18th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Planning and Implementation of a Prototype for Validating the Need for an AR Application in the Context of Product-Production-CoDesign

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Abstract

The relevance of AR applications in production, particularly in the (dis)assembly of intricate systems, is increasing. AR proves beneficial in incorporating assemblability insights early in the developmental phase. However, its utilization in Product-Production-CoDesign (PPCD) is currently limited because the relevant stakeholders need to be convinced of the benefits of solutions and there is therefore a need for these applications. Therefore, the continuous validation of this need is relevant, but existing products cannot fulfil this. Prototypes offer an opportunity to integrate stakeholders into this process at an early stage. In this publication, a possibility of stakeholder integration with the help of prototypes in a very early phase of development projects is presented. The benefits which could add value compared to the current market are implemented in a prototype based on elements from references. On the basis of this publication, requirements can be validated in very early phases of development projects by assessing the benefits and checking them in prototypes. This allows the development of a new AR application to begin based on a valid need.

Keywords: Validation, stakeholder need and benefits, AR prototype, right prototype

1. XR as an Enabler of Product-Production-CoDesign?

According to Albers et al., "[PPCD -] Product-Production-CoDesign describes […] the iterative planning, development, and realization of products and the associated production system […]" [1]. Furthermore, PPCD supplies guidance aimed at facilitating comprehensive and synergistic collaboration between product engineers and production system engineers. To enable this collaboration, there must be a possibility to exchange insights between the engineers about the product and production system at an early stage. [1] Extended Reality (XR) is a promising technology for this case because the motivation for using XR in industry is to make several scenarios tangible and accessible. These scenarios are intended to provide relevant stakeholders with early insights regarding the product. Scenarios include interactive training opportunities in VR or opportunities to show or animate 3D models in AR. The latter in particular is used in assembly planning to gain a deeper insight into the assemblability of the product and the associated processes. This scenario has been implemented in the industry for years using videos successfully. The reason for this is that videos are easier to use and more attractive in terms of price compared to AR applications. As a result, the industry needs to be convinced of the implementation of AR applications and the thought that they have value-adding benefits for example compared to videos through their interaction and immersion

and, therefore, a valid need. [2] These AR applications must be continuously validated during development [3].

2. Validation with prototypes in early development phases

Albers describes validation as the central and knowledge-generating activity in the product engineering process [4]. Validation deals with the question of whether the right product is being developed, whereas verification addresses whether the product is being developed correctly [5]. To determine the validity of a product, a mere comparison of the specification and the product is insufficient (verification). Instead, it is necessary to continuously relate a development status to the future use of the product through direct or indirect integration of relevant stakeholders. [6, 7]

This continuous validation plays a significant role in the context of product engineering, especially the continuous validation of the need for a product [3]. Schwarz et al. introduce four fields of action (FoA) to meet the challenges of continuous needs validation [8]:

- FoA1: Enabling Prototyping in the Early and Continuous Validation of Product Profiles,
- FoA2: Integrating stakeholder as a Part of the Early and Continuous Validation of Product Profiles,
- FoA3: Managing Variety in the Early and Continuous Validation of Product Profiles,
- FoA4: Interpretation of Early and Continuous Validation of Product Profiles.

Thereby, Schwarz et al. point out that these field of actions need to be addressed by design support to enable the early and continuous validation of product profiles [8].

The product profile is a model of a bundle of benefits that makes the desired provider, customer and user benefits accessible for validation and explicitly specifies the solution space for the design of a new product, system, or service. A bundle of benefits is understood here as an entirety of products and services that is created with the purpose of being sold to a customer and creating extended benefits for them. A product profile is a solution-open description of the product or system, as no requirements, functions, or design elements of the solution are specified [9].

Product profile validation through references is based on the model of SGE – System Generation Development by Albers, which is based on two hypotheses: Every development is based on references (I) and every development is based on the variation types of carryover, attribute, and principle variation (II). This implies that every development does not start from scratch but is based on a reference system. The reference system describes the sum of the references used for the development of new subsystems. References can include competitor products, previous generations, or systems from research, thus representing development increments that have already been validated in different contexts. [10]

Prototypes can be seen either narrowly as physical, functional artifacts or broadly as all types of product models [11]. Prototypes serve as a means to indirectly integrate stakeholders, as they provide feedback through interaction with the prototype for its intended use [6, 7].

3. Research Profile and Preliminary Project Results

The application of AR solutions in PPCD holds great potential in the interdisciplinary work in the field of assembly. However, the implementation of these applications has failed to this date because the product profile is not valid. The reason is that the benefits provided by new AR applications do not offer added value compared to current solutions and are neither perceived as improvement nor do they trigger excitement in relevant stakeholder. It follows that the need or product profile for a new AR application is valid if the benefits generate an added value triggering excitement or perceiving improvement based on the Kano model [12, 13]. Such excitement or improvement is to be evaluated early, yet existing validation approaches struggle to perform this effectively in the early phases of development projects. Prototypes provide a viable means to evaluate this excitement and improvement through indirect stakeholder integration. [8] In early stages of development projects, limited or no information often makes it difficult to plan and implement a right prototype [14].

Therefore, the aim of this publication is to plan and implement a right prototype for the AR application to validate the product profile in the early phases of a development project. The operationalization of this objective led to the following research questions:

I. How can benefits be assessed with existing models to identify value-adding benefits to point out the added value?

II. How can the right prototypes based on the value-adding benefits be planned?

III. How can the right prototype be implemented based on the prototype understanding?

To address the research questions, a real development project was used as a practice-oriented research environment. This project can be located in a very early phase and focused here on validating the need. In this development task, the aim was to validate the need for an AR application in intelligent assembly planning and to develop an initial prototypical AR implementation to consider the assemblability of systems and products during early development activities in the context of the PPCD. An intelligent assembly planning tool, which specified the interfaces for the AR application, was already available. This tool allows users to upload 3D models on the web, create animations of the assembly steps, and subsequently produce a video or a guide. A potential and a reference analysis were conducted within the project beforehand. During the potential analysis, a product profile was created, and the benefits modelled therein were identified.

The results of the potential analysis indicated that there is a demand for an AR application that visualizes assembly processes simplified, flexible and animated in space to enhance joint, interdisciplinary discussions about the product. Such an application would be particularly beneficial in assembly phases in companies with complex or frequently changing assembly processes and would support, among others, assembly and maintenance personnel by enabling them to quickly take a look at the assembly process, thereby achieving a better spatial

understanding of the product and its assembly. This understanding, as well as the stimulation of discussions through the new visualization possibilities, also has its advantages in the Product-Production-CoDesign. Assembly planning is integrated early into the development process by allowing production or assembly experts to discuss and concretize assembly and assembly feasibility with developers based on the new visualization options. From the potential analysis and the subsequent reference analysis, a total of 16 benefits (B1-B16) of a new AR application was identified (see Table 1).

Table 1. Numbering (#) and description of the identified benefits

#	Description of benefits
B1	Discussion during assembly for potentials
B2	Quick visualization of the assembly
B3	Simple 3D presentation of the animation
B4	Show effects during presentation
B5	Joint, interdisciplinary discussion on a product
B6	Quickly show animations from different directions
B7	Live remote broadcast to experts
B8	Hands-free operation through wearables
B9	Automated creation of parts lists
B10	Real-time adaptation of assembly plans
B11	Automation of assembly planning
B12	Simple operation of the creation of assembly plans
B13	Locally distributed collaboration
B14	Adding digital information to physical components
B15	Derivation of assembly plans from 3D representations
B16	Flexible access to 3D data

Based on the product profile from the potential analysis, eight references were identified in the reference analysis. These references for the development of the AR application come from the products and applications of competitors in the same and other industries, as well as from the company whose application under development is being considered here. The references include AR applications that…:

- …enable 3D-viewing and animations of assembly processes and support the creation of assembly plans (Reference R1-R2),
- …allow for the AR representation and animation of CAD data (R3-R4),
- …are used by companies to support assembly and maintenance personnel by adding virtual elements to the real environment using tablets and wearables (R5-R8).

The references (R1-R8) were analysed based on their functions, use cases, and usability. The benefits identified in the analyses (B1-B16) and the references (R1-R8) are the basis for answering the research questions.

4. Assessment of the Degree of Fulfilment for Identifying the Value-adding Benefits

The term "value-adding benefits" refers to the benefits that are currently minimally or not at all met in the market through existing products or competitive products from both the same and different industries, such as the AR application.

To identify these value-adding benefits, references must be classified based on whether they originate from the same company as the product in development (R2), a competitor within the same industry (R1; R6), or a competitor from a different industry (R3-5; R7-8). This classification is crucial because it precedes the evaluation of the extent to which each benefit is fulfilled by the references (see Table 2). Fulfilment by an internal company reference is deemed more critical for the evaluation than that by a reference from a different industry, as the added value in the market of the product under development diminishes.

Table 2. Assessment of the degree of fulfilment of a reference (grey numbers on the left) in relation to a benefit (grey numbers on top) using a scale from 1 (very low, red) to 5 (very high, dark green)

		Benefits B#															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
References R#	1	3	3	3	3	3	3	1	1	5	4	4	5	3	3	5	3
	2	3	3	3	3	3	3	1	1	4	5	4	5	3	3	5	3
	3	4	3	4	4	3	4	3	2	3	3	3	4	4	3	3	5
	4	3	2	3	4	4	5	4	5	3	1	1	3	4	2	2	2
	5	2	3	3	2	1	2	5	5	1	2	1	2	3	5	2	2
	6	2	3	4	4	1	3	5	2	3	3	2	3	2	4	2	3
	7	2	2	2	2	1	2	4	5	1	1	1	2	2	4	3	3
	8	2	2	2	2	1	4	3	4	1	1	1	2	4	4	2	1

From the classification of the origins of the references and the evaluation of the fulfilment extents, a quantitative value was calculated to identify the value-adding benefit by calculating the average of the values assigned using Fig. 1.

Origin of the Reference	Rating: Level of Fulfillment				
	1	2	3	4	5
Other Industry	1	1	2	2	3
Same Industry	1	2	3	3	4
Same Company	1	2	3	4	5

Assigned Values for Added Value

Fig. 1 Assigning Values for the Assessment of a Quantitative Value for Identifying Value-Adding Benefits

5. Planning the Right Prototype Based on the Degree of Change of the Benefits

In the following chapters the assessment of the degree of change and the planning of the right prototype is presented.

5.1. Assessing the Benefits' Degree of Change

From the assessment of the degree of change, the risk associated with the further development of a reference to fulfil the respective benefit can be elaborated. For the assessment of the realizability, the type of variation was first considered based on the model of SGE System Generation Development [10]: Principle Variation (PV), Attribute Variation (AV), and Carryover Variation (CV). Furthermore, it is important to consider whether the change affects the requirements, a function, or the embodiment (logical/physical) of the product. This subdivision into requirements, function, and embodiment is based on the RFLP concept [15] and the reference model [16]. With these considerations, the benefits can be evaluated as shown in Fig. 2.

Fig. 2 Assigning Values for the Assessment of a Quantitative Value realisability of the benefits

The assessment of the degree of change, based on the classification shown in Fig. 2, yielded the following results (see Table 3).

Table 3. Assessed benefits regarding their realisability.

Benefits B#	1	2	3	4	5	6	7	8
Rating (see Fig. 2)	6	6	5	2	8	8	3	8
Benefits B#	9	10	11	12	13	14	15	16
Rating (see Fig. 2)	2	1	2	1	2	6	2	2

These assessments of benefits in terms of both the degree of change and the degree of fulfilment are the foundation for modelling the prototype profiles.

5.2. Planning the Right Prototype

From the assessment of the degree of fulfilment and the degree of change of the benefits, recommendations for action can be derived to evaluate the benefits using the Kano model.
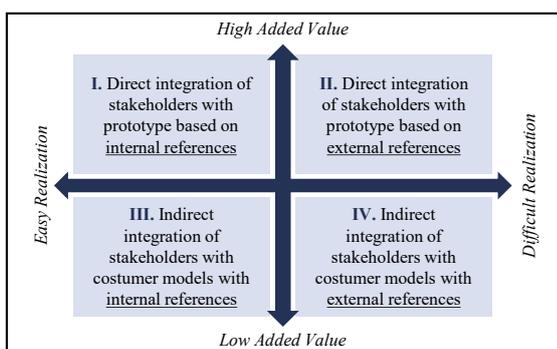

Fig. 3 Recommendations for action for the further validation using prototypes based on the assessment of the benefits

In these action derivations, two decisions are made: indirect vs. direct stakeholder integration and prototypes from industry-internal references vs. industry-external references. As a result, four recommendations for action can be deduced (see Fig. 3).

A direct integration of stakeholders is suggested in the lower half because the benefits are already met by many market references, thus only necessitating an assessment to determine if the benefits are reverse or indifferent. For supporting direct stakeholder integration, competitive products can be used when significant changes are required, or own products if the realization is easy. In the upper half, prototypes are used (indirect stakeholder integration) to evaluate whether the benefits are perceived as improvements/excitements, indifferent, or regressive. For high degrees of change, products from different industries are used as references to adopt elements for the prototype. For minor changes, references within the company or the own industry are suitable.
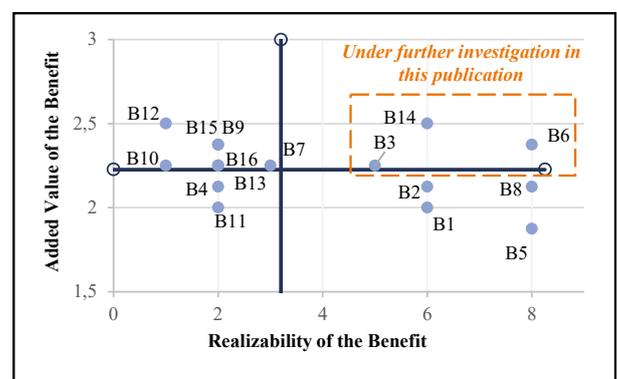

Fig. 4 Plotting the benefits in terms of their level of realisability (x-axis) and added value (y-axis) and dividing them into four areas for recommendations for action for the desired benefit

Based on the assessment of the degree of fulfilment and the degree of change, the following can be defined to plan the right prototype according to an existing understanding [17]. It distinguishes between need-appropriate and situation-appropriate aspects. Need-appropriate aspects refer to the objective of the prototype (purpose, stakeholders, outcome). A situation-induced prototype focuses on aspects describing the current situation (available resources, competence profile, conditions). Using these aspects, the right prototype can be described, which is established addressing recommendations for action I & II. The description of the right prototype based on recommendation for action II is introduced in the next paragraph, with the implementation in Chapter 6, starting with the need-appropriate prototype, followed by adding the situation-appropriate prototype to establish the right prototype.

The purpose of a prototype describes the reason why it is created, correlating for example directly with the validation need and objective [18]. In this case, based on the recommendations for action, the validation need arises from the uncertainty regarding whether benefits B3, B6, and B14 are perceived as improvements, excitement, indifferent, or even rejective. From this, four validation objectives related to a benefit can be defined (see Fig. 5). The target group of a prototype includes the stakeholders who will interact with the prototype based on its purpose. In this prototype, the stakeholders are the users, product developers, and production

system developers. They have a high affinity for these tools, but a familiarisation period during the prototype testing must be considered, as not all have previously interacted with AR technologies. During testing, both developer groups provide feedback on the derived validation objectives to fulfil the validation needs. This feedback represents the outcome, which describes the classification according to the Kano model [12, 13]. It is expected that using the prototype will lead to an unambiguous classification of the benefits in terms of excitement, improvement, indifference, and reversibility for each stakeholder individually.
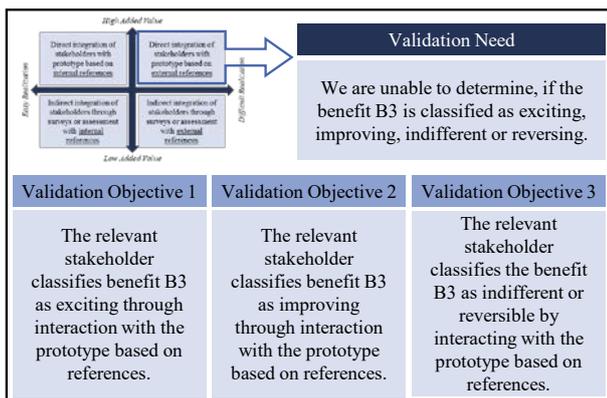

Fig. 5 Example of validation need and the derived validation objectives for benefit B3

The available resources for the AR prototype are limited to the use of tablets, as AR head-mounted displays are not widely spread. Furthermore, existing solutions must be utilized for implementation because developing a new one would be too intricate and there is no defined idea yet due to the solution-openness of the product profile. The competence profile of the prototype developers is limited to developing virtual prototypes and experience with the most common tools. Two conditions existed for creating the prototypes. Firstly, the virtual prototypes had to integrate files that could be derived from the existing assembly tool because post-processing would be too cumbersome. Secondly, based on the phase in the development project, only elements from the references should be used, and no new solution components should be developed.

Starting from this description, the prototype development team discussed the implementation of the AR application to achieve the validation objectives and meet the validation needs, followed by the construction of the prototype using elements from the references.

6. Implementation of the Prototype Based on the Description of the Aspects of a Right Prototype

The implementation of the prototype was divided into four phases according to RFLP [15]. In the R(equirements) phase, based on the benefits, design requirements were derived from references identified in the reference analysis to derive relevant functions in the F(unction) phase. This created a set of functions and corresponding references, which were used in the L(ogical) phase to assemble function-fulfilling elements from the references into a concept on paper for further elaboration.

This concept was then transformed into a working AR prototype in the P(hysical) phase for prototype testing. In the following, the R, F, and L phases are demonstrated on benefit B3 as an example and the entire prototype as the outcome of the P phase is presented.

For benefit B3, based on its assessment of the degree of fulfilment (see Fig. 2), references R3 and R6 were chosen. Four requirements were derived from the reference analyses. The prototype should include a selection feature for quickly switching between different models and ensure the model remains stationary (R3). Additionally, quick toggling rather than sequential jumping should be implemented, and no assembly information should be displayed (R6).

The following functions were then adopted from the references to meet these requirements:

- F1: The AR prototype displays multiple selection options for different models.
- F2: The AR prototype can jump forward and backward by 10 seconds in the animation.
- F3: The AR prototype pauses the animation.
- F4: The AR prototype resets the animation.

These elaborated functions and requirements adopted from references R3 and R6 were incorporated into a concept sketch. This concept sketch was subsequently transformed into a prototype (see Fig. 6).
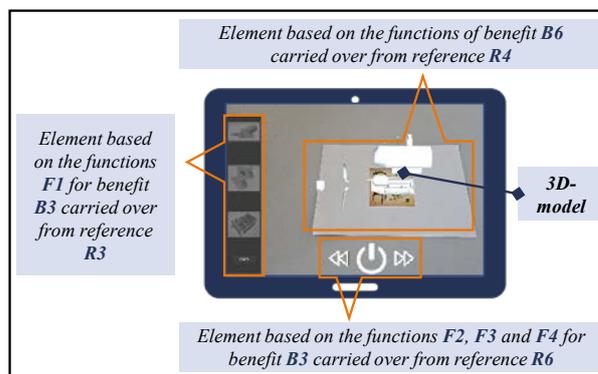

Fig. 6 Own illustration of the AR prototype in the P phase for adressing the validation need

7. Summary and Outlook

In summary, the results addressed all three posed research questions effectively. For the first research question, an assessment scheme was developed using existing models, which facilitated the theoretical assessment of value addition for product profiles by examining the degree of fulfilment and the resultant value-adding benefits. This schema allows for an objective and understandable evaluation of value-adding benefit. Regarding the second research question, based on an assessment of realizability and fulfilment degree, four recommendations for action were defined to derive validation needs and objectives that can be addressed or achieved with an early and right prototype. The implementation of the prototype (third research question) was achieved without new development by adopting elements from references in four

phases (RFLP). These outcomes enabled the planning and implementation of an AR prototype enabling the validation of the product profile, thus achieving the publication's aim. These steps provide an initial process to validate product profiles in early development phases based on the fields of action by Schwarz et al. [8] (see Fig. 7).
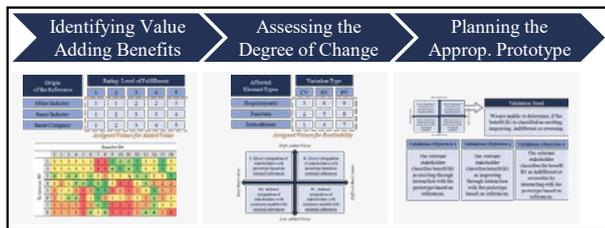

Fig. 7 Initial Process for Validation of Product Profiles in Early Development Phases

Through the designed approach, three of the four fields of actions are addressed. Only FoA3 Managing Variety in the Early and Continuous Validation of Product Profiles is not addressed due to missing variety. However, some potential questions remain unanswered. Further tests with the derived AR prototype need to be carried out to meet the validation needs and goals. Also, the transferability to cyber-physical systems remains to be examined, because these systems are more complex. Especially, the development of hybrid or even purely physical prototypes in cyber-physical products are more complex, because of cost and time factors. Their transferability needs to be applied in real development projects within practical-oriented environments in which cyber-physical products or systems are being developed. Out of this application, the presented process could be adapted for validating the product profiles of cyber-physical.

Acknowledgements

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