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Integrating assembly considerations into CAD: preliminary insights from industry practitioners

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Abstract

Multidisciplinary collaboration is key to product development; however, integrating multiple perspectives and design intent within the outcome of this process remains challenging. Although 3D product models are widely employed, they still lack relevant production details. A previous work established a coherent framework for enriching CAD files with assembly process information. This work offers the industrial perception and alignment of such a system through a preliminary impact assessment survey. Insights from experts and practitioners confirmed the solution's suitability to address these gaps, revealing organizational connotations and offering recommendations for improvement. These findings provide a user-centred perspective to guide the future implementation of the approach into established product development processes

Keywords: CAD file enrichment; assembly; impact assessment; collaborative product development, MBD

1. Introduction

Collaborative product development is essential for successful product realization. However, translating user demands and production constraints into a feasible product definition requires extensive communication efforts, including seamless information sharing across various engineering disciplines. Computer-aided design (CAD) tools have greatly facilitated the creation of digital product definitions, which can take the form of pure 3D models, known as model-based definitions (MBD), or a combination of 3D models and 2D drawings, as outlined in the ASME Y14.41-2012 standard [1]. A comprehensive product definition model includes annotations, attributes, and the CAD design model itself, incorporating geometry and additional supplemental elements, as defined in the ISO 16792:2021 standard [2].

In manufacturing, MBD has attracted increasing interest in recent years prompting CAD vendors to progressively develop tools that support its implementation. Both, industry and academia have focused on MBD's implementation methods, deployment strategies, and its anticipated impact. Preliminary studies suggest that MBD is a logical progression from 2D drawings [3, 4] with the potential to improve efficiency [3], ensure data consistency [4, 5], and enhance collaboration throughout product development [3, 6, 7]. Among the projected benefits are a potential reduction in product development time [8] and significant cost savings achieved through design element reuse [9].

Nevertheless, several authors have highlighted significant technical and organizational challenges associated with MBD implementation. From a technical perspective, incomplete standardization [4, 10] and low interoperability [8] remain major concerns, along with limitations in software capabilities [8, 11], high computational requirements [7, 12], visualization tools [13], and data-capturing methods [7]. Organizational challenges include specialized training [14–16], supplier readiness [7, 14, 16], resistance to change [7], and company adaptability [14].

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While previous works have primarily focused on high-level and theoretical approaches to MBD, this paper builds upon previous work by the authors [17, 18] to offer a more practical, user-centric perspective. By engaging with industry experts, this study gathers insights into real-world usability and the factors influencing the successful implementation of a functional MBD tool that displays an assembly-enriched 3D CAD model, specifically designed for handling processes in the assembly domain. Specifically, this work aims to evaluate the alignment of the recently developed assembly-enriched CAD model [17, 18] with current product development practices and identify areas of improvement to facilitate its adoption. At the same time, this paper collects the experts' and practitioners' insights regarding the anticipated impact and challenges for its implementation. To facilitate the analysis, the research aim has been segmented into four partial research questions: a) How aligned do industry experts believe the proposed approach is with current product development practices?; b) How do experts evaluate the impact of integrating the proposed approach on the efficiency, communication, and decision-making within the product development process (PDP)?; c) What challenges do experts foresee in implementing the proposed solution?; d) What potential improvements or adjustments do experts suggest for broader adoption?

With this aim, this paper begins by summarizing relevant academic work and providing an overview of the assembly-enriched CAD model developed prior to this study. It will then describe the applied methodology and present its findings. Finally, it will discuss the findings in the context of existing literature and provide concluding remarks.

2. Background

Collaboration has become a key component of engineering in current manufacturing contexts, as the involvement of multiple disciplines is required. Beyond concurrent approaches, collaborative engineering involves not only good communication and common goals but also shared learning, coordination, consensus, and co-creation [19]. In product development, collaboration is essential to establish an effective communication channel allowing design and production teams to consider production requirements early in the PDP [20]. Advancements in AI make capturing all stakeholders' PDP knowledge vital for reuse and management.[21].

A means to facilitate the capture and communication of knowledge generated during these collaborative PDPs is the creation of digital product definitions [4, 22]. Among these definitions, MBD has received the most attention, with some practitioners considering it a single source of truth [8] for product information. Several works have analyzed MBD's current status, potential, technical requirements for its deployment, and shortcomings, e.g., [5–9, 12]. Relevant claims have been made advocating for the need to understand workflows and relevant information across different lifecycle stages [6, 23], to emphasize design intent and the explicit communication of design rationale [9], to capture a wider range of product information beyond geometry, including functional requirements, manufacturing processes, and inspection data [22], and to apply standardized representations in MBD deployments to enable interoperability [24].

Relevant academic MBD implementations have also been developed. An MBD that extracts information from a CATIA proprietary model to populate a STEP AP242-compliant model was presented by [10]. Similarly, the suitability of the STEP AP242 standard to communicate geometric dimension and tolerance (GD&T) information in MBD was assessed by [25], while the work by [3] showcased an application of MBD to enable computer-aided tolerance analysis.

However, as stated by [11], the application of MBD to assembly processes has not yet been fully exploited, which is why this work centers on a previous study by the authors proposing a model to enrich 3D models with assembly information [18] and a tool for its implementation [17]. The proposed model leverages the STEP AP242 standard's capabilities to capture non-geometrical information while maintaining its semantics and relation to the product shape's geometrical elements and GD&T. This model is complemented with 3D annotations to present the information to the user and store it in compliance with the standard, enabling interoperability. The tool, developed as proof-of-concept, facilitates the addition of information related to handling activities for assembly processes. The present work continues this research by collecting expert feedback to identify areas of improvement from a user-centric perspective.

3. Methods

This study gathered qualitative data from professionals actively involved in product design, production preparation, and tooling and fixturing design to evaluate the potential impact of assembly-enriched CAD files on the PDP. Feedback was obtained on a functional prototype displaying an enriched 3D CAD model tailored for assembly processes.

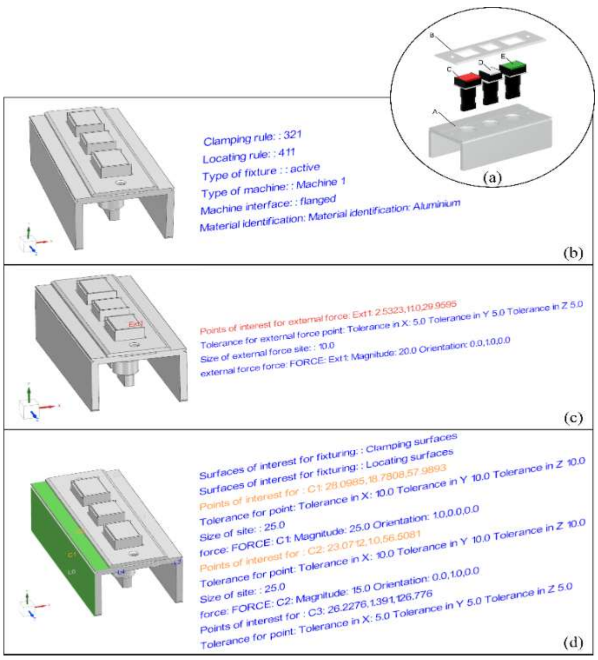

Fig. 1 Demonstrative case showed to the interviewees (a) Exploded view of the assembly components

To demonstrate the capabilities of the assembly-enriched CAD model proposed in [17], a lamp kit assembly with five components (Fig. 1) was created using the tool developed in [18] and use as a case study. The model was populated with fixturing information to showcase how the proposed approach presents data to users and the advantage of using a standardized model in a neutral CAD format within commercial CAD systems. This example served as a basis to prompt discussion with experts participating in a preliminary impact assessment through semi-structured interviews. These interviews were designed to encourage open discussion and capture the perspectives of the participants on the prototype's usability, impact, and implementation challenges.

The details of the interview design and participant are summarized in Table 1 and Table 2, respectively. Interview data were analyzed using thematic analysis coded in MAXQDA, with a focus on identifying recurring themes, answering trends, outliers, and other significant observations.

Table 1 Specifics of the interview design

Sample	10 participants (See Table 2 for details)
Interview type	Semi-structured interview
Interview language	English
Interview mode	Online meeting via Zoom platform
Interview structure	- Personal introductions - Description of the context and objective of the interview - Brief presentation of the research, including a demonstration of the proposed solution - Application of the questionnaire / discussion.
Transcription type	Verbatim
Transcription method	Software-assisted based on audio recordings using Microsoft Word transcribe function.
Analysis method	Content analysis: thematic analysis
Analysis tool	MAXQDA

Table 2 Description of the participants. Companies A, B, and C are large manufacturing firms with over 5,000 employees. Companies B and C have highly developed PDP workflows, while Company A's are less mature.

No.	Role	Experience *(years)*	Interview duration *(min)*	Company
1	Production system designer	3	47	A
2	Tool designer	1	55	B
3	Manager	18	62	B
4	CAD expert	11	63	C
5	Manager	25	61	C
6	Manager	15	53	B
7	Product designer	21	51	B
8	Manager	35	53	B
9	Tool designer	30	55	B
10	Product designer	5	60	B

4. Results

To assess the industry alignment, potential improvements and anticipated challenges for implementing the proposed approach, a series of expert and practitioner interviews were conducted. Data collection and analysis were performed according to the methodology described in Section 3.

4.1. Found codes, categories and themes

Interview data were analyzed using thematic analysis, resulting in the identification of several codes grouped into eleven categories, as depicted in Fig. 2. From these categories, five key themes emerged (Fig. 3): four aligned with the research questions and one presenting the participants' assessment of the proposed approach.

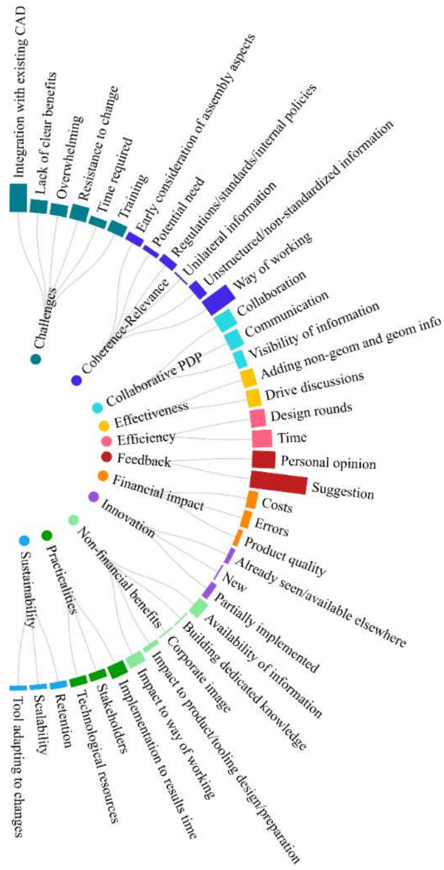

Fig. 2 Derived codes and categories

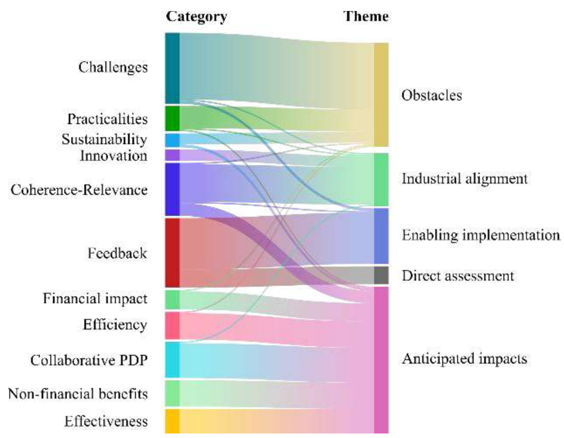

Fig. 3 Relationship between the defined categories and themes

4.2. Findings within the identified themes

Themed segments of the interview served as the basis for answering the research questions. The following sections outline the condensed results for each theme.

4.2.1. Alignment to current product development practices

To examine the alignment of the proposal, the analysis began by identifying common practices in product development across the themed segments. Some of these practices could be supported by the proposed approach, while others present potential obstacles to its implementation. Among the practices that could be supported, early integration of manufacturing requirements into product design and the participation of multidisciplinary teams stood out. Regarding hindering practices, high dependency on CAD vendors and the continued use of 2D drawings for communication with suppliers were mentioned. Other practices that could impede the implementation of the proposed approach include preferences for proprietary data formats over neutral standards, challenges in managing non-geometric information within PLM systems, fragmented workflows, and informal communication practices. Table 3 summarizes the identified practices, and the alignment of the proposed solution based on the interviewees' statements.

Table 3 Identified practices and their alignment with the proposal. Numbers in parentheses indicate the number of experts who mentioned the practice. In column Alignment: A= aligned, NA= not aligned.

	Identified practice	Alignment
P1	Early inclusion of manufacturing aspects (2)	A
P2	Multidisciplinary design teams (3)	A
P3	Even when product information is available, it is hard to find (1).	A
P4	Fragmented workflows (2)	A
P5	Informal communication of design decisions (2)	A
P6	Company prefers managing non-geometric information in the PLM system, avoiding PMI annotations (1).	NA
P7	High dependence of the companies on their CAD vendor (4)	NA
P8	Neutral file formats, e.g., STEP, are not used for internal communication or during PDP (1)	NA
P9	Use of 2D drawings is still extensive when dealing with suppliers (4)	NA
P10	Use of non-standardized documents and templates (1)	A
P11	Multidisciplinary teams are mainly at high levels and are not spread to all departments (1)	A

4.2.2. Impact of integrating the proposed approach

A summary of the impact anticipated by the interviewees according to the identified practices is presented in Table 4.

Regarding the impact of the proposed approach, the experts anticipated several potential economic and non-economic benefits. Economic benefits include potential savings derived from error reduction and enhanced product quality. Time savings during design were also mentioned, depending on the assembly complexity and the time consumed in populating the model. Some experts anticipated savings derived from fewer design review rounds and the inclusion of non-geometric information. Non-economic benefits were primarily related to improved information management and the availability of information throughout the product lifecycle. However, the interviewees highlighted that the more seamlessly the proposal integrates with current processes, the greater its potential benefits. Since enhanced internal and external communication was a big proportion of the anticipated non-economic benefits, it was considered a separate type of impact in the analysis.

Table 4 Foreseen impact according to the experts. Shaded cells highlight impacts with the most expert support. In column Type: E=Economic, NE= non-economic, C=Improved communication.

Practice	Potential impact	Type
P1	Saving from enhanced product quality (3)	E
	Economic benefit from incorporating non-geometric information, depending on product complexity (1)	E
	Adverse economic effects if machine restrictions or equipment specifications are determined too early, potentially leading to purchasing more expensive equipment than necessary for executing the tasks (1)	E
P2	Help drive the discussions between the main stakeholders (design and production) (5)	C
	Potential enhancement to internal collaboration (5)	C
	Reduced redoing or product changes at advanced stage (2)	NE
	Savings attributed to "doing things right the first time" (1)	E
	Aid in building dedicated knowledge and corporate image (1)	NE
P3	Benefit from adding non-geometrical information by having all the information in one place (5)	NE
	Having visible information would enable a more collaborative PDP (4)	C
	Greater benefits to complex design projects (1)	C
	Having the information available would allow early problem identification and solving (1)	C
P4	Savings in the long term derived from error reduction (5)	E
	Time reduction in the PDP (3)	E
	Improvements to their overall workflow (1)	C
	Reduced production deviations (1)	E
	Greater applicability to large projects rather than small ones (1)	C
P5	Unified understanding and increased accessibility to the information would improve communication (5)	C
	Slight reduction on the number of design review rounds (3)	E
	Having explanatory texts as non-geometrical information would contribute to improved communication (1)	C
	Having the information available to other people beyond the designer (1)	C
P6	Overall time would remain unchanged, as the time spent adding the information would be compensated along the PDP (4)	E
	The availability of information throughout the product lifecycle ensure it remains accessible and outlasts the designer (4)	NE
	No direct benefits in the way of working because of the changes required to introduce the proposal and the fact that the company has access to the information using a different approach (2)	NE
	PDP time reduction would depend on the complexity of the assembly, given the time required to input the data (1)	E
P7	Proposal usage is conditioned to its integration with other software (1)	NE
P8	Standardizing the way to represent the information could improve collaboration with the supplier (1)	C
P9	Little impact on product/tooling design/preparation (4)	NE
	Communication improvements would depend on the company's adaptability and the variability of the product (1)	C
P10	Capability to add standardized and structured information for both their internal use and sharing information with the stakeholders (2)	NE
	Support standardizing the product information, reduce unilateral information addition, and enhance compliance with regulations and policies (1)	NE
P11	The proposal could be more effectively exploited by small and medium enterprises, as it could enhance their workflows and positively impact their business (1)	E
	Proposal use could be limited to critical components (1)	NE

4.2.3. Foreseen challenges and suggested improvements for broader adoption of the proposed solution

The interviewed experts and practitioners also identified several challenges related to the proposed approach from both technical and organizational viewpoints. Critical technical challenges included CAD software compatibility with existing platforms and current computational equipment, integration with suppliers' systems, and the additional workload on the design team. Similarly, the need for involvement at all organizational levels and overcoming resistance to change were identified as organizational challenges.

During the analysis, the challenges were classified as technical or organizational and linked to the recommendations made by the experts to address them; the condensed results are shown in Table 5.

Additional suggestions made by the experts included:

- Adding information about the assembly sequence to help predict the effect of each assembly step.
- Implementing mechanisms to facilitate sorting and filtering of information when displaying the 3D model.
- Maintaining a history log to enable traceability.
- Allowing to add environmental characteristics and special process needs.
- Expanding the approach to other production activities influenced by assembly, e.g., packaging and logistics.
- Integrating the model with external applications enabling instant calculations or simulations.

Finally, in terms of innovation, four interviewees implied that the proposed approach was not a novelty for them, as their companies already included critical text annotations in 2D drawings, although they couldn't mention a similar application in 3D models. Two participants reported seeing a similar approach in a different context or external to their company. Overall, nine out of ten interviewees considered the implementation of this proposal beneficial to the industry.

5. Discussion and concluding remarks

This research aimed to gather insights from experts and practitioners on implementing an assembly-enriched 3D model to realize an MBD for assembly. Semi-structured interviews were conducted following a live demonstration of the proposed approach. During these interviews, the term MBD was intentionally avoided to prevent confusion among users who may not be familiar with it, as reported by [23].

Regarding the research questions, the findings confirmed the alignment of the proposed approach with current industrial practices. The experts expressed that the proposed approach would support current practices implemented for collaboration (P2, P4, P11) and information sharing (P1, P3, P5). In contrast, current practices derived from companies' dependency on specific CAD platforms (P7, P8) will mostly hinder its implementation. This dependency was confirmed when some interviewees raised concerns about the model's performance across different platforms, even though the approach was developed under a well-established international standard, and ensuring full compliance with international standards falls within the responsibility of CAD vendors.

An unexpected finding was that, in the current state of the proposal, experts foresaw little to no positive impact on tooling design/preparation. Instead, adverse economic effects were predicted if machine restrictions or equipment specifications were set too early, potentially leading to the purchase of unreasonably expensive equipment.

Table 5 Identified challenges (ranked by expert consensus) and suggested solutions. Numbers in parentheses indicate the number of experts who agree with each statement. T= technical challenge, O= organizational challenge.

	Challenge	Suggestion
T	Compatibility with existing CAD software and potential investments in technological equipment (7).	Further develop means of integration to current existing CAD platforms
O	Resistance at the beginning of the implementation (6).	Make all the team aware of the benefits derived from the proposal to reduce resistance. Remark on the benefits to the team, not only to the company.
O	Defining a time to see results derived from the implementation of this proposal is challenging (6), depending on the nature of the products.	
O	Lack of perceived benefits from this proposal. The company must effectively convince, support, and motivate the design teams to achieve positive results (5)	Present case studies for different teams related to their specific activities so people can easily understand how to add this information.
O	Level of competence would be required to take full advantage of the proposal (4)	Involve all the team in the implementation and make them define a common terminology and nomenclature for the required information
O	Difficult to foresee a retention time if good results are obtained; probably at least mid-term (4).	
T	Keeping a seamless integration to the suppliers' systems is essential to their cooperative work, but simultaneously, software platforms cannot be imposed on them (3).	Establish an option to transfer the 3D annotation to a 2D drawing when the user needs to share the information with an external party in this way.
O	Resistance due to the required time to fill in the information (3)	Have a simplified list of characteristics according to the product's needs
O	Additional workload placed on the design team to include the information manually (3).	Implement it gradually to prevent the workload from becoming overwhelming for the team.
O	People's involvement. The company would need to include all organizational levels in this change, emphasizing the operators, to include their practical knowledge in the process (1)	Assess the benefits of implementing this proposal according to the team size. In their opinion, small teams cannot get enough benefits from this proposal
T	Time required when transferring information between product versions and design iterations in the lack of an automatic method (1).	Provide templates to facilitate the creation of new parts with predefined characteristics. Be able to transfer the information added in the master part to a new product variant.

Considering the challenges, the data confirmed CAD software compatibility as the significant technological concern, as indicated by [3]. On the organizational side, resistance to change, supplier readiness, and integration of the approach into established workflows were mentioned, consistent with [7, 15].

This study also revealed the challenges from the end-user perspective. Optimal information presentation, potential information overload, overwhelming workload on the design team, and the role of assembly complexity in these matters were deemed relevant factors to consider in this area. Furthermore, interviewees expressed concerns about the time required to transfer information to other engineering applications, new PDP projects, and between product variants.

Several suggestions aligned with those determined in previous works were also collected, such as motivating collaboration among multiple stakeholders, providing adequate training, and effectively communicating the approach's benefits before its implementation. Moreover, the interviewees mentioned that the proposal could be more effectively exploited by companies with less mature PDPs and small and medium enterprises, as it could enhance their workflows and positively impact their business.

In conclusion, although the current study is based on a small sample of participants, the findings suggest that the proposed approach does align with current industrial practices and fulfills requirements identified by previous authors. However, the expected benefits, such as enhanced information flow and improved collaboration, will depend on the company's efforts to foster multidisciplinary PDP and integrate the approach at all organizational levels.

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