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Exploring the Integration of Visual Assembly Process Among the 3C Manufacturing Firms in China

Wang Qinjian, Joy N. Savellano
Nueva Ecija University of Science and Technology
bujoynsavellano17@gmail.com

Abstract. The study delved into the visual assembly process planning and information systems within the context of the ever-evolving manufacturing landscape. The manufacturing sector had witnessed a shift from traditional assembly methods, often plagued by inefficient manual processes, to a more technologically advanced approach involving 3D visualization and information systems. The aim of this study was to improve assembly processes' efficiency, accuracy, and flexibility.

Incorporating insights from existing literature, the study outlined the significance of visual assembly process planning using immersive virtual reality and virtual reality technology in enhancing assembly efficiency and product quality. Additionally, the study emphasized the impact of digital assembly based on virtual assembly process planning on productivity and quality. These technologies optimized the assembly process, reduced errors, and improved product quality, with practical applications for the manufacturing industry.

Nonetheless, challenges, including system integration issues, had hindered the seamless integration of assembly systems and technologies, affecting efficiency and quality. To overcome these challenges, a comprehensive plan was presented. This plan spanned various aspects of manufacturing, such as organizational structure, product diversification, workforce optimization, technology integration, quality enhancement, and cost reduction, culminating in profitability enhancement.

The research provided valuable insights for academia and practice, offering a promising path to optimizing production processes, improving assembly efficiency and quality, and reducing carbon emissions. In the face of global climate change, the integration of visual assembly processes in 3C manufacturing enterprises held the potential to enhance competitiveness and contribute to sustainable development.

Keywords: 3C manufacturing, assembly efficiency, information systems, technology integration, visual assembly process planning

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1. Introduction

The exploration of visual assembly process planning and information systems originated from the complexity and challenges experienced in manufacturing assembly processes. In traditional assembly process planning, certain aspects could be improved through manual assembly drawing creation and the documentation of process details. Issues such as inaccurate information transmission and challenging process adjustments had a detrimental impact on assembly process efficiency, quality, and flexibility.

With the evolution of manufacturing, the growing product complexity, and the rapid progress in computer science and information technology, research into visual assembly process planning and information systems garnered significant attention. The study aimed to enhance the process and management of assembly process planning using visualization technology and information systems, thereby augmenting the assembly process's efficiency, accuracy, and flexibility.

Existing literature formed the foundation for comprehending and enhancing assembly process planning and management by employing visualization techniques and information systems. For instance, Fan et al. (2018) conducted a survey on digital assembly process planning, emphasizing the potential of virtual assembly process planning through immersive virtual reality to enhance assembly process efficiency and quality. Through immersive experiences, simulation evaluations, and real-time interactions, assembly engineers could efficiently plan and optimize assembly processes, boosting productivity, reducing costs, and enhancing product quality.

Furthermore, Liu et al. (2017) explored the influence of virtual reality-based visual assembly process planning on productivity and quality, revealing that virtual reality technology had the potential to improve engineer work efficiency, reduce assembly errors, and enhance product quality. This underscored the crucial role of visual assembly process planning based on virtual reality technology in improving engineer productivity, minimizing assembly errors, and elevating product quality, with practical application potential in the manufacturing industry.

Moreover, Su et al. (2019) examined the impact of digital assembly based on virtual assembly process planning on productivity and quality, demonstrating that engineers could better optimize processes, reduce assembly time, and

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enhance product quality through digital assembly visualization and simulation. The study underscored the positive effect of digital assembly based on virtual assembly process planning on production efficiency and quality. By visualizing and simulating the digital assembly process, engineers could optimize processes, reduce assembly time, and improve product quality, providing manufacturing companies with an innovative approach to enhancing assembly processes and increasing production efficiency and quality levels.

However, as noted by Hu et al. (2021), it was crucial to acknowledge the challenges related to system integration in visual assembly process planning. The study found that integrating diverse assembly systems and technologies into a unified system could encounter challenges such as technical compatibility, data transmission, and interaction, which affected the efficiency and quality of the assembly process.

The primary objective of this study was to provide valuable insights for both academia and practical application. In conclusion, research exploring the impact of visual assembly process planning on productivity and quality aimed to offer valuable insights to academia and practice. Visualized assembly processes represented an effective technique for optimizing production processes, enhancing assembly efficiency and quality, and had the potential to reduce carbon emissions. In the face of global climate change, investigating the integration of visual assembly processes in China's 3C manufacturing enterprises not only helped enhance enterprise competitiveness but also aligned with sustainable development requirements, thereby mitigating the adverse environmental impact. Hence, conducting this study was clearly justified and practical.

2. Methodology

The study adopted a descriptive research design to explore the integration of descriptive research on visual assembly processes in Chinese 3C manufacturing enterprises, It focused on describing what was being done rather than explaining the root cause or mechanism. The study employed a descriptive research design to delve into the intricacies of integrating descriptive research on visual assembly processes within the realm of Chinese 3C manufacturing enterprises.

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The descriptive study design was very suitable for this research because it objectively and comprehensively described the phenomenon, applied to natural settings, covered diverse factors, explored trends, had fast timeliness, provided valuable information for basic research, offered reference and data support for subsequent further research, and also explored the specific impact mechanism of visualization technology application in the assembly process on production efficiency and quality. By collecting and analyzing data and information from the assembly process, researchers further explored how visualization technology could improve the monitoring, adjustment, and optimization of production processes, and how it could provide more intuitive, real-time information feedback to increase productivity and reduce error rates, thereby improving product quality. At the same time, the research also focused on the operators' acceptance and experience of visualization tools, as well as the challenges and limitations encountered in practical applications, in order to provide practical suggestions and improvement directions for further optimizing the application of visual assembly processes. Overall, the study aimed to gain insight into the role of visualization technology in the assembly process and provide empirical support for the improvement and quality enhancement of the production process.

To gather data for analysis, the researchers employed quantitative methods, utilizing techniques such as frequency analysis, percentage calculation, and weighted mean calculation. These statistical analyses provided quantitative answers to the research questions posed in the study.

By employing a descriptive study design, the study aimed to describe and explore the integration of visual assembly processes in 3C manufacturing enterprises in China. In addition, it sought to propose an action plan to improve the economic performance of the surveyed businesses. The findings and recommendations of the study contributed to a better understanding of the role of visual assembly process planning in 3C manufacturing and provided practical guidance for improving operational efficiency and quality.

2.1. Sampling Procedure

The study focused on five subsidiaries of the company: Beijing Foxconn Precision Electronics Co., Ltd., Langfang Foxconn Precision Electronics Co., Ltd.,

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Shandong Foxconn Precision Electronics Co., Ltd., Shanxi Foxconn Precision Electronics Co., Ltd., and Jincheng Foxconn Precision Electronics Co., Ltd. A sample of approximately 50 individuals representing these enterprises was conducted to investigate the integration of visual assembly processes in Chinese 3C manufacturing companies. Participants included managers, employees, other professionals, and product users. Managers provided insights into strategic planning related to visual assembly process planning, employees offered direct feedback on project operations, other professionals contributed their perspectives to optimize production and quality planning, and product users provided valuable feedback on exploring the integration of visual assembly processes in Chinese 3C manufacturing enterprises. The survey aimed to collect comprehensive data from various stakeholders within the subsidiary to fully understand the impact of visual assembly process planning on productivity and quality. The readiness and eagerness of participants to engage in the research were pivotal, optimizing data collection efficiency and efficacy (Domingo, 2023a; Domingo, 2023b; Domingo, 2023c).

2.2. Respondents

The respondents of this study were primarily composed of representatives from Beijing Foxconn Precision Electronics Co., Ltd., Langfang Foxconn Precision Electronics Co., Ltd., Shandong Foxconn Precision Electronics Co., Ltd., Shanxi Foxconn Precision Electronics Co., Ltd., and Jincheng Foxconn Precision Electronics Co., Ltd, totaling five companies.

The sample included approximately 50 individuals, carefully selected to represent various roles within these companies. This selection was deliberate, aiming to capture a comprehensive spectrum of perspectives and insights. Specifically, 15 managers, 25 employees, and 10 other professionals were chosen for their diverse roles and expertise, ensuring that the study could provide a well-rounded understanding of the impact of visual assembly process planning on productivity and quality.

By including managers, the study gained insight into the strategic and decision-making aspects of assembly process planning, while employees offered frontline experiences and practical challenges. The inclusion of other professionals helped incorporate perspectives from different functional areas within the organizations. This holistic approach to respondent selection ensured

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that the research could address a wide range of viewpoints and generate more robust conclusions about the integration of visual assembly processes in 3C manufacturing enterprises.

The distribution of respondents is shown in Table 1:

Table 1

Distribution of Respondents

Manufacturing Enterprises	Manager	Employees	Other Professionals	Total
Beijing Foxconn Precision Electronics Co., Ltd.,	3	5	2	10
Langfang Foxconn Precision Electronics Co., Ltd.,	3	5	2	10
Shandong Foxconn Precision Electronics Co., Ltd.,	3	5	2	10
Shanxi Foxconn Precision Electronics Co., Ltd.,	3	5	2	10
Jincheng Foxconn Precision Electronics Co., Ltd.,	3	5	2	10
Total	**15**	**25**	**10**	**50**

2.3 Research Site

This study was conducted at Beijing Foxconn Precision Electronics Co., Ltd., Langfang Foxconn Precision Electronics Co., Ltd., Shandong Foxconn Precision Electronics Co., Ltd., Shanxi Foxconn Precision Electronics Co., Ltd., Jincheng Foxconn Precision Electronics Co., Ltd., and other manufacturing enterprises. This provided an ideal opportunity to research and explore the integration of visual assembly processes in China's 3C manufacturing enterprises. As a global manufacturing giant, Foxconn had a total of 500,000+ employees worldwide and possessed rich production experience and extensive assembly process data in various fields such as electronics, communications, and computers. Its production lines involved numerous assembly tasks that required high precision and efficient production processes.

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Collaborating with Foxconn in this research endeavor enabled researchers to gain access to real-world assembly scenarios and data, facilitating a deeper understanding of the challenges and opportunities associated with assembly process planning in practical production environments. Furthermore, Foxconn's expertise in digitalization and intelligent manufacturing, along with its advanced technologies, served as valuable references and insights for the study.

This collaboration not only contributed to the research objectives but also fostered collaboration and knowledge exchange between academia and industry. By jointly exploring the integration of visual assembly processes for 3C manufacturing enterprises in China, the study aimed to provide Foxconn and other manufacturing companies with improved assembly solutions to further improve production efficiency and product quality. The research results promoted the overall development of the industry and encouraged a closer integration between academic research and practical applications.

3. Results and Discussion

3.1 Profile of 3C Manufacturing Enterprises

3.1.1 Form of Organization, Ownership

The study investigated the organizational structure and ownership of 3C Manufacturing Enterprises, revealing that most surveyed enterprises were subsidiaries or business units within larger corporations or groups, indicating varying degrees of autonomy and integration. Three out of five enterprises were subsidiaries, controlled by another entity owning more than 50% of shares, while two were business units with distinct operations. Three out of five were joint ventures formed for specific purposes, and two were public companies traded on stock exchanges, indicating collaborative partnerships and transparency to shareholders. This suggests that the majority of 3C manufacturing enterprises in the study were part of larger corporate structures or engaged in collaborative ventures, impacting their operational dynamics and accountability.

3.1.2 Product/ Services Offered

Among the 3C manufacturing enterprises surveyed, 2 offered communication products, 1 offered computer products, and 2 offered electronics, reflecting a diverse portfolio covering various segments of the industry. Communication products facilitate information transmission, while computer products support computing functions, and electronics utilize electric circuits or components. Additionally, it's shown that 2 enterprises offered product design and development support, 1 offered assembly process optimization, 1 offered assembly training and education, and 1 offered quality control and defect prevention, showcasing a range of value-added services provided by these enterprises to their customers, aimed at enhancing product quality and efficiency in the assembly process.

3.1.3 Number of Employees

The findings reveal that among the 3C manufacturing enterprises surveyed, the distribution of employees was uniform across different categories, ranging from 10-20 persons to 101 persons and above, with each category represented by one enterprise. This suggests a wide variation in size and scale among the enterprises, with some being small and others significantly larger.

3.1.4 Description of the equipment used (3D)

Among the 3C manufacturing enterprises surveyed, 40% utilized 3D scanners, 40% utilized interactive display devices, and 20% utilized 3D modeling software. 3D scanners capture real objects' shape, size, and texture, converting them into digital 3D models, while interactive display devices enable users to interact with 3D models or environments through touch, gesture, or voice commands. Additionally, 3D modeling software allows users to create and edit 3D models using various tools and techniques. These findings indicate that enterprises employed diverse 3D technology devices for visual assembly process planning, tailored to their specific needs and preferences.

3.2 Experiences in the Use of 3D Visual Assembly Process

The utilization of 3D visual assembly methods within manufacturing has attracted significant attention due to its potential to revolutionize various facets of assembly operations. This extensive investigation delves into respondents'

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firsthand encounters, shedding light on the efficacy and efficiency of 3D visual assembly processes across diverse dimensions, encompassing defect reduction, rework rates, problem identification, precision, consistency, productivity, and the pace of assembly operations.

In the realm of quality enhancement, respondents overwhelmingly concurred on the instrumental role of 3D visual assembly processes in mitigating defects throughout the product assembly journey. Their responses underscored a profound confidence in the efficacy of 3D visualization in identifying and rectifying flaws, ultimately bolstering product quality and elevating customer satisfaction. Despite overall satisfaction with their experiences, there remains ample opportunity for refining the effectiveness and efficiency of 3D visual assembly practices, particularly in the realm of detecting and preempting assembly defects. Nonetheless, these findings echo previous research, which has extolled the virtues of 3D visual assembly in curbing defects, minimizing rework rates, and fortifying product quality and customer satisfaction.

Similarly, respondents acknowledged the constructive impact of 3D visual assembly processes on mitigating rework rates in product assembly. They expressed unwavering confidence in the potency of 3D visualization in curtailing rework instances and forestalling assembly errors, thereby fostering heightened production efficiency and fiscal savings. While respondents generally expressed contentment with their encounters, avenues exist for amplifying the influence and benefits of 3D visual assembly practices in rework reduction. These insights resonate with earlier studies, which have showcased the capacity of 3D visual assembly to streamline assembly protocols, diminish rework rates, and optimize resource allocation, thereby bolstering production efficiency and cost-effectiveness.

In the realm of identifying and resolving potential assembly hiccups, respondents unanimously lauded 3D visual assembly processes for furnishing precise depictions of probable issues and their efficacy in remedying assembly-related challenges. Their feedback underscored the pivotal role of 3D visualization in pinpointing and remedying assembly conundrums, ultimately fortifying product quality and enhancing customer satisfaction. However, avenues exist for refining the precision and effectiveness of 3D visual assembly practices in delineating and resolving assembly quandaries. These observations echo earlier research, which has underscored the significance of 3D visual

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assembly in pinpointing and mitigating potential problems, thereby augmenting product quality and customer contentment.

Moreover, respondents acknowledged the pivotal role of 3D visual assembly processes in heightening the accuracy and uniformity of product assembly. They collectively attested to the efficacy of 3D visualization in enhancing assembly precision and uniformity, consequently fostering enhanced product quality and customer satisfaction. While respondents generally expressed contentment with their experiences, opportunities exist for magnifying the impact and benefits of 3D visual assembly practices on accuracy and uniformity enhancement. These insights resonate with prior studies, which have extolled the virtues of 3D visual assembly in refining assembly precision, uniformity, and overall product quality.

In the realm of efficiency augmentation, respondents underscored the potential of 3D visual assembly processes to curtail cycle time, amplify throughput, and optimize resource utilization within assembly systems. While respondents concurred with statements pertaining to cycle time, throughput, and resource utilization, avenues exist for fully realizing the advantages of 3D visualization in fortifying assembly efficiency. These observations are buttressed by earlier research, which has showcased the ability of 3D visual assembly to streamline assembly operations, boost throughput, and optimize resource allocation, thereby enhancing overall assembly efficiency.

Furthermore, respondents acknowledged the constructive impact of 3D visual assembly processes on assembly time, production efficiency, and the pace of assembly operations. They collectively recognized the role of 3D visualization in expediting assembly time, heightening production efficiency, and accelerating the pace of assembly operations, ultimately fostering enhanced productivity. While respondents generally expressed contentment with their encounters, opportunities exist for further amplifying the influence and benefits of 3D visual assembly practices on assembly time, production efficiency, and the pace of assembly operations. These findings align with previous research, which has underscored the advantages of 3D visual assembly in bolstering assembly productivity, efficiency, and overall performance.

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3.3 Effects Integration of visual assembly process for 3C manufacturing enterprises

3.1.1 Profitability

The data analysis shows that respondents generally agree on the profitability of using 3D visual assembly. There's a clear consensus, with Statement 5 receiving the highest score, indicating satisfaction with the profitability aspects of 3D visualization. However, Statement 4 trails behind, suggesting doubts about how much 3D visual assembly improves product quality and competitiveness. This implies there are hurdles hindering the full realization of 3D visual assembly's profitability benefits, like market dynamics or customer satisfaction.

These findings align with previous research by Kumar et al. (2018) and Mahajan and Sankman (2019), who found tangible reductions in manufacturing costs and increased productivity through the use of 3D simulation and packaging architectures. In summary, respondents recognize the potential of 3D visual assembly to reduce production costs, increase profitability, and improve quality. They also see benefits like increased productivity and better product quality, contributing to overall competitiveness. Overall, respondents are satisfied with the profitable aspects of using 3D visualization in assembly processes.

3.1.2 Cost:

Looking at respondents' views on cost dynamics in 3D visual assembly, a clear trend emerges. They tend to agree with statements about cost considerations. Statement 4, in particular, underscores their belief that 3D visual assembly can reduce waste and unnecessary costs in production. However, Statement 1 suggests lingering doubts about how much 3D visual assembly actually reduces production costs.

These findings are consistent with research by Kumar et al. (2018) and Mahajan and Sankman (2019), who found significant reductions in manufacturing costs and increased productivity. In summary, respondents acknowledge the potential of 3D visual assembly to reduce production costs, increase profitability, and reduce wastage. They also recognize benefits like increased productivity and optimized resource utilization. Ultimately, respondents are satisfied with the cost aspect of using 3D visualization in assembly processes.

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3.1.3 Human Resource:

Examining respondents' perceptions of human resource dynamics in 3D visual assembly, there's a notable alignment. Statement 2 stands out, indicating respondents believe 3D visual assembly can improve new employee training and operator skills. However, Statement 3 suggests some reservations about whether 3D visualization can optimize human resource allocation dynamics.

These findings resonate with previous research by Potgieter and Mokomane (2018) and Kirpes et al. (2018), who highlighted the importance of human resource management and the value of 3D product models in assembly contexts. In summary, respondents recognize the potential of 3D visual assembly to reduce operator burdens, improve human resource efficiency, and optimize resource allocation. They also acknowledge benefits like enhanced training and operator skills. Ultimately, respondents express satisfaction with the human resource aspect of using 3D visualization in assembly processes.

3.2 Proposed Plan for the Optimization of the Assembly Process of a Manufacturing Firm

The plan, drawn from research among 3C manufacturers, seeks to optimize a manufacturing firm's assembly process using 3D visual assembly planning. It tackles various factors affecting performance and competitiveness, including organizational structure, product range, workforce, technology, quality, efficiency, productivity, cost, and profitability.

Implementing these plans offers numerous benefits. They align the firm's organizational structure with its strategic goals, enhancing flexibility and responsiveness. They also aid in diversifying the product portfolio to meet market demand, boosting customer satisfaction and market share. Additionally, they optimize workforce and skill development programs, improving employee efficiency and satisfaction. Integrating 3D technology in the assembly process enhances efficiency and precision. Furthermore, implementing quality control measures with 3D visual assembly reduces defects and rework rates, elevating product quality. Optimizing assembly systems maximizes operational efficiency by increasing cycle time and throughput. Moreover, improving assembly time and speed through technology compatibility and process streamlining enhances productivity. Minimizing waste and unnecessary costs in production processes

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reduces overall production costs. Finally, leveraging 3D visual assembly improves profitability by reducing costs, enhancing quality, increasing productivity, and strengthening competitiveness.

However, implementing these plans poses significant challenges. Firstly, a thorough assessment of the current situation and identification of areas for optimization is necessary, involving data collection, analysis, and interpretation. Secondly, a clear vision and direction for the desired outcomes must be established, including setting goals, objectives, and indicators. Thirdly, detailed plans and action steps for achieving the desired outcomes need to be developed, involving resource allocation, assigning responsibilities, and setting timelines. Fourthly, continuous monitoring and evaluation of progress and results are essential, including collecting feedback, measuring performance, and making adjustments. Finally, strong commitment and collaboration from all stakeholders involved in plan implementation are required, necessitating effective communication, coordination, and cooperation.

4. Conclusion

The 3C manufacturing firms are typically part of larger corporate structures, with diverse product ranges and varying technology adoption. Respondents generally view 3D visual assembly positively for its quality, efficiency, and productivity benefits, although challenges remain regarding technology compatibility. Integrating visual assembly processes is seen to positively affect profitability, cost reduction, and human resources, despite challenges like technology quality and market demand. The proposed optimization plan highlights the need for multifaceted strategies to enhance operations, quality, efficiency, productivity, cost-effectiveness, and profitability in 3C manufacturing assembly processes, potentially boosting competitiveness and sustainability.

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