A Multi-Dimensional Analysis of the Current State of Research into Globally Distributed Product Development

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Abstract

This contribution aims to investigate the challenges and potential solutions associated with the globally distributed development of complex products (GDPD). The research focuses on three key questions: (1) What factors influence GDPD? (2) What challenges and solutions have been encountered in GDPD? (3) What are the research gaps for further exploration in order to advance GDPD research? Through a comprehensive literature review and analysis of 83 relevant papers, the study reveals that both operational and strategic challenges receive equal attention, while normative challenges are relatively neglected. Among the proposed solutions, operational approaches centred around objects and representations emerge as the dominant approach. The study underscores the importance of adopting a balanced approach and conducting further research to address both strategic and normative challenges in GDPD. The findings contribute to enhancing the current understanding of the state of the art in this field and provide a foundation for future research endeavours in this domain.

Keywords

globally distributed product development (GDPD), distributed collaboration, coordination, engineering management

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1. Introduction

Effective collaboration in product design necessitates the integration of various skill sets to attain the desired final product design. This often entails specialists from both internal and external sources engaging in multidisciplinary teamwork, which can introduce communication challenges due to the diverse expertise and different tools employed. Sharing information becomes imperative to ensure the efficiency of the process and maintain coherence between specified requirements and achieved outcomes. The key to the success of cooperative initiatives primarily lies in effectively managing a complex network of interdependencies among diverse organisations that aim to achieve a common goal [1].

This can be realised in several ways. One possible approach is for companies expanding globally to share some of the costs and risks associated with developing a complex product by consolidating with other companies [2]. The resulting globally distributed development of complex products (GDPD) faces its challenges, but it also depicts a promising way to master the multiple interfaces in the development of mechatronic systems [3]. The primary objective of this contribution is to present a comprehensive and contemporary analysis of the various factors that impact distributed product development. Additionally, it seeks to compile an extensive list addressing the challenges associated with this development approach. The result intends to provide valuable insights that can inform future research efforts in this area, assuming that certain areas are underrepresented in the classification and that the interplay between the different levels plays an important role. This leads to the following research questions:

- RQ1 Which set of influencing factors allows the classification of research concerning distributed product development?
- RQ2 Which challenges and solutions does the literature document accordingly?
- RQ3 What are the gaps for further research?

The first two research questions focus on the current state of research into GDPD and consider challenges as well as potentials therein intending to create a general understanding of the subject area. The third research question reposes on the first set to define a space for further research activities in the field of GDPD.

2. Research Approach

The research process started with RQ1 to set the scope and create a reference space in which to classify prior research contributions. There are two major requirements for these factors. First, as categorical variables, they should at least provide a conclusive nominal scale. Second, these factors should be independent of each other to allow for an unambiguous classification. Since the topic of the research is GDPD, the factors should on the one hand represent coordination and on the other hand include the management side as well. While professional on-task competencies certainly play a role in product development, a major premise of GDPD is that development tasks can be distributed among different teams in the first place. As such technical expertise was omitted from the research at hand. RQ2 was addressed after that to draw a picture of the current state of GDPD. For this, a literature search performed as a structured database analysis provided access to the subject. The analysis followed a 4-step procedure. After an initial search, a coarse analysis of the abstracts within the resulting hit list was conducted. Subsequently, the keywords for the search were adjusted accordingly for the next refined search. These first two steps were repeated until the results were sufficiently refined and catered to the delineated topic without erroneously excluding relevant work from the outset. The search criteria were continuously refined during the research according to the actual hit rate. Scopus was the sole data source, limited to peerreviewed English-language contributions. The latter choice helped to manage the search volume, while a loss of quality was unlikely due to the inherently international nature of GDPD as the field of interest. While the initial search yielded 900 hits due to the broad usage of the term "distributed" in different engineering research fields, it could be narrowed down to 195 results with the help of the process, as mentioned earlier, using the final search string below.

TITLE-ABS-KEY ("*globally distributed*" OR "*distributed teams*") AND TITLE-ABS-KEY (*product** AND *develop**) AND SUBJAREA (*engi*) AND TITLE-ABS-KEY (*team** OR *resource** OR *department** OR *"distributed development"* OR *"distributed product development"*)

These results were analysed for context based on their abstracts and the full text where necessary in a third step. Thus, 70 contributions were deemed highly relevant, while 42 entries contributed at least partially to the topic. Another 83 papers did not contribute to the body of knowledge regarding the product development process in GDPD itself. However, they focused on adjacent challenges arising from a global workforce distribution, e.g., within manufacturing or accounting. While it is understandable that many research projects rely on student teams as their data source for accessibility reasons, the authors excluded works that did not contribute sufficiently to understanding real-world problems, most of which intentionally focused on improving education itself. Two duplicate entries had to be removed from the remaining set of 112 contributions. Furthermore, ten entries were not accessible to the authors. Finally, the full-text content analysis was performed on the remaining 100 articles, during which 17 contributions had to be excluded retroactively as non-relevant to our research questions upon closer investigation. To elaborate on RQ2 and RQ3, the final 83 hits were classified along three dimensions based on RQ1; the resulting classification was analysed descriptively (numerical and graphical), and the first conclusions were drawn.

3. Results

The choice of factors for the classification is arbitrary up to a certain degree provided that these factors meet the requirements for RQ1 laid out in the previous section. While many different existing dimensions are thinkable – and each researcher might choose a differing emphasis –, the authors of this work decided to stick with proven concepts for each dimension to provide a well-anchored point of reference. The first dimension chosen was the addressed vertical layer of management by each contribution as described by Bleicher [4], which later was extended by Rüegg-Strüm & Grand [5] in the St.-Gallen Management Model. Even though this concept originates from the realm of management, earlier variants have been successfully shown to be able to describe engineering processes before [6]. Thus, it allows the classification of the contributions into three hierarchical layers to describe necessary structures, activities and behaviour [4]:

- The *normative* level contains governance structures, policies, the overarching mission and the organisational culture.
- The *strategic* level describes the implemented structures therein, management systems that enable innovation behaviour and higher-order learning
- The *operative* level consists of process control on the micro and macro level, steering and regulation of development actions and enables operational learning and on-task cooperation

The second dimension relies on the extensive work of Okhuysen & Bechky [7] on coordination mechanisms. Building upon an extensive literature review they were able to derive five distinctive mechanisms of coordination from the body of knowledge:

- *Plans and rules* facilitate resource allocation and developing agreement
- *Objects and representations* support information sharing, align tasks and create a common perspective
- *Roles* structure expectations and expedite monitoring and updating
- *Routines* provide a template for task completion, bring people together and create common perspective across groups
- *Physical Proximity* supports familiarity and visibility and therefore helps with building trust

These mechanisms are either leveraged to support the design & development process or augmented to cushion negative effects. In the following analysis, each contribution was assigned up to two different main mechanisms. Peripheral lower-order mechanisms were omitted for the sake of clarity.

Finally, the third distinction was made whether a contribution elaborates on a proposed *solution* to improve the status quo, describes an underlying *problem* to overcome, or takes a hybrid point of view that dialectically addresses both sides *half and half*.

Based on the aforementioned three dimensions, the authors visualise the results of the literature search in two different ways. Figure 1 plots and illustrates the overall outcomes of the literature search in a three-dimensional representation. The surface area of the circle at each data point is proportional to the frequency of its respective combination of all three dimensions in the dataset. Tables 1, 2, and 3 additionally display the specific two-dimensional perspectives derived from the three-dimensional cube depicted in Figure 1 and elaborate on the interaction between each twofold set of dimensions. In Tables 1 to 3, each column serves as a closed reference point and therefore calculated percentages refer to each respective space as an entity only, notwithstanding that multiple assignments were possible in Tables 1 and 2 for coordination mechanisms.

The x-axis of Figure 1 subdivides the works concerning their contribution to one of the five coordination mechanisms. The y-axis distinguishes whether an entry puts a solution forward [cf. 2, 8–53], a problem description [cf. 54–71] or a combination of both [cf. 1, 72–88]. The management layers derived from the St. Gallen Management Scheme are represented on the z-axis. Figure 1 shows that on the normative level, neither solutions are described, nor were there publications describing both problems and solutions. Only from the problem-related perspective, normative aspects were addressed. At the strategic level, certain studies discuss both challenges and solutions, while also emphasising a hybrid perspective. Moreover, Figure 1 visually demonstrates that, at this level, there is a predominant focus on describing the problem rather than developing solutions. When considering the strategic level in conjunction with coordination mechanisms, it becomes apparent that investigations primarily revolve around the mechanisms of Plans and Rules, objects and representations, as well as Roles. At the operational level, the results concerning the point of view shift to the solution space. Most papers present solution approaches in the coordination mechanism objects and representations. To conduct a more comprehensive assessment of the three-dimensional cube, Table 1 presents the Occurrence of Coordination Mechanisms in both the Problem Space and the Solution Space.

It becomes apparent that the inclusion of objects and representations is significantly prominent in both the solution space and the hybrid space. Conversely, the attention given to other mechanisms is considerably lower, particularly within the solution space. A distinct pattern emerges when examining the problem space, where a more balanced distribution of mechanisms becomes visible. It is important to note that multiple assignments of coordination mechanisms are possible, which consequently affect the numerical values presented in Tables 1 and 2. The second table presents a comparison of coordination mechanisms across management levels. Similar to the findings in Figure 1, there is a notable emphasis on objects and representations at the operational level, while this mechanism holds no relevance at the normative level. Regarding the strategic level, the works analysed primarily focus on the plans and rules mechanism, though the consideration of objects and representations at this level is also noteworthy. At the normative level, a concentrated examination of routines, roles, and plans & rules is observed. Lastly, the third table provides a comparison between the management levels and the three observation areas, with the percentage values further reflecting the focus indicated in Figure 1.

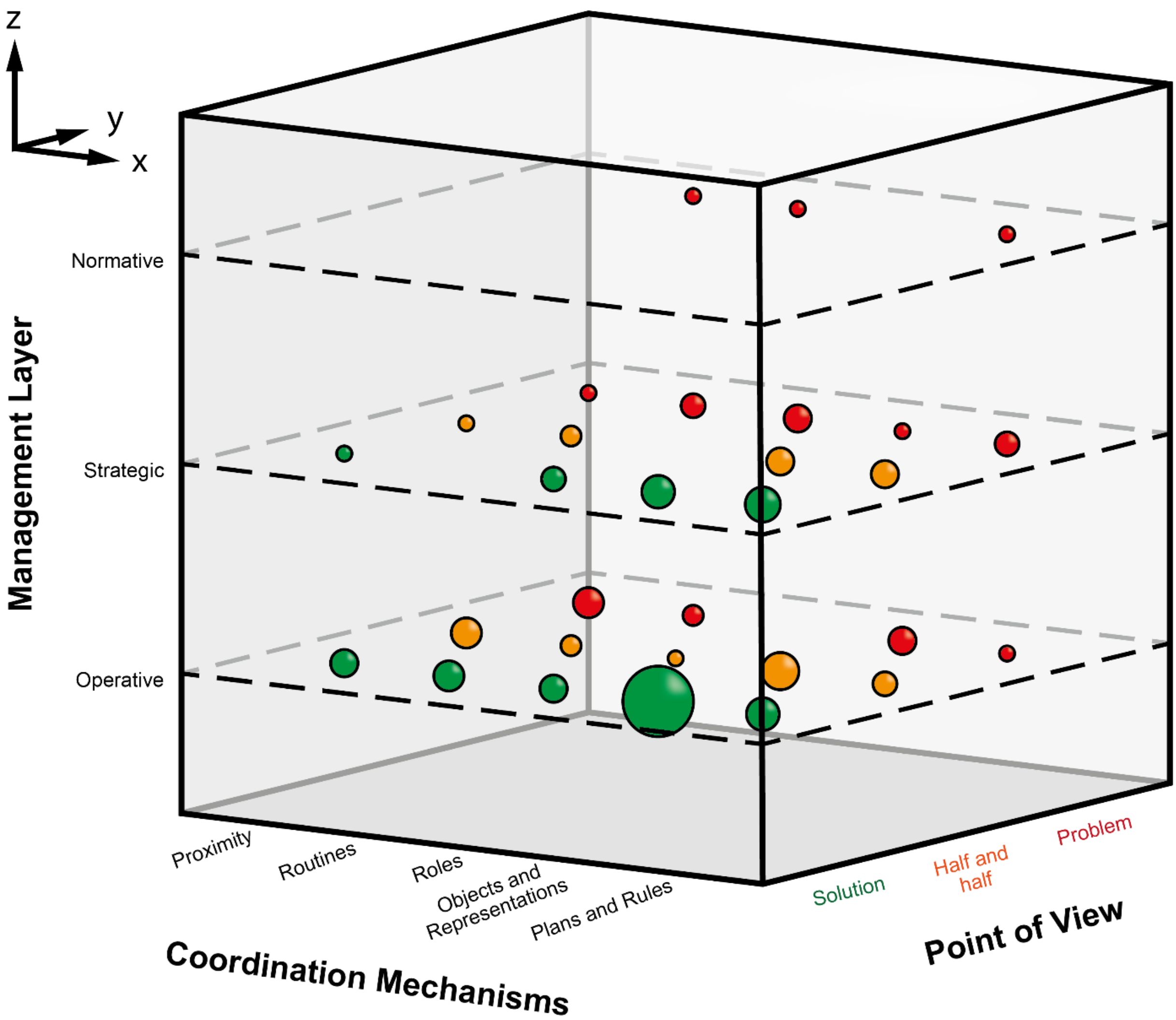

Figure 1: Three-dimensional representation of the distribution of papers along three dimensions of interest

Based on the present analysis there is a two-fold answer to RQ2. From a problem perspective, there is an equal focus on operative and strategic challenges to overcome in order to exploit the potential of GDPD. At the same time, a few contributions also highlight challenges in the normative layer of companies. Moreover, in this part of the analysed space, coordination mechanisms are all considered equally well. Switching to the solution space, however, there is a significant imbalance towards operative approaches that are based on objects and representations (i.e. containers and carriers of information) as their modus operandi. At the same time, not a single solution-focused contribution tackled the topic on a normative layer.

Thus, the answer to RQ3 follows simultaneously; research on GDPD lacks attention to the normative level in general, and to solutions on that very level specifically. From the viewpoint of coordination mechanisms there is a big gap regarding routines and roles, and – to a lesser extent – to plans and rules as well.

Table 1: Occurrence of Coordination Mechanisms in the Problem and Solution Space respectively, multiple assignments of coordination mechanisms allowed

	Point of View		
Coordination Mechanisms	Problem	Half and half	Solution
Proximity	33.3%	33.3%	10.6%
Routines	33.3%	22.2%	10.6%
Roles	27.8%	5.6%	14.9%
Objects and representations	27.8%	66.7%	78.7%
Plans and rules	27.8%	38.9%	27.7%

Table 2: Occurrence of Coordination Mechanisms in the respective Management Levels, multiple assignments of coordination mechanisms allowed

	Management Level		
Coordination Mechanisms	Operative	Strategic	Normative
Proximity	25.5%	11.5%	0
Routines	16.4%	19.2%	50.0%
Roles	9.1%	26.9%	50.0%
Objects and representations	78.2%	42.3%	0
Plans and rules	18.2%	53.8%	50.0%

Table 3: Addressed Management Levels in the Problem and Solution Space respectively

	Point of View		
Management Level	Problem	Half and half	Solution
Operative	50.0%	61.1%	74.5%
Strategic	38.9%	38.9%	25.5%
Normative	11.1%	0	0

4. Discussion and Outlook

The investigation of the inventory of proposed solutions for the challenges of distributed product development based on a literature analysis represents on the one hand the first building block for further research activities in this field. On the other hand, it provides a basic understanding and awareness of the current state of the art. As such, the findings depicted in Figure 1 demonstrate a tendency of the density distribution towards the operational level. The literature review reveals that only problem areas were identified at the normative level so far. For instance, Zeid et al. [60] discuss the increasing interest in exploring cross-cultural aspects in distributed development education, while Šmite et al. [56] caution against excessive cultural variation that cannot be effectively reconciled at this level of abstraction. Resolutions to these challenges are yet to be determined. Hence, the crucial question arises as to whether cultural aspects should be perceived as obstacles requiring solutions or whether they possess untapped potential in terms of fostering creativity and reinforcing alternative modes of thinking, which may in turn generate additional developmental solutions. Notwithstanding the aforementioned distinction, visible organisational structures have been addressed for the general case before [cf. 89], just as well as underlying individual requirements are discussed in the social sciences [cf. 90, 91]. The unanswered question so far is whether these findings are valid in the case of GDPD, how they interact in this case and if and where adjustments are necessary.

Strategic initiatives can be identified as initial approaches that tackle organisational structures, management systems, and problematic behaviour. For instance, Tripathi et al. [79] demonstrate the importance of effectively managing workflows and offer insights into how transparency, such as utilising a Kanban path for visibility, can be employed in a supportive manner. Likewise, Ulhas et al. [24] assert that a collaborative information system plays a vital role at this level by facilitating interdependencies among organisational units.

Germani et al. [14] propose a solution that involves the practical implementation of a platform for exchanging data and information, aiming to establish connections among individuals, teams, and organisations with shared objectives. Another perspective is presented by Lamsellak et al. [13], who advocate for substantial endeavours in process optimization during the planning phase at the operational level.

In summary, the findings from the classification approach reveal that solutions employing the coordination mechanism of Objectives and representations dominate with a percentage of 78.3%, despite the problem spaces being nearly evenly distributed. The emphasis on objectives and representations can be attributed to their focus on information transfer (data consistency and shared perspective), which are fundamental considerations. Monitoring data and ensuring transparent information flows are made possible through this mechanism. Training of future engineers, although mentioned, receives less attention. Therefore, it becomes essential to question which cultural aspects can be addressed at the normative level. Training might be necessary, rather than optional, for the effective and efficient implementation of distributed development at the operational level. The authors critically examine whether a singular tool-based solution can overcome the challenges of distributed development, as only a limited number of solutions can be found in that realm.

Consequently, the answer to RQ3 uncovers an apparent mismatch: Currently, the engineering field seemingly attempts to address strategic and normative challenges using operational approaches. This is especially obvious in contributions like the one from Acosta & Moreno [85]. While this does not inherently pose a contradiction, it raises the question of why there is no corresponding approach to normative challenges at the same level. In conjunction with the overrepresentation of informational aspects, an imbalance between problems and matching solutions can be suspected (refer to Figure 1).

Although there is a tendency towards contributions that centre around a solution, these are often limited to very specific problems [e.g. 29, 44] or use cases [e.g. 9, 47, 82, 83] that provide limited opportunities for a more formal generalisation irrespective of their management layer. These pointed solutions for GDPD contrast with the broad approaches from the realm of general organisational development and therefore leave a significant gap in the middle ground. More specifically, the present work was not able to identify any prescriptive or system-theoretical models addressing GDPD from a general perspective. That means, overarching methodologies that transcend multiple layers away from selective informational aspects are still missing and should be addressed in the future.

The work of Lauer et al. [33] can be mentioned as an exemplary solution approach at the operational level. Their contribution focuses on implementing haptics and the haptic dimension through a rope pull tool. This way, Lauer et al. aim to foster easy interpersonal communication and enhance the proximity mechanism by introducing new interaction possibilities for individuals in distributed teams. Besides, Wende et al. [21] researched improving the proximity mechanism through the utilization of mobile remote presence (MRP) technologies. They explored the use of an MRP system, which is a robot-mounted video conferencing system. The authors employed an outsourced software development team as a case study, which was globally distributed across two regions, considering linguistic and cultural factors.

Moreover, Wu et al. [26] have developed an approach for knowledge integration and sharing in the context of complex product development at the operational level. Their work involves leveraging different developers and distributed product development knowledge. The outcome is an ontology-based framework comprising a knowledge representation model and an active knowledge-sharing mode. Another example of an ontology-based approach is presented in the work of Lv et al. [30]. The central idea here is to capture and reuse construction knowledge through a flexible ontology-based schema with formally defined semantics. Furthermore, Fan et al. [16] focus on providing a suitable framework and methodology to support the collaborative design and analysis of devices in distributed development. They propose the development of a distributed and collaborative system for integrated fixture design and analysis (IFDA). The findings indicate that the developed IFDA system promotes the utilization of existing expertise and facilitates the exchange of information between the synthesis and analysis stages.

In light of the overall findings described above, the need for a more balanced approach to addressing challenges and providing solutions across all management layers becomes clear. While operative solutions based on objects and representations are essential and deserve attention, there should be a concerted effort to explore strategic and normative solutions as well. Additionally, further research should focus on developing prescriptive or system-theoretical models that can address distributed product development comprehensively and holistically instead of punctual solutions as of now. Furthermore, understanding and addressing cultural aspects at the normative level could play a crucial role in optimizing distributed development. Overall, the results suggest that a more comprehensive and integrated approach might be worth exploring to fully leverage the potential of distributed product development and effectively manage its challenges.

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