


## Article

# Value of the 3D Product Model Use in Assembly Processes: Process Planning, Design, and Shop Floor Execution

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**Abstract:** Organizations can enhance the value of their assembly planning, assembly design, and assembly shop floor execution through the use of the 3D product model. Once a tool targeted at product design, the 3D product model, enabled by current and emerging manufacturing process management technologies, can create additional value for organizations when used in assembly processes. The research survey conducted and described in this paper demonstrates the value organizations have seen in using the 3D product model in the assembly process. The paper also explores the current state of those organizations who have not yet implemented the use of the 3D product model in their assembly processes and the value that they foresee for possible future implementation. The essential findings of this research are the five qualitative areas in which value is derived from using the 3D product model in complex assembly processes and how those value drivers apply across various industries and organization sizes. These results provide a framework for future research to develop quantitative models of the value of the 3D product model use in assembly processes.



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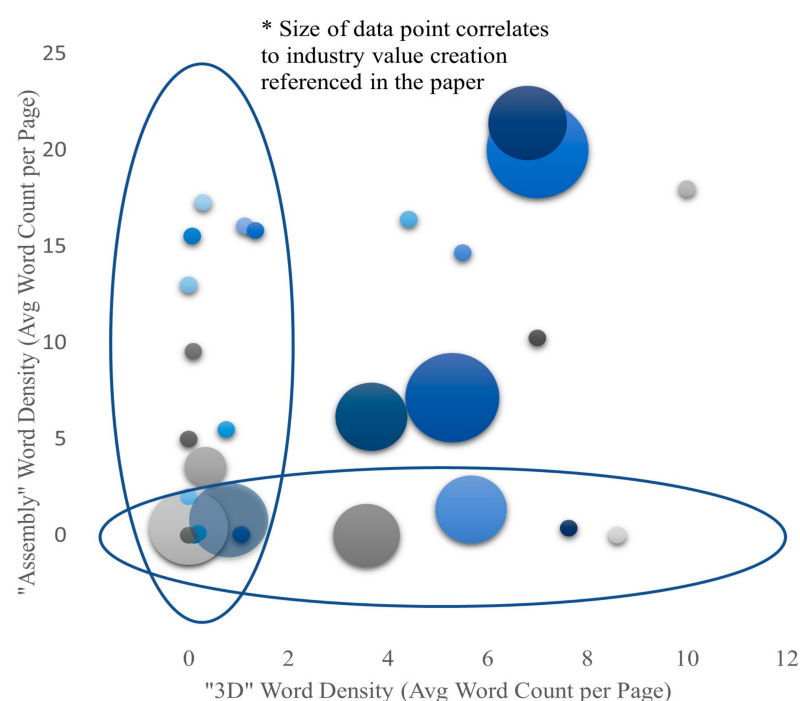
**Keywords:** assembly; process planning systems; concurrent engineering; automotive industry applications; manufacturing industry applications

## 1. Introduction

The first adoption of 3D product models among the engineering disciplines was in product design. Whereas 2D drawings previously required engineering expertise and an object-oriented mindset to imagine a 3D object based on the shapes depicted, the 3D product model provides a non-engineering trained person with the same opportunity to visualize the product before it is built. Such functionality is of great benefit as engineers work on the design of the product with marketing, sales, suppliers, potential customers, and other functions inside and outside of the organization. However, if the use of the 3D product model stops at the design phase, the benefit of the 3D product model is not fully realized.

To better understand the value of the 3D product model in the assembly process, a literature review was conducted. Journal papers, articles, and conference papers were sourced using the Compendex and Scopus databases. Articles searched for included reference to “3D” and “assembly” but not “printing” (in order to remove articles on 3D printing, which is not the focus of this study). Then, an analysis was run on the number of times these key words were used throughout the article. Noting that some articles are longer than others, the total count was divided by the article page count to get an understanding of the density of the use of the “3D” and “assembly” keywords in each article. Each article was also reviewed for mentions of the value that using 3D product models in the assembly processes could create. Such value might include improving the efficiency and reliability of the assembly process design, reducing process planning problems, and shortening the process planning cycle [1,2]. Then, the same approach was

taken in terms of dividing the number of mentions of value creation by the total page count to get a density value for value creation mentions in each paper. The plot of these relative densities of “3D” to “assembly”, where “value creation” is the size of each bubble, is shown in Figure 1 [1–34] where each different colored bubble represents a different journal paper, article, or conference paper. Figure 1 demonstrates that while there was a lot of research published on 3D product models, and an equivalent amount published on assembly processes, less literature had been published on the use of 3D product models in assembly. This was especially evident in the lack of data points in the upper right corner of Figure 1 and the fact that of those papers that do have a high density of “3D” and “assembly”, there is still a gap in the literature in terms of the value that the use of 3D product models creates in assembly processes. Exploring this gap and better understanding the value that 3D product models create in the assembly process provided the guiding purpose for this research.



**Figure 1.** 3D product model in the assembly process: literature review.

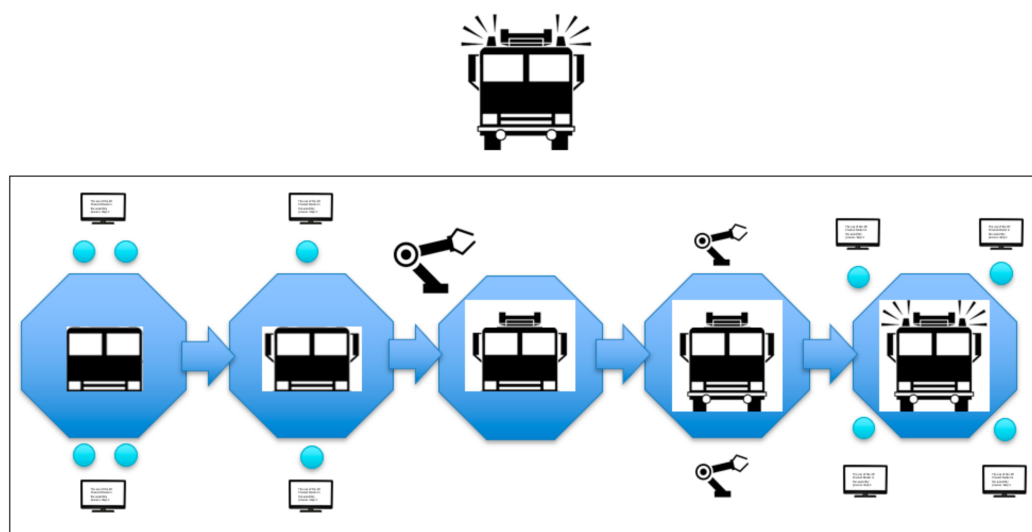
The ability to capture the value that 3D product models create in assembly processes has been limited by the availability of software to bring the 3D product model to the assembly processes [3,4]. Enabling factors including innovative education and training along with data-sharing systems and standards have created an environment for technology to advance in such a way that smart manufacturing and the use of the 3D product model in the assembly process becomes feasible [5]. As such feasibility came to fruition, researchers and industry alike have found ways to transform the engineering Bill of Materials into the Manufacturing Bill of Materials [6–8]; develop manufacturing process management software [9]; and extract 3D product model data and transfer it to virtual manufacturing and assembly software [10–15]. Researchers and industry also advanced this virtual assembly knowledge further, developing tools to automate assembly planning for complex products [16,17].

Once technology enabled the use of the 3D product model in the assembly process, research was conducted demonstrating how the 3D product model could be used in the assembly process planning, assembly design, and assembly shop floor execution processes (referred to in individual and in aggregate as “the assembly process” for the sake of brevity in this paper). This can be done by integrating the 3D product model with assembly line bal-

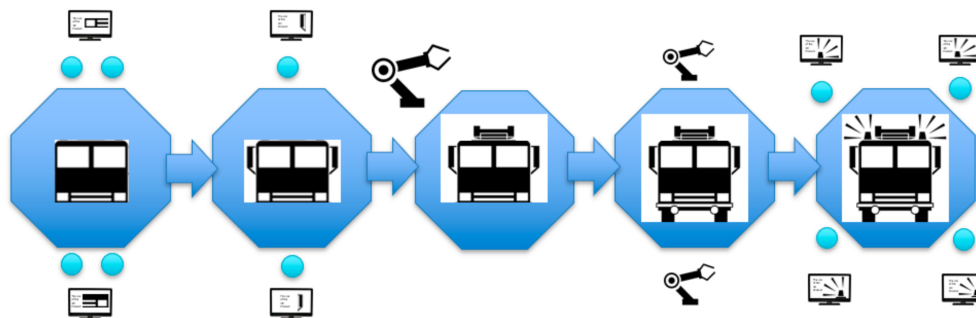
ancing via process consumption and leveraging the 3D product model in the link between the Bill of Process and the Bill of Materials including Model/Option dependency [18,35]. A similar approach includes the creation of a digital mock-up to transmit models and attribute data between the Engineering Bill of Materials and the Process (or Manufacturing) Bill of Materials and serve as a unified data source in assembly planning [19]. By implementing such approaches, the use of the 3D product model in assembly processes allows for engineers to check the product's configuration for assemblability [20]. The 3D product model can also be used on the shop floor to enhance shop floor work instructions, improve process planning, and increase efficiency of assembly work [21,22]. Each of these studies indicate ways that companies can utilize the 3D product model developed by design teams in assembly processes. Given that some research has shown that such a feat is possible, then, the question becomes whether industry sees value in using the 3D product model beyond product design, and if so, in what areas industry believes value exists.

The objective of this research is to evaluate the use of 3D product models in assembly planning, assembly design, and assembly shop floor execution. The authors note that the 3D product model can have a large array of meanings from the virtual computer-aided design (CAD) model, to a digital mock-up, to a digital twin, or even a physical 3D model. The 3D product model application focused on in this paper is the value of bringing the virtual CAD model and digital 3D assembly mock-up to the assembly process beyond the engineering design. To illustrate an example, Figure 2 shows an assembly process where a fire truck is being built. Each octagon represents a station on the assembly line; some operations are completed by operators (the blue dots in the figure), and others are completed by robots. The operators have written work instructions which they use to know what parts to assemble and where to assemble those parts as different models and options of the fire truck progress down the assembly line. Figure 3 shows this same assembly line, but the written work instructions are replaced with 3D product models (virtual CAD models) of the part with visual assembly guidance. This is an example application of the 3D product model in the assembly process.

The paper explores the value organizations see in implementing the 3D product model in assembly processes. This paper will go through the methodology and results of a survey that was conducted to understand the value that organizations are seeing by implementing the 3D product model in assembly processes. The paper concludes with a review on the value of 3D product model use in assembly processes based on the survey results and a discussion on future research recommendations.



**Figure 2.** Assembly process using written work instructions.



**Figure 3.** Assembly process deploying the 3D product model to the shop floor.

## 2. Materials and Methods

In this study, we adopt a survey to reach industry practitioners and understand if and how they have deployed the 3D product model in assembly planning, assembly design, and assembly shop floor execution processes. In addition, the survey aims to capture the value that the respondents have seen, or plan to see, in using the 3D product model in these assembly processes. The following are example survey questions developed accordingly:

- (1) Please indicate your level of knowledge about the use of 3D product models in the assembly process, assembly design, or assembly shop floor execution at your organization:
  - (a) Not at all knowledgeable
  - (b) Somewhat knowledgeable
  - (c) Knowledgeable
  - (d) Very knowledgeable
- (2) Has your company implemented 3D product models into the assembly process planning/design?
  - (a) Yes
  - (b) No
- (3) Has your company implemented 3D product models into the assembly shop floor execution?
  - (a) Yes
  - (b) No
- (4) To what extent does your company use 3D product models in the assembly process?
  - (a) Screenshots of 3D model
  - (b) 3D model mapped to process activities
  - (c) 3D model mapped to parts consumption within process activities
  - (d) 3D model fully integrated with Engineering Change Order/Manufacturing Change Order Process
  - (e) Other (please describe):
- (5) What technology is your company deploying to accomplish the use of 3D product models in the assembly process?
  - (a) Proplanner's Assembly Planner
  - (b) PTC's MPMLink
  - (c) Siemens Teamcenter
  - (d) Software developed in-house
  - (e) Other (please describe):
- (6) What are the limitations of the technology your company is using to communicate the information contained in the 3D product model to the assembly team?



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- (7) If your company has implemented the 3D product model in the assembly process planning/design, what was your company doing before implementing the use of 3D product models for assembly process planning/design? (Select all that apply)
- (a) Excel
  - (b) Simulation
  - (c) Paper/Post-It notes
  - (d) Physical mock-ups
  - (e) Other (please describe):
  - (f) Not applicable
- (8) If your company has implemented the 3D product model in the assembly shop floor execution, what was your company doing before implementing the use of 3D product models in the shop floor execution?
- (a) Virtual work instructions without the 3D product model
  - (b) Hard copy work instruction with 2D drawings
  - (c) Hard copy work instructions with pictures
  - (d) Work instructions without visuals, words only
  - (e) Operator training with no shop floor work instructions
  - (f) Other (please describe)
  - (g) Not applicable
- (9) How did your company move from the former state to implementing 3D product models in the assembly process? (Select all that apply)
- (a) Pilot study
  - (b) Wholesale cutover
  - (c) Started small and scaled implementation
  - (d) Other (please describe):
- (10) What is the value your company has seen in implementing 3D product models in the assembly process? (Select all that apply)
- (a) Accuracy of assignment of the right parts, tools, work allocation, and work instructions
  - (b) Faster new product/model roll out to production
  - (c) Less time updating work instructions
  - (d) Quicker operator training
  - (e) Other (please describe):
- (11) What are the savings/estimated value/return (quantitative and/or qualitative) of implementing the use of 3D product models in the assembly process?
- (12) What is the size of the company you work for?
- (a) 1–999 employees
  - (b) 1000–9999 employees
  - (c) 10,000–49,999 employees
  - (d) 50,000+ employees
- (13) What industry is your company a part of?
- (a) Aerospace
  - (b) Agricultural Equipment
  - (c) Automotive (e.g., Light Car and Truck)
  - (d) Consumer Appliances
  - (e) Heavy Industrial (e.g., Heavy Equipment, Trucks, and Buses)
  - (f) Recreational Vehicles (e.g., Motorcycles, RVs, Four Wheelers, and Boats)
  - (g) Supply Chain
  - (h) Other:
- (14) What is your title?
- (a) C-level Executive

- (b) Vice President
- (c) Director
- (d) Manager/Supervisor
- (e) Engineer
- (f) Other Individual Contributor
- (g) Other:

To ensure these survey questions would be applicable to industry, the research team connected with a Manufacturing Process Management (MPM) software company. Discussions with the engineers and customer-facing employees in the organization allowed the research team to refine the questions around what level organizations were deploying 3D product model functionality in the assembly process planning, assembly design, and assembly shop floor execution; what the limitations were of the software used to deploy the 3D product model in the assembly process; and what plans the organization had for further deployment of the 3D product model in the assembly process. Using this framework, the research team came up with three categories that companies would be divided into based on their responses to the set of survey questions. These categories were (1) companies that had implemented the use of the 3D product model in the assembly process; (2) companies that had not yet implemented the use of the 3D product model in the assembly process but planned to; and (3) companies that did not plan to implement the use of the 3D product model in the assembly process. The later survey questions were tailored accordingly to fit within the context of the category an organization was classified into based on their responses to the initial survey questions, while still retaining the following overarching themes: what the company was doing before they implemented the use of the 3D product model in the assembly process, how that functionality was rolled out, what software was used, what the limitations are of that software, and what value the company was seeing or planned to see based on the use of the 3D product model in assembly processes. The research team used Qualtrics to develop and administer the survey. The survey hierarchy is shown in Figure 4.

The research team sent the survey out to individuals who were a specific subset of the population. Potential survey candidates were first screened based on the company that they worked for. Since the focus of the study is specific to companies that have manufacturing production and assembly operations, only individuals who worked for these types of organizations were included as potential survey respondents. As an example, an individual that worked for an automobile manufacturer or an agricultural equipment manufacturer would be considered a potential survey respondent, as organizations in those industries are engaged in assembling complex products and thus could use the 3D product model in the assembly planning, assembly design, or assembly shop floor execution processes. However, an individual who works at a hospital or a food/beverage company would not be considered a potential applicant for the survey. Those organizations do not have assembly as a part of their business processes and thus are not viable survey candidates. Including respondents that do not have assembly operations could skew the survey results, as those organizations would likely answer that they do not plan to implement the use of the 3D product model in the assembly process (simply because they do not have an assembly process through which to implement the use of 3D product models).

Once potential survey respondents were screened based on the industry in which they worked, they were then filtered down based on their role in the organization. For example, an engineer or director-of-operations is likely to have knowledge about the company's plans or current use of 3D product models in the assembly process. However, an individual in accounting or human resources is likely not to have knowledge in that regard. As a result, if an individual worked for a company in an applicable industry, but was not in an applicable role, that individual was contacted in the context of providing an introduction to (or sharing the survey with) someone in their organization who was in an applicable role or was not sent the survey at all.

## Survey Flow Value of 3D Product Model use in Assembly

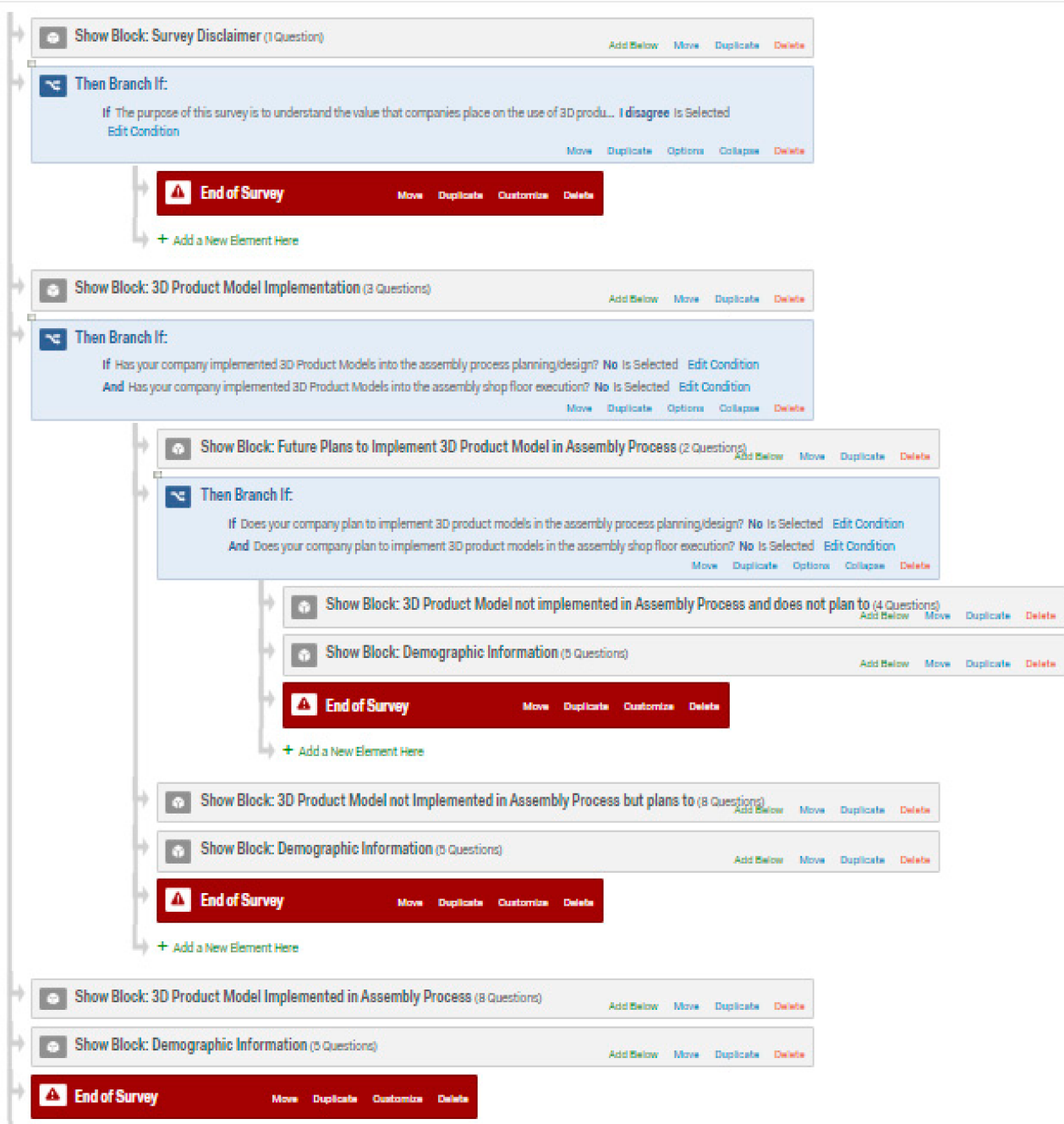


Figure 4. Survey flow hierarchy.

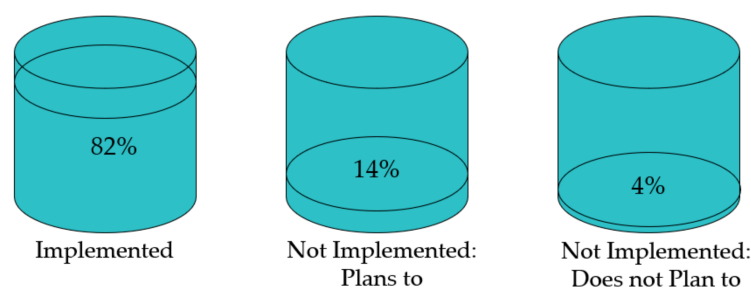
The research team started with a database of over 2700 contacts, which were filtered based on companies in applicable industries and individuals in applicable roles within those industries to 151. Of these 151, the research team found that the contact information was up to date for 85 individuals. These 85 individuals were provided with the link to take the survey on the value of the 3D product model use in the assembly process at their organization. Of the 85 individuals sent the survey, 35 responded, equating to a response rate of 41%. Note that the date between when the survey was administered and the final data were collected was approximately one month. The number of respondents in the first week was 21; in the second week, it was 8, in the third week, it was 6, and in the fourth

week, it was 0. The decreasing number of respondents and the fact that by the fourth week there were 0 respondents provided the research team with the indication that the majority of all respondents who were likely to respond had, and therefore, it was a good time to collect and analyze the data. The survey software was also set up to automatically record an individual's response after two weeks of no activity on the survey. The objective of this being that if the survey respondent had answered the majority of the questions but forgot to click submit, as an example, then the survey information would be captured and of use in the analysis. However, this approach also led to some survey responses being logged where, as an example, the survey respondent had started the survey, answered the first couple questions, and then exited the survey. In such a case, not enough data were available for analysis. Of the 35 responses, 7 responses were removed prior to the detailed analysis due to survey responses getting recorded with too few questions answered for meaningful analysis.

Prior to analyzing the survey results, the research team's hypothesis was that most companies would fall under the category of having not yet implemented the 3D product model in the assembly process but planned to do so in the future. This hypothesis was based on the research's team review of the academic literature written on the topic, including the lack of papers that correlate the implementation of the 3D product model in the assembly process to the value such implementation creates for an organization. In addition, the research team conducted several meetings with an MPM software company to gain a further understanding of industry-capable 3D product model software functionality and limitations through the lens of this organization, which helped shape the hypothesis. Given the lack of literature discussing the value of the 3D product model in the assembly process, the research team also hypothesized that the value of using the 3D product model in the assembly process is expressed qualitatively and unknown quantitatively.

### 3. Results

Of the 28 survey respondents with enough data for analysis, the responses were categorized into three buckets as noted in the Materials and Methods section of this paper. A total of 23 respondents (82% of those analyzed) said that they have implemented the 3D product model in the assembly process. Note that assembly process means assembly planning and design and/or assembly shop floor execution. A total of five respondents said they had not yet implemented the 3D product model in the assembly process; of those, four respondents (14% of those analyzed) said they planned to implement the 3D product model in the assembly process, and one respondent (4% of those analyzed) did not plan to implement the 3D product model in the assembly process. This categorization of the survey responses is shown in Figure 5. It is worth noting that of the 23 respondents that implemented the use of the 3D product model in the assembly process, eight had implemented the use of the 3D product model in assembly planning and design but not shop floor execution, one had implemented the use of the 3D product model in shop floor execution but not assembly planning and design, and 14 had implemented the use of the 3D product model in both.



**Figure 5.** Categorizations of survey responses.

### 3.1. Company Has Implemented the 3D Product Model in the Assembly Process

As discussed in the Materials and Methods section of this paper, potential survey candidates were screened based on the organization/industry in which they worked and their role within that organization to increase the likelihood that these individuals would have knowledge of the use of the 3D product model and how it was or was not being deployed in the assembly process in their organization. To test the effectiveness of the survey screening approach, survey respondents were asked to indicate their level of knowledge about the use of 3D product models in assembly planning, assembly design, or assembly shop floor execution. The categories and responses were as follows: very knowledgeable (6), knowledgeable (11), somewhat knowledgeable (5), not at all knowledgeable (1). With only one of the 23 respondents indicating that they were not at all knowledgeable about the use of the 3D product model in the assembly process, the survey screening approach appears to have been a success and drives greater confidence in the results described in this paper.

To ensure that results were not biased by any one industry, the researchers checked the distribution of responses by industry type. As shown in Figure 6, there is a relatively even distribution of survey responses across multiple industry types, and all industry types have applicability to an organization in an industry that would be a candidate for the use of 3D product models in the assembly process. The authors note that when viewed as a group, the aerospace, agricultural equipment, and automotive industries comprise a large portion of the survey responses. Based on the authors' experience, and comparison to the relative percentage of these industries to others with complex assembly operations on the 2020 Fortune 500 list (the largest 500 publicly traded companies in America by revenue), these three industries are a large portion of the population of the manufacturing organizations that have complex assembly operations. Of the Fortune 500 companies, only 44 companies are in industries that have complex assembly operations applicable to this research. Figure 7 shows the comparison of the percentage of survey respondents by industry relative to the percentage of companies with complex assembly operations by industry from the Fortune 500 and validates that the sample of industry respondents is representative of the broader population of manufacturing companies with complex assembly operations.

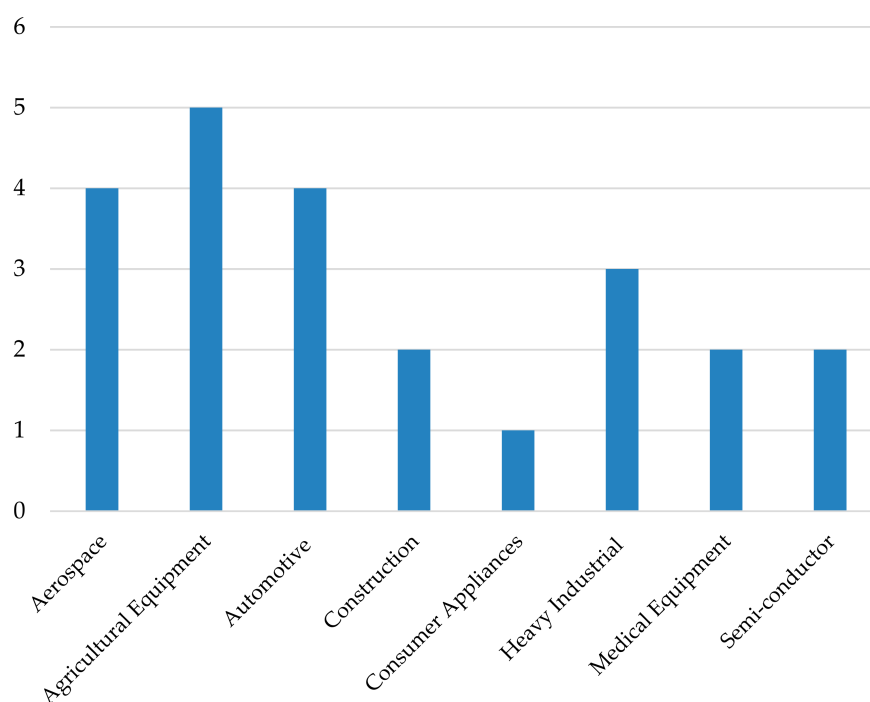
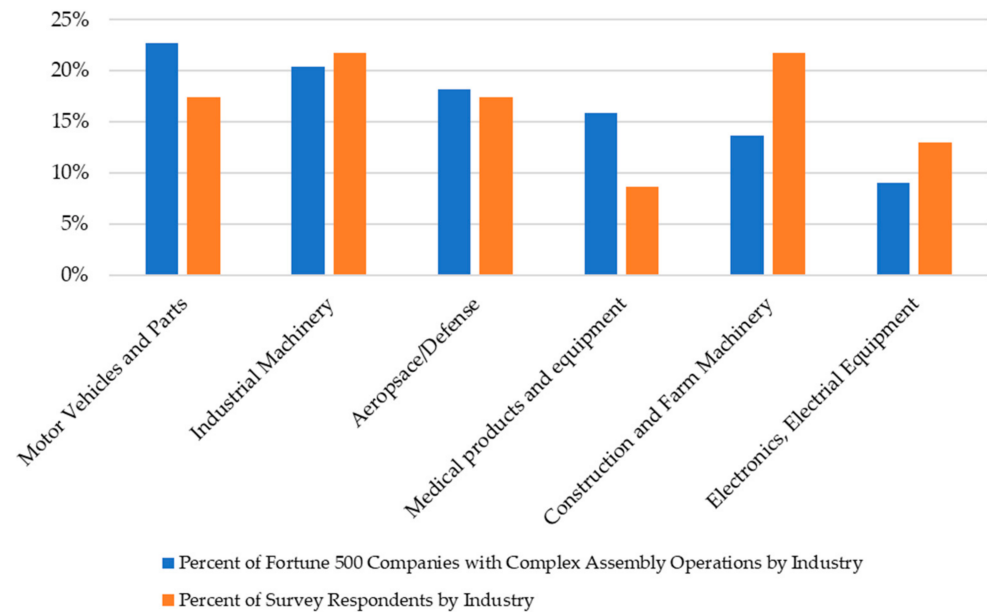
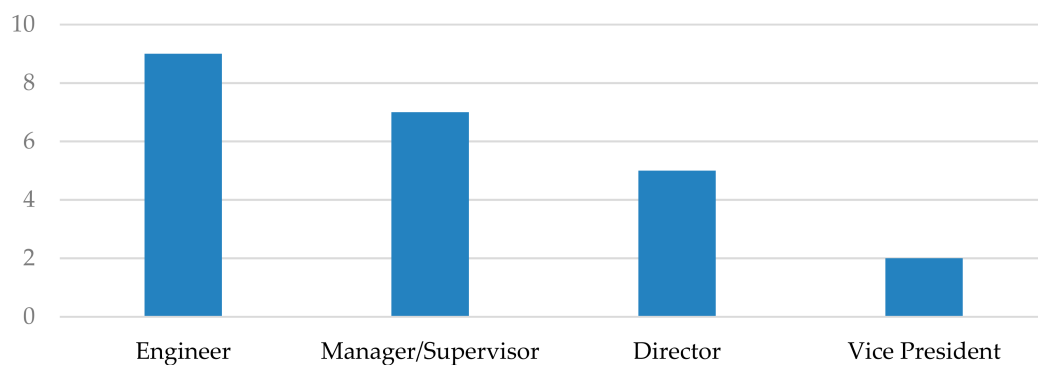


Figure 6. Industry distribution of respondents.



**Figure 7.** Comparison of survey respondents percentage by industry to Fortune 500 companies with complex assembly operations percentage by industry.

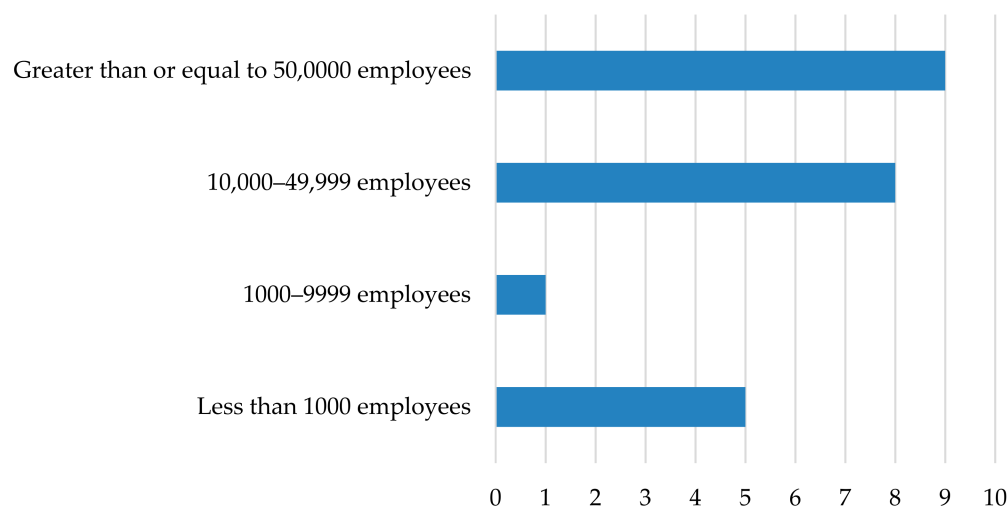
In addition to ensuring that the industries represented by the survey respondents were reflective of the population, the research team also wanted to ensure that the jobs of the survey respondents within those organizations were representative of the population. Due to the nature of organizational hierarchies, there are more engineers than engineering managers/supervisors, more managers/supervisors than directors, more directors than vice presidents, etc. When reviewing the survey respondents, as seen in Figure 8, the categorization of respondents follows this general trend, which demonstrates that the survey responses are not biased by any one job type when compared to the broader population.



**Figure 8.** Job title distribution of respondents.

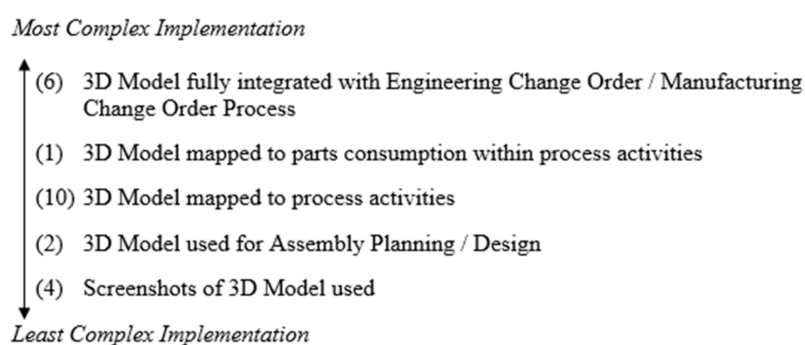
The research team also gathered information on the company size, by employee count, which was represented by the respondents. An interesting finding is that all respondents who worked for a large corporation said that their organization implemented the 3D product model in the assembly process. Figure 9 shows the breakdown of which size company the respondents work for based on employee count.





**Figure 9.** Company size based on employee count.

Noting that the majority of companies implemented the use of the 3D product model in the assembly process, further segregation into at which levels these companies implemented the use of the 3D product model in the assembly process is warranted. Figure 10 shows the responses in order of the most complex to least complex deployment of the 3D product model implementation in the assembly process.



**Figure 10.** Extent to which 3D product models are used in the assembly process.

The software most commonly used to deploy the 3D product model was software developed in-house (nine total responses). The next two highest response counts for 3D product model software use in the assembly process were PTC's MPMLink (six responses) and Siemens Teamcenter (five responses). Although this demonstrates that technology is available on the marketplace today to use the 3D product model in the assembly process, the respondents did list limitations that these software currently face. In general, the responses show that the ease of use, the ability to handle revision/change control, and the integration with other software/processes were common limitations experienced by the software developed in-house and the software available on the market today.

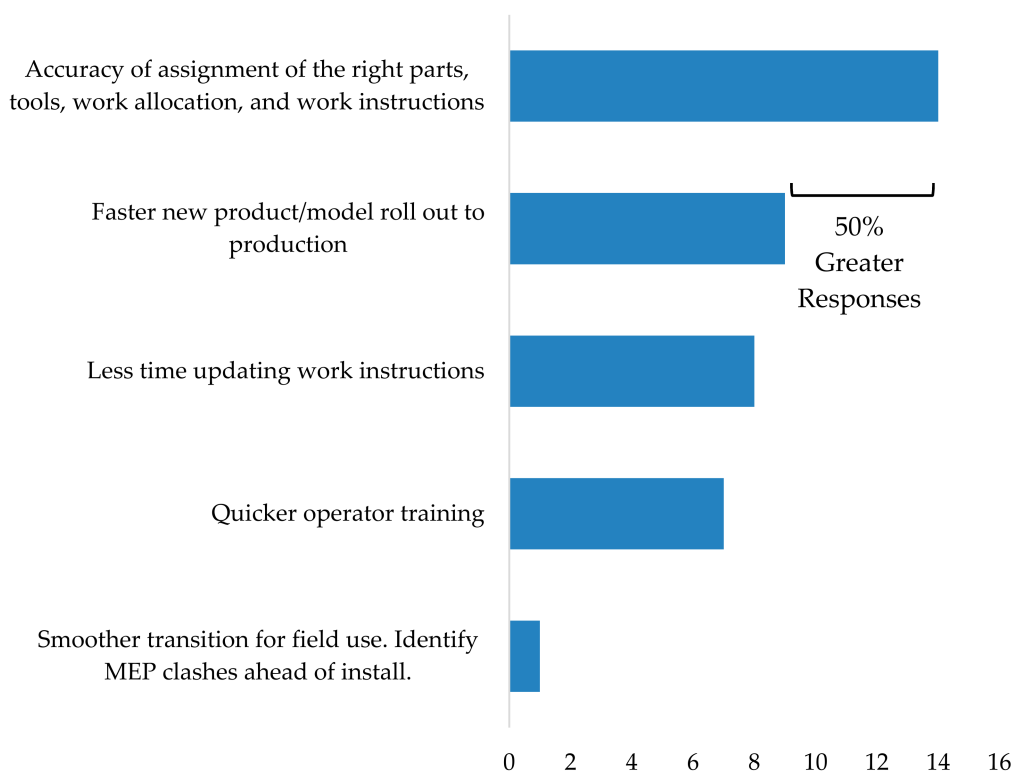
Prior to deploying the software that allowed these organizations to use the 3D product model in their assembly process, the organizations relied on varying ways to communicate information contained in 3D product models to the process planning and design team. These included physical mock-ups (8), Excel (7), simulation (7), and paper/Post-It notes (4). Note that the sum of these responses (26) is greater than the number of survey respondents (23), as survey respondents were allowed to select more than one way in which this information was communicated prior to implementing the software that enabled the use of the 3D product model in the assembly planning/design. For those respondents who

had implemented the 3D product model in the shop floor execution, they were also asked what they were doing to communicate the 3D product model information to the shop floor prior to their current state. All respondents to this inquiry shared that they used work instructions in some form to communicate this information; this included work instructions without visuals, words only (1), hard copy work instructions with pictures (3), hard copy work instructions with 2D drawings (6), and virtual work instructions without the 3D product model (6).

To transition to the 3D product model use in the assembly process, most organizations started small and scaled implementation (15), while some conducted a pilot study first (7). Only one respondent did a wholesale cutover to the 3D product model deployment and use in the assembly process.

Having the context of what companies were doing prior to implementing the 3D product model use in the assembly process and how they transitioned to their current state was important, as it provides insight for those organizations that have not yet implemented the 3D product model in the assembly process direction on how they might do so. However, more importantly is the value that the organizations have seen from implementing the 3D product model in the assembly process, as that is the incentive through which other organizations might consider doing the same. Figure 11 demonstrates that more respondents found value in the accuracy of assignment of the right parts, tools, work allocation, and work instructions relative to the other areas of value when implementing the 3D product model in the assembly process by a factor of more than 50%. This value driver was selected by over 60% of the survey respondents, and at 50% or greater of the total survey respondents at every level in the organization (engineering, manager/supervisor, director, and vice president). In addition, the accuracy of assignment of the right parts, tools, work allocation, and work instructions was selected by more than 67% of the participants across the aerospace, agricultural equipment, automotive, consumer appliances, and heavy industrial industries. These results indicate that the greatest potential for industry and academia to quantify the value of the 3D product model use in the assembly process is within the category of the accuracy of assignment of the right parts, tools, work allocation, and work instructions. Interestingly though, organizations with less than 1000 employees infrequently listed this value driver, meaning that developing models and quantifying the value for the accuracy of assignment of the right parts, tools, work instructions, and work allocation will likely be more beneficial to medium and large organizations. The results indicate that smaller companies would benefit greater by a model that quantitatively calculates the value of the 3D product model in the assembly process as it relates to faster new product/model roll out. The results also show that as the organization size increased, the number of value drivers indicated by the survey respondents increased. This points to larger organizations being able to better scale the deployment of the 3D product model in the assembly process and thus capture more of the value drivers accordingly.

Survey respondents further elaborated on the areas where they were finding value in the use of the 3D product model in the assembly process. Respondents shared comments on value gained such as “substantial”, “20:1”, and “multi-million-dollar savings in time to market”. Respondents shared that implementing the 3D product model in assembly processes “helps ensure no parts are forgotten in the work instructions for large, complex equipment” and created a “more efficient process for manufacturing engineers who develop the assembly process” and “reduced errors in assembly”.



**Figure 11.** Value of 3D product model in the assembly process by response count.

### 3.2. Company Has Not Implemented the 3D Product Model in the Assembly Process but Plans to

Although the majority of the survey respondents had implemented the use of the 3D product model in the assembly planning and design or assembly shop floor execution processes, a small number of respondents had not. Of the five survey respondents that had not yet implemented the 3D product model in the assembly process, four said that their organizations planned to. The four respondents self-identified as somewhat knowledgeable (2), knowledge (1), and very knowledgeable (1) regarding their level of knowledge of 3D product model use in assembly processes. The individuals had varying titles, were from companies that ranged in size, and were from varying industries. As such, similar to the organizations that had already implemented the 3D product model in the assembly process, no one industry, company, or individuals' level within the company seemed to dominate or skew the data.

The plans to implement the 3D product model in the assembly process also varied but were amongst the less complex phases of the implementation of the 3D product model use in assembly process implementations, including using only screenshots of the 3D model and mapping the 3D product model to process activities. This makes sense, as the next logical step for a company that is not using the 3D product model in the assembly process is to move to a phase that allows them to capture value by doing so but does not require the investment/scope of a more complex implementation. The technology that respondents said their organizations planned to use to accomplish this was software that was developed in-house, which is what the majority of the respondents that had implemented the 3D product model in the assembly process had done, and the evaluation of Assembly Planner as the software platform.

Without the 3D product model in the assembly planning and design process, the respondents shared that their organizations are currently using Excel (2), physical mock-ups (1), and 3D model snapshots (1) to communicate the information today to the assembly planning and design team. The information contained in the 3D product model

is currently being conveyed to the shop floor execution team through hard copy work instructions (3) and virtual work instructions that do not include the 3D product model (1). When the organizations do move from this current state to the future state of integrating the 3D product model in the assembly process, they expect to see value in areas ranging from less time updating work instructions (1); quicker operator training (1); accuracy of assignment of right parts, tools, work allocation, and work instructions (1); and faster new product/model roll out (1). One organization, who identified themselves as the smallest tier company available on the survey, shared that they believe implementing the 3D product model in the assembly process will save that organization \$50,000 per year.

### *3.3. Company Has Not Implemented the 3D Product Model in the Assembly Process and Does Not Plan to*

Only one respondent of the 28 responses analyzed said that they do not plan to implement the 3D product model in the assembly process. While this respondent shared that they are knowledgeable about the 3D product models use in the assembly process, that individual shared that they were unaware of technology solutions to integrate the 3D product model in the assembly process. It is the authors' aim that this paper will demonstrate such options to implement the 3D product model in the assembly process. Through the examples of how those organizations who have implemented the 3D product model in the assembly process transitioned to that state and the value that those companies have seen as a result, now other organizations such as the one noted here that are unaware of solutions to integrate 3D product models into the assembly process can see the value and direction through which they can do so.

## **4. Conclusions**

The use of 3D product models beyond product design is gaining traction in industry. Companies are moving away from 2D drawings and paper-based work instructions to take advantage of the value that 3D product models offer beyond product design in not only the assembly planning and design process but also in shop floor execution. This survey disproved the research team's first hypothesis that the majority of companies would fall under the category of having not yet implemented the 3D product model in the assembly process but planned to do so, as most companies had already implemented the 3D product model in their assembly process.

While companies recognize that there is inherent value in applying the 3D product models beyond just product design, up to this point, much of that value is still described in ways that are very qualitative in nature. The research team failed to disprove the second hypothesis: that the value of using the 3D product model in the assembly process is expressed qualitatively and unknown quantitatively. Thus, future research focuses should include developing a more quantitative approach to the value companies can expect to gain when deploying 3D product models in the assembly planning and design process as well as in assembly shop floor execution.

In one application of the 3D product model in the assembly process, a large agricultural equipment manufacturer transitioned from using Microsoft Excel to reconcile engineering change orders to using the 3D product model in combination with Proplanner's Assembly Planner. In the original process using an Excel sheet, the company spent almost seven hours updating work instructions following an engineering change order. In the new process, the company could complete the same update, with the 3D product model included in the assembly process work instructions, in just over two hours. This resulted in a savings of over four and a half hours per engineering change order and with over 1500 engineering change orders processed each year that is greater than 6500 man-hours saved per year. By integrating the 3D product model into the assembly process, and automating that through Proplanner's Assembly Planner, the organization is able to save hundreds of thousands of dollars as a result.

In another application of the 3D product model in the assembly process, a large automotive manufacturer uses the 3D product model to verify assembly interferences

before launching a product model change. The automotive manufacturer has a virtual assembly lab that allows them to complete such studies and check how a 3D product model change will work in the context of how it will integrate with tooling and the existing products already assembled onto the vehicle on the assembly line. The manager of the digital manufacturing group at this organization stated that the application of the 3D product model through the virtual assembly lab provides the company with a key competitive advantage over other automakers, where using the 3D product model in the assembly process saved millions of dollars in a new product launch.

Beyond these examples, the results shown in Figure 11 are substantial because they provide a framework through which industry and academia alike can start to develop a quantitative model for the value of the 3D product model in the assembly process. These five value areas can be used to determine the value of implementing the 3D product model on a given assembly line, which is then summed across assembly lines in a plant and across assembly plants within a company to get the enterprise value of implementing the 3D product model in the assembly process. The paper also demonstrates findings on which value drivers are more applicable to different size organizations and which value drivers are recognized the most in given industries. Then, via the survey results and the five value areas determined, this paper creates the building blocks for quantifying the value of the 3D product model in the assembly process in future research.

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