. proposed a digital expression method for the process planning information of automobile products. The non-geometric manufacturing information was annotated and expressed in 3D models using label and attribute methods, and the process planning information was expressed in 3D models [19]. Zhu and Li proposed a 3D

digital process design method by combining MBD with knowledge engineering to solve many problems in the process planning of 2D engineering drawings. The method realized the efficient design of process information and the integrated application of process methods [8]. Liu et al. adopted the MBD technology to build a 3D casting process model and a 3D casting process planning system. Based on this, the casting product process geometry information, process size information, and process information's integrated expression and management were achieved [20]. Zhang et al. comprehensively considered the geometric and non-geometric information in the machining process and established a 3D machining process model and a system of mechanical parts. Meanwhile, they applied the MBD technology to processing process expression and realized quality control in the manufacture of mechanical parts [21]. Geng et al. proposed a lightweight 3D assembly instruction production and control method for complex products. The method takes full advantage of the MBD technology and employed a lightweight model to fill the gap between process planning and instruction release in the 3D virtual manufacturing environment [22]. At present, the MBD technology has been widely used in the manufacturing industry for digital management and control of the product manufacturing process. However, the construction industry, with similar characteristics to the manufacturing industry, has not introduced the MBD technology into process management and quality control.

3. Methodology

3.1. Process Information Processing

The process information covers the technological requirements from the design stage to the construction stage, which is an important part of the construction of building products and has great complexity and particularity. Traditional process information expression only contains the final delivery status of the construction process and part of the process information, without considering the intermediate status of different processes, and fails to fully express the process information in product construction. Therefore, this paper takes the construction steps as the basic unit to handle the process information, and the basic implementation process is described as follows:

1. Combining quality control and technical points

To provide a basis for process refinement, this paper systematically analyzes the quality control points that affect the performance, safety, life, reliability of building products and the normal development of the next process, as well as the technical points of specific operation methods, structural requirements, and auxiliary requirements of construction steps.

The construction steps are divided into basic steps and auxiliary steps according to the operation content of the process. Specifically, the basic step refers to the activity content that can change the activity object and directly affect the activity object; the auxiliary step is the activity content that provides working conditions for the process or the next process.

2. Technological process refinement

According to the process division of the existing construction products, the construction steps are divided according to the process information and quality control and the technical points of important construction processes, and the flow chart is used to make refinements.

3.2. Process Design Model

Design is the pre-stage of building product construction. Design information determines the product construction process, and is finally achieved in a certain process of the construction stage. The process design model comes from the design stage, fully considers the design requirements, construction sequence and operation process of building products, maintains consistency with the actual construction practices, and reflects the process and geometric evolution of the construction technology. Based on BIM technology, this paper uses the Revit platform of Autodesk Company to create the model. The creation process is described as follows:

1. Parameterized unit creation

According to drawings, construction resources (materials, machines), and the related design requirements, the types and quantities of model components, and the modeling sequence are planned as a whole. The name of the model components refers to the “Architectural Engineering Design Information Model Drawing Standard” (JGJ/T448-2018), which is developed from the part-level model unit. Meanwhile, the parametric unit of the Revit platform is created in a similar way.

After the planning and naming of the model component unit are determined, the geometric and non-geometric parameters of the component unit are set. The parameter setting includes the following parts:

- Geometric information parameters.
- Material property parameters.
- Positioning reference parameters.
- Engineering quantity calculation parameters.
- Production, processing, and inspection of relevant parameters.

2. Modeling for the construction process

According to the final state of construction products and the process content of forming the intermediate process of products, the pre-model, auxiliary process content, key process nodes, and process details of construction products are modeled for the construction of construction products. The construction process involves the evolution of the model over time. Specifically, the pre-model is the final delivery state of the previous process acceptance, as well as the input resource and starting point of the process. The auxiliary process deals with various raw materials and semi-finished products in the construction process to produce the expected products, but the part that is not visible in the final delivery state of the products is an indispensable construction measure in the construction process. The key process node is the embodiment of the key node construction requirements and quality control points in the construction process, which originates from the mandatory provisions regarding the design and quality acceptance specifications. The process detail is the specific operation to ensure the quality of process products.

3.3. Process Information Expression

The purpose of process information expression is to integrate geometric information and non-geometric information during product construction. Therefore, the process information expression proposed in this paper is based on MBD technology, using the CATIA Composer of Dassault to integrate various process information for expression. The basic implementation process is described as follows:

1. Process design model processing

After the process design model is created with Revit, it is exported to the standard CAD model data format. The geometric model and part of the process data in the data format are read by the CATIA Composer, and a lightweight processing is conducted. Then, similar building parts are grouped and given their name, color, texture, and other attribute information.

2. Key view creation

According to the process information mentioned in Section 3.1, the key view of process expression is determined. By setting the explicit and implicit model components in the view, the view only shows the model state of the current process or step. Specifically, the view is the function provided by the CATIA Composer, which can create multiple 3D model views for expression based on the same model, and multiple views are connected in series to realize the dynamic expression of relevant information.

3. Process information mapping

The process information is added to the key view through the functions of the CATIA Composer, such as measurement annotation, text box, image attachment, and link object. In this way, the process information is attached to the process and process model.

4. Export of key views

After the attachment of process information is completed, the key view is exported to a variety of data formats to express the process information, and the process data are developed based on the Composer Player ActiveX control provided by the CATIA Composer. Specifically, the key view can be exported separately, or the visual set can be uniformly exported. The visual set contains multiple key views, corresponding to the process content of each process and important steps in the technological process.

5. Interactive construction work instruction

After the key view is exported, the secondary development is conducted based on CATIA Player ActiveX control, and the three-dimensional interactive view and process information are integrated into the traditional construction work instruction based on a two-dimensional transmission mode.

3.4. Digital Expression Method of Construction Process Based on the MBD Technology

Based on the process information processing introduced in Section 3.1, the process design model described in Section 3.2, and the process information expression presented in Section 3.3, the digital expression method of technological process is established.

First, the expression method refines the quality control points, technical points, and technological process of process information. Then, the process design model in the construction process is modeled based on the BIM technology to fully reflect the evolution process of construction products. Finally, based on the MBD technology, the process information and process design model are integrated and expressed, and the integrated process files are judged to determine whether the integrated process files fully express the quality and technical points. If it does, the output process files can guide the construction of building products; otherwise, the process information processing and process design model are returned for modification. This method dynamically expresses discrete process information and enhances the processability and quality control level of process information expression. A flow chart of the proposed method is shown in Figure 1.

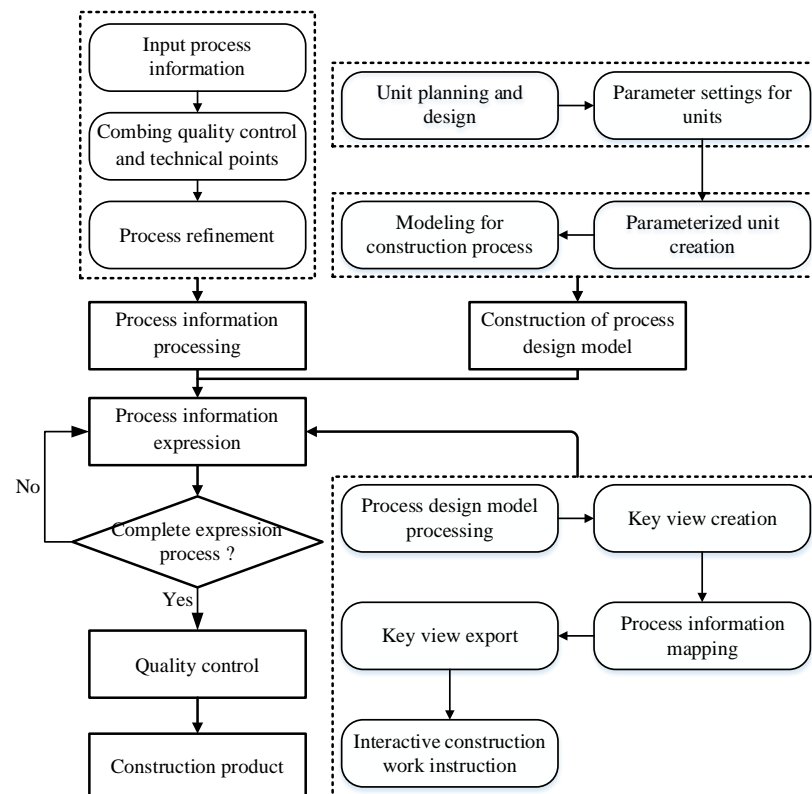


Figure 1. Digital expression method of technological process.

4. Application Examples and Discussion

4.1. Background and Data Source

The masonry of the infilled wall in the case adopts autoclaved and block concrete as the main material. The masonry length is 5 m, and the masonry height is 3.4 m. The wall does not contain doors, windows, holes, and the structural column ring beam. The details of the selected materials are presented in Table 1.

Table 1. Case infill wall material table.

Serial Number	Name of the Material	Specification	Remark
1	Steel reinforcement	Φ16	Preservative treatment
2	Vapor compression concrete block	B06: 600 × 240 × 200 mm B06: 215 × 240 × 200 mm	Strength grade A3.5, block density ≤6.5 KN/m ³ Product age greater than 28 days, moisture content less than 30%
3	Autoclaved sand-lime brick	MU10: 200 × 95 × 53 mm	/
4	Cement	Grade 32.5 ordinary portland cement	/
5	Sand	Medium sand	5 mm sieve
6	Additive	Finely ground raw lime powder and fly ash	Raw lime powder ripening no less than 2 days

4.2. Infill Wall Masonry Process Information Expression

4.2.1. Infill Wall Masonry Process Information Processing

1. Combing quality and technical control points

The quality and technical points of each construction process of the infill wall masonry are presented in Table 2.

Table 2. The common problems and technical points table of infilled wall masonry construction quality.

Construction Process	Technical Essential	Quality Problems
Preparation for construction	<ul style="list-style-type: none"> Watering wet 1–2 days in advance to ensure the moisture content of masonry. Draw brick layout, site brick. The strength grade of block and masonry mortar meets the design requirements. 	<ul style="list-style-type: none"> Bricks are not wet enough; mortar bond strength is not enough. Site disorder.
Measurement and discharge line	<ul style="list-style-type: none"> Fixed base point, hanging head-tail large-angle line. On the benchmark level line, set each layer brick outside line, inside line. Bullet height control line, beam position line, etc. 	<ul style="list-style-type: none"> The whole wall is unevenly bricked. The position deviation of each window hole is large. Wireless bit control of the first row of bricks. The verticality of the wall has no control line.

Table 2. Cont.

Construction Process	Technical Essential	Quality Problems
Wall reinforcement	<ul style="list-style-type: none"> The position of tie bars and the setting of bending hooks. Size of tie bar and length into the wall. The choice of planting method, to ensure a strong planting. 	<ul style="list-style-type: none"> The number of unfit bricks with tie bars. The tie bar is bent and not straight. Does not meet the seismic design requirements.
Mortar preparation	<ul style="list-style-type: none"> Concentrated mortar distribution. Controlling the consistency of mortar according to the proportion of registered mix and water-cement ratio. Stir for at least 3 min in order. Mastering the mortar after 3 h. 	<ul style="list-style-type: none"> Mortar quality out of control. Excessive consistency affects the thermal insulation performance; too small consistency is not easy to construct. Poor quality of mortar and workability. Water loss hardening mortar, not easy to construct.
Wall construction	<ul style="list-style-type: none"> Slit up and down, overlap inside and outside. The corner and junction should be built together or reinforced. Mortar paving method and maximum paving length. The fullness of mortar, top brick masonry 14 days later. Daily masonry height control. Control of ash seam within 15 mm. 5 mm vertical. Set construction columns as required. 	<ul style="list-style-type: none"> Seam prone, poor overall stability. The wall is unstable. Sinking Cracks at the Bottom of Beam. Too thick cement seam is easy to increase mortar shrinkage and masonry shrinkage; smaller and prone to false and transparent seams. Wall vertical deviation.

2. Technological process refinement

Based on the typical technological process and the process information of infill wall masonry, the important processes were refined, as shown in Figure 2.

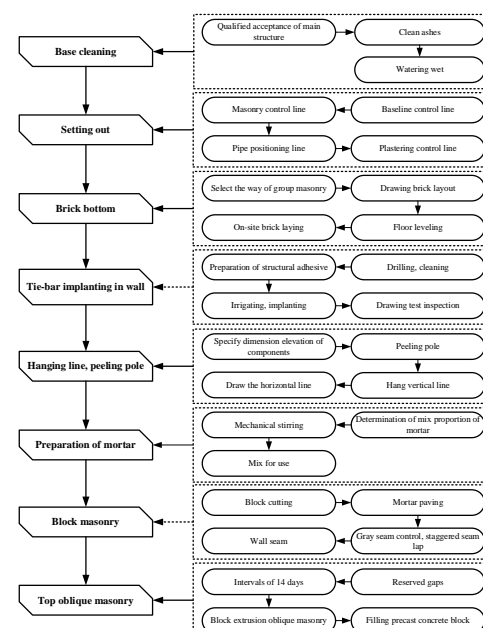


Figure 2. Refinement of typical technological process of infilled wall masonry.

4.2.2. Infill Wall Masonry Process Design Model

1. Parameterized unit creation

Referring to Sections 3.2 and 4.2 of this paper, the parametric elements to be created for the Revit-based masonry process design model of infilled walls include beams, slabs, columns, bottom lime-sand bricks, concrete plus blocks, lime joints (horizontal and vertical), skin count rods, and top oblique bricks. The bottom grey sand brick and top inclined brick were created by the nested method, which parameterizes the masonry rules and methods of the bottom and top of the infilled wall masonry so that the change in the model could be driven by changing the parameters in a certain range.

2. Modeling for the construction process

Referring to Sections 3.2 and 4.2 of this paper, the modeling of the construction process of the infill wall masonry works includes the pre-model, the auxiliary process model, the key process model, and the process detail practice model.

(1) The creation of a pre-model

The beam plate column was created according to the design requirements of the drawings and the location of the masonry filling wall project. As shown in Figure 3, the spacing of the column was the masonry length of the wall, and the spacing of the beam plate was the masonry height of the wall.



Figure 3. The preposition model of the infilled wall masonry process design model.

(2) Establishment of the auxiliary process model

For the masonry infill wall, it is necessary to set the positioning line and the wall sideline, use the line hammer to measure the verticality, place the skin pole to assist the masonry wall, and establish the corresponding model in the process design model, as shown in Figure 4.

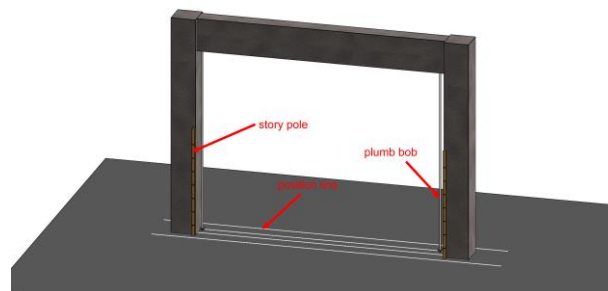


Figure 4. Process content modeling based on the infill wall masonry process design model.

(3) Establishment of the key process model

To show the details of the process, the key nodes of the infilled wall masonry project need to be combined with the structural design requirements of the specific project and the mandatory provisions of the sub-project in the relevant specifications. Considering that there are many quality control points in infilled wall masonry engineering, this paper takes the practice of masonry tie bars as an example to illustrate the effectiveness of our method.

According to the design specification, when the infill wall and frame are not separated, it is appropriate to configure two tie bars with a diameter of 6 mm every 500 mm along the column height. Meanwhile, the length of the steel bar into the infill wall should not be less than 700 mm. A hook of 90°, extended into the infill wall or column, should be made at the end of the tie bar. The tie bar should be reasonably laid in the horizontal ash seam, and the vertical spacing should meet the modulus requirements of the specification and masonry. The modeling of masonry tie bars should fully consider these key process nodes, as shown in Figure 5.

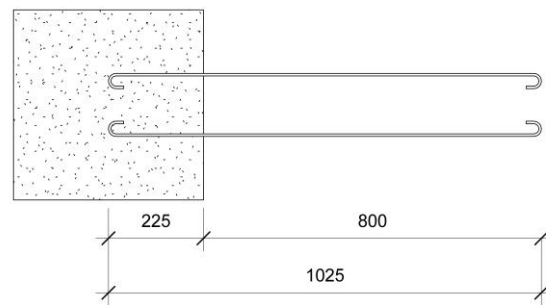


Figure 5. Modeling of masonry tie bars.

(4) Creation of the process detail practice model

In the masonry process, following the ‘three-one masonry method’ (i.e., a brick, a shovel of ash, and a rub masonry method), horizontal ash seam and vertical ash seam are evenly distributed, and the maximum length of the ash should not exceed 800 mm. Meanwhile, to meet the overlapping of staggered joints, a reasonable layout of the brick arrangement is set in the modeling. The overlapping length of the autoclaved aerated concrete block should be no less than 1/3 of the block length, and the vertical joint should not be greater than 2 skins. The block length was 600 mm, the overlapping length was greater than 200 mm, and there was no vertical joint.

4.2.3. Infill Wall Masonry Process Information Expression

1. Infill wall masonry process design model processing

The filling wall masonry process design model established in Section 4.2.2 is exported to the sat file, and the file is imported into the CATIA Composer platform to read the geometric information in the design model. Then, the same type of building parts (beams, slabs, columns, etc.) in the platform is selected to create a selection set, the texture, material, name, brightness, opacity, and other information of the building parts in the attribute panel are mapped, and the parts of the operation process are simulated. The completed filling wall masonry is illustrated in Figure 6.

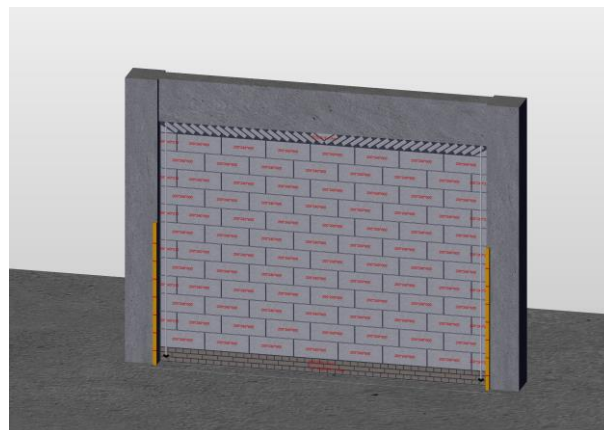


Figure 6. Treatment of the infilled wall masonry model.

2. Creation of the infill wall masonry key view

The key frame view is created according to the detailed technological process. By setting the explicit and implicit model components in the view and fully utilizing the feedback and interaction of the three-dimensional model to the information, the quality control points of the process and the steps, the details of the node practice, and the construction sequence and the mandatory requirements are displayed to simulate the dynamic construction process. The collection of some key views is shown in Figure 7.

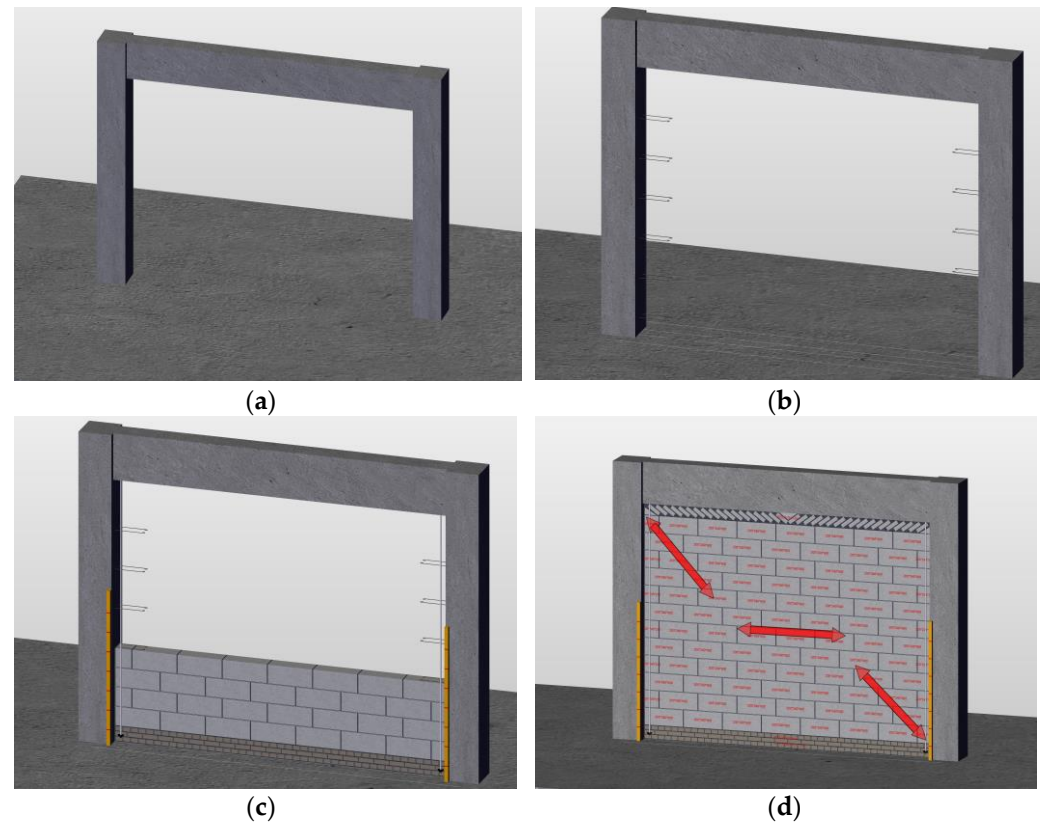


Figure 7. The set of key views of the infill wall masonry construction technology: (a) preliminary stage; (b) tie-bar implanting in wall; (c) wall masonry; (d) flatness check.

3. Infill wall masonry process information mapping

Taking the filling wall masonry key view (wall tie bar planting bar) as an example, the three-dimensional model in the view originates from the process design model of the current construction process. Meanwhile, the quality and technical control points of the planting bar are expressed by the annotation method (the yellow text box), and the detailed structure is explained by the mapping (the construction details). The relevant standard specifications are linked (the white text box) to facilitate in-depth understanding and research, as shown in Figure 8.

Continuous key views can express dynamic process operations, as shown in Figure 9. Therefore, the filling wall masonry ‘three-one masonry’ process content can be expressed through multiple continuous key views.

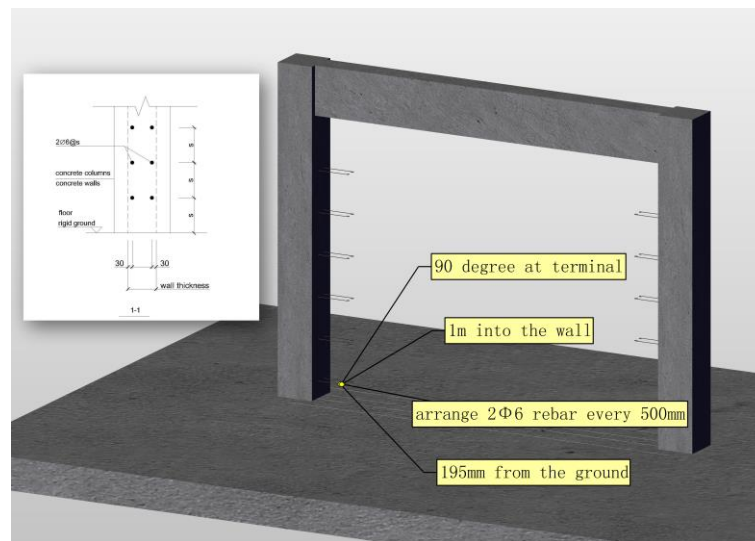


Figure 8. Process mapping of key views for planting a reinforcing bar in the wall.

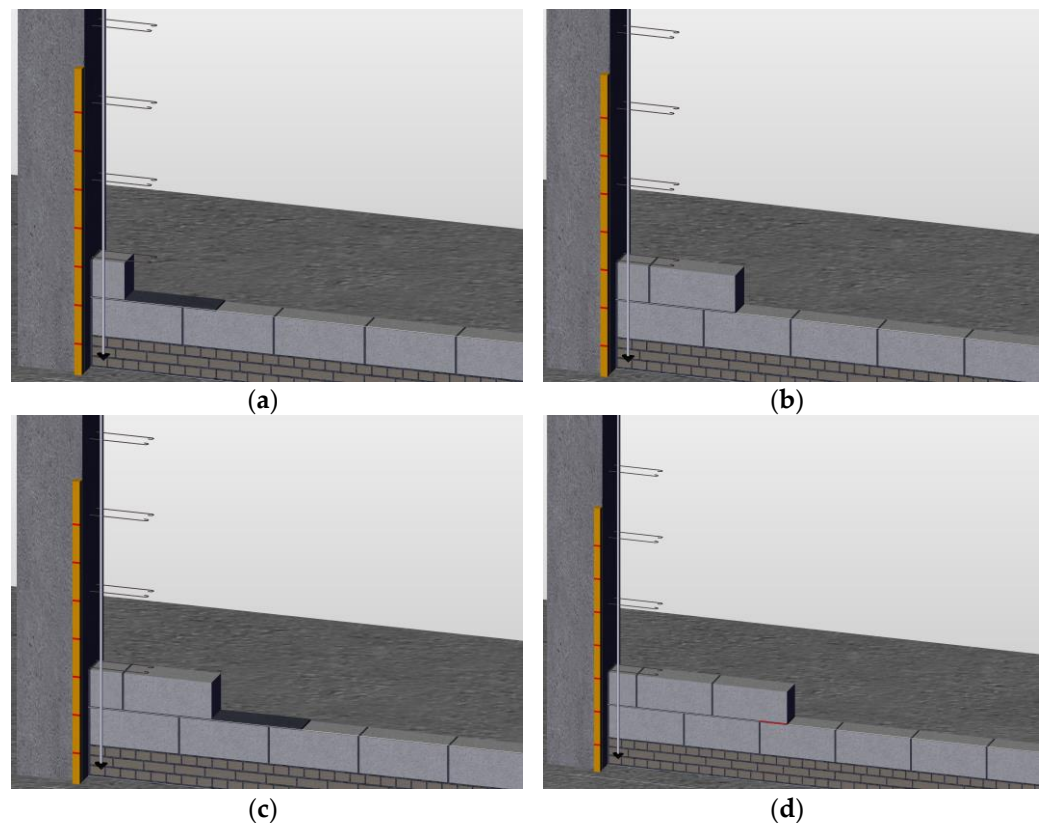


Figure 9. Three-one masonry key views: (a) the first step of masonry; (b) the second step of masonry; (c) the third step of masonry; (d) the fourth step of masonry.

4. Export the key view of infilled wall masonry

After the process information of the masonry infill wall is attached, the key view is exported to a variety of format files, such as exe and smg, on the CATIA Composer platform. Then, these files can be directly published to PDF, HTML, and other formats for viewing.

Specifically, the exported exe file can run directly in the Windows system without the limitations of the software platform and achieve the same function as the software platform.

The derived smg format can be used for secondary development based on the Composer Player ActiveX control provided by the CATIA Composer platform.

5. Formation of an interactive construction instruction book for masonry infill wall

The VBA language based on the Excel platform calls the Composer Player ActiveX development control, imports the three-dimensional interactive view, processes information in the platform into the work instruction book based on the Excel platform, and compiles the process and process instructions according to the process information of the infilled wall masonry in Supplementary Materials. Specifically, the three-dimensional interactive view can be directly controlled in the view playback area created by the Excel platform, and the VBA macro-code can be used to create command buttons for view control.

In addition, the lightweight process information expression program is also linked in the view control area. After activation, it can be viewed in the Windows environment, which is conducive to the multi-dimensional expression of process information. The interactive operation guidance of the filling wall masonry is illustrated in Figure 10.

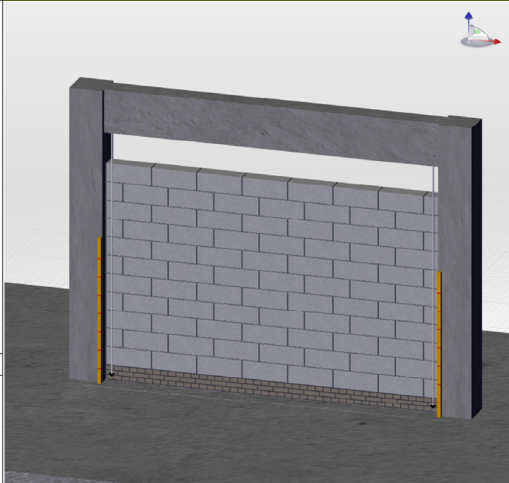
Straight masonry filled wall construction work instructions						View control area					
Process number		07		Constructor		XXX		Page number		X/X	
Process name		wall masonry		Auditor				XXX			
Process working hours		XXX		Date of manufacture				XXX			
Process content: wall masonry											
Process step number		Process step		Technical essential		Quality control		View playback area			
1		Draw the horizontal line		(1) The three-one masonry method is adopted: at the beginning of each layer, starting from the corner or the positioning block, the large shovel, a shovel ash, a brick, a kneading and squeezing with a large shovel, ash spoon for block ash paving, the smaller the amount of blocks, the larger the length of ash paving should not exceed 800 mm. (2) Grey seam control: horizontal ash seam thickness and vertical ash seam width should not exceed 15 mm. The mortar fullness of horizontal and vertical mortar joints is $\geq 80\%$. (3) Staggered: the staggered joint lapping length should not be less than 1/3 of the block length, and the vertical joint should not be greater than 2 skins. (4) Wall seam: with masonry with hook joint, each building a skin block, in-situ correction mortar pouring vertical joint, the original mortar hook joint, depth of 3 -5mm.		(1) Pull level during masonry, should be masonry, correction of a skin, skin pull line control masonry elevation and wall fitness (2) Bricks or blocks with serious corners should not be used at the junction. (3) Masonry height in 1.5m or one step scaffold height in rainy days should not exceed 1.2m, strictly prohibited once masonry to the top. (4) Except the bottom, top and door and window openings, they should not be mixed with other blocks. The use of cutting machines or special tools to cut, no knife or axe cut. (5) The grey seam does not meet the requirements: the ash thickness should be strictly controlled according to the marking rod. In order to ensure the uniform size of the ash seam, it is necessary to ensure that the height is consistent when the skin is erected for several bars, and the ash seam at the corner of the plate should be mastered uniformly. When bricklaying, the small wire is tightened to prevent a layer of loose wire and a layer of tight wire.					
2		Block cutting									
3		Mortar paving									
4		Grey seam control									
5		staggered lap joint									
6		Wall seam									
7											
8											
Safety measures				Allocation of resources							
XXX				(1)Block strength grade A3.5, block bulk density $\geq 6.5\text{KN} / \text{m}^3$, product age $\geq 28\text{d}$, moisture content $<30\%$ (2)5mm sieve for medium sand. (3)Raw lime powder ripening not less than 2 days.							

Figure 10. Infill wall masonry construction guide.

4.3. Discussion

Table 3 presents the application results of 3D process information expression based on the MBD technology and the comparison with 2D process information expression. It can be seen from the results that the method proposed in this paper improves the systematicness and integrity in the expression of process information and overcomes many defects in the expression of two-dimensional process information. This contributes to better process training, quality control, and quality management of the construction site.

- Express the evolution of the architectural production process by making full use of the advantages of three-dimensional space, taking the three-dimensional digital model as the core, and according to the dynamic changes in the three-dimensional model. In addition, this paper innovatively attaches the process information to the three-dimensional model for expression, which overcomes many limitations of the two-dimensional expression methods (e.g., drawings, texts, and pictures), effectively improves the understanding of the process details by construction personnel and management personnel, reduces the incorrect operations in the process of building products, and avoids the waste of resources caused by improper process operation. For example, construction personnel and management personnel can view the

- three-dimensional model and various information interactively and visually in the construction work instructions and key views, thereby increasing their understanding of the process. As emphasized by Wang and Sepehr, interactive and 3D visualization virtual environments can improve the quality of learning and understanding [23,24].
2. By taking advantage of desktop virtual reality, construction and management personnel can display and use 3D digital models on fixed devices (such as PCs or large screens) and mobile devices (such as tablets) without complicated operational training. Compared with expensive virtual reality devices and augmented reality systems, this is more suitable for cost management in construction sites.
 3. By taking the construction steps of building products as the basic unit of technological process expression and using the process-based dynamic expression, our method is more refined, structured, and standardized than the traditional construction technology disclosure and quality control scheme, improving the control of construction personnel and management personnel on the details of product construction, reducing the quality defects hidden inside the building products, and avoiding the quality problems caused by internal defects.
 4. The three-dimensional digital model is created by BIM technology, and the construction products in the construction process are accurately reproduced in the digital environment. The quality control and quality management of the construction process are conducted according to the three-dimensional digital model and the process information attached to this. Compared with the traditional process management method, our method has obvious advantages. For example, our method can achieve the timely detection of many problems in the construction process based on the three-dimensional model of different process nodes and building products in the construction process of shape, location, size, etc.
 5. The three-dimensional geometric model based on BIM technology has the characteristic of parameterization, which can realize the reuse and quick adjustment of the construction process of building products through parameter transformation, and is more efficient than the complicated traditional process document creation process. In addition, the multidimensional integration of the MBD technology has obvious advantages. It can integrate the information of different dimensions, such as size, tolerance, material, technical requirements, and specification standards, into the three-dimensional model. Additionally, in terms of the data source for information transmission, it has more advantages than other technologies.

Table 3. Results of application examples.

Content	2D Process Information Expression	3D Process Information Expression	Evaluation
Synergy between process information and 3D model	Separate	Integrated	
Size of process file	25.6 M	14.6 M/11.1 M/5.1 M	Reduced by 42.9%/56.6%/80.1%
Format of process file	DOCX + XLS + BIM model	Single XLS/EXE/SMG	
Can it control and simulate process expression?	No	Yes	
Can it be used as a basis for quality control?	No	Yes	
Can it accurately express the process?	No	Yes	
Is it interactive?	No	Yes	
Time to understand process information	1 h	0.4 h	Reduced by 60%
Times of process information explanation	3	1	Reduced by 66.7%

5. Conclusions

Focusing on the lack of traditional two-dimensional process information expression and the lack of research on quality control and quality management of building products, this paper proposes a three-dimensional process digitization method combined based on BIM and MBD technology. In this method, with the solid geometry of the process design model as the core, the process information is attached to the changed solid geometry to fully reflect the process change of the construction of building products and realize the quality control and quality management in the construction process of building products.

This paper provides an effective method for 3D digital processes. The proposed method makes it possible to dynamically express the process flow of building products, and it provides great convenience in the construction management and process control of building products. As an ongoing project, there are still many aspects to improve in future research. Firstly, the process information database should be established to better deal with the process information. Secondly, the informatization degree of process information processing and the process design model should be enhanced, and more functions of CATIA software should be developed to improve the effectiveness and integrity of process expression. In future studies, it will be significant to develop the process information database's interactions with the CATIA environment.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app12178585/s1>. Video S1: Display of infill wall masonry construction guide; Exe files S1: The technological process digitization of straight masonry wall.

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