UNDERSTANDING USERS AND PRODUCTS IN PRODUCT DEVELOPMENT: THE APPLICATION OF PRODUCT USAGE INFORMATION AND ITS CHALLENGES

Deng, Quan (1);
Wellsandt, Stefan (1);
Hribernik, Karl (1);
Thoben, Klaus-Dieter (2)

1: BIBA – Bremer Institut für Produktion und Logistik GmbH;
2: Faculty of Production Engineering, University of Bremen

ABSTRACT

The need to understand users and products is one of the cores for product success. There are many ways to reach this understanding,such as,interviews and consumer cocreation. This study put a focus on the application of product usage information (PUI). Although amount of product-related information is available in the middle of a product's life, producers have not realized the full potential of these data in product development. The academic literature describes various use cases that outline how PUI supports this kind of understanding, and eventually benefits product development. Each of them provides fragmented information from certain perspectives. This diversity and the lack of systematic overview facilitates a fragmentation in the research of PUI usage in product development. To have an initial and unified overview of PUI's value on the understanding of users and products, this paper conducted a combination of systematic and descriptive review to form a sample with 12 papers. The result indicates that PUI increases producer's understanding about the product, its users and the context of usage. However, producers need to address several challenges if they want to apply PUI in product development successfully.

Keywords: Product Lifecycle Management (PLM), Case study, Design informatics, Product Usage Information, Product Improvement

Contact:
Deng, Quan
BIBA – Bremer Institut für Produktion und Logistik GmbH
IKAP
Germany
dqu@biba.uni-bremen.de

Cite this article: Deng, Q., Wellsandt, S., Hribernik, K., Thoben, K.-D. (2021) 'Understanding Users and Products in Product Development: The Application of Product Usage Information and its Challenges', in *Proceedings of the International Conference on Engineering Design (ICED21),* Gothenburg, Sweden, 16-20 August 2021. DOI:10.1017/pds.2021.591

1 INTRODUCTION

A critical factor that makes a product successful is its acceptance in its market. Producers collect and analyze various information from their markets to achieve this goal. This information originates from different market actors, including retailers, customers, users, competitors, and the providers of product-related services like maintenance, renting, and leasing. Its content, format, and quality are heterogeneous and cover opinions, service reports, review reports, and embedded systems' measurements. One of the prominent places to obtain market information is the Internet. Various channels convey Internet users' information about products through, for instance, weblogs, social networking services, product review services, and online marketplaces. They complement acknowledged methods, such as interviews with lead users, user surveys, and customer service information. Producers may also purchase the information from business partners or third parties.

Information from the market allows producers to learn about actual user expectations, usage situations, product behavior, and product performance. Used in product design, it substitutes assumptions for evidence, increasing simulation models' accuracy, creating comprehensive test cases, and evaluating solution alternatives. For instance, the analysis of performance information can concretize failure and degradation mechanisms that a producer can use to prioritize critical issues, analyze root causes, and eventually improve current and future product generations (Shin *et al.*, 2015). Producers collect information from the market for various reasons other than product development, such as customer service, product monitoring, or maintenance. Development departments may repurpose this information for their benefits, but information quality problems may limit such attempts.

Previous research focused on how this information improves product design conceptually and with realized application cases. Literature also covers Product-Service Systems and Functional Products because they benefit significantly from market information (Lindström, 2017). More recent studies demonstrate how information technologies, such as machine learning, can significantly enhance its creation, organization, processing, and sharing. A key issue with the application-oriented literature is that it is highly heterogeneous in scope. Application cases vary in the investigated products, information sources, and product development tasks. Related research results include new approaches, concepts, methodologies, methods, and software tools. Since more than 60 articles are available today, it becomes more challenging to identify unique and shared concepts, semantics, and application domains. The heterogeneous terminology may also increase the chance that upcoming articles will not find the relevant related work. A systematic literature survey could address this problem by structuring relevant articles and summarizing unique viewpoints.

This paper presents the results of a survey of 12 articles concerning the application of market-related information in product development. The collection is a sample of a more extensive work-in-progress survey covering 67 papers. This paper's research question is *how market-related information contributes to a better understanding of users and products*. Answering this question would be the first step to combine one part of the fragmented knowledge into an overview. Section 2 describes the conceptual foundations of this article and the related work. Section 3 outlines the survey's methodology and scope, and Section 4 presents the findings for the research question above. Section 5 discusses how the results answer the research question, and it pinpoints future challenges. Section 6 concludes this paper and indicates the next steps.

2 FOUNDATIONS

2.1 Product Development as a Problem-solving Process

Products with a distinct usage phase are durable. They degrade and are subject to service activities, such as maintenance and repair. A durable product can be a consumer good (CG) or an industrial good (IG) (Kotler and Keller, 2012). The former is for personal use and the latter for the production of other goods. For various products, producers can apply different product development processes.

A general understanding of the product development process is an iterative process encompassing the following phases (Pahl *et al.*, 2007):

- Product planning. Analyses the company situation, develops and assesses product ideas. This task results in the requirements list.
- Task clarification. Plans the following work activities and clarifies the requirements list where necessary.

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

- Conceptual design. Abstracts the essential problems, identifies function structures and working principles and combines them into a working structure. This task results in a principle solution (concept).
- Embodiment design. Creates technical layouts in line with the requirements. After several iterations, this task results in a definitive layout.
- Detail design. Defines the arrangement, forms, dimensions, and surface properties of the individual parts of the solution. This task results in the product documentation that is necessary to produce the product design.

In each design phase, there are many existing methodologies, for instance, CostBenefit analysis and Brainstorming. Some of them can be transferred and applied in all design phases during the product development process, such as the general problem-solving cycles described in VDI-Guideline 2221 (VDI, 1993). With the problem-solving process, the problem is first analyzed and defined. Based on problem understanding, solutions are searched, evaluated, and selected.

2.2 Information flows in Product Lifecycle Management

Information is data with meaning and often a critical resource in product development. Product lifecycle management (PLM) differentiates information flows, as illustrated in Fig. 1.

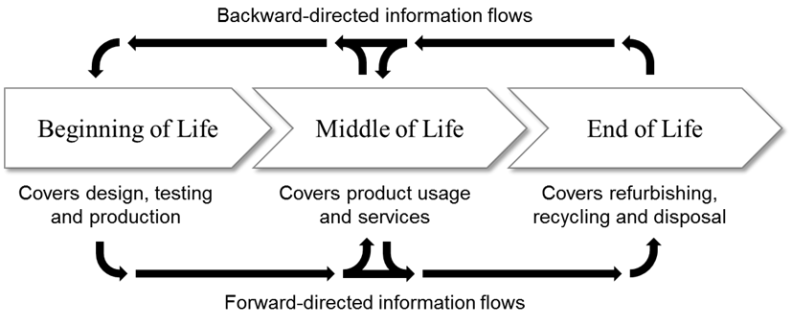

Figure 1. Phases and information flow of the product lifecycle (Wellsandt et al., 2015)

A product's lifecycle has three subsequent phases, and product development occurs during the first one. The development process provides information for subsequent activities, such as product testing and production, and receives information as "feedback" from the second and third phases. Wellsandt *et al.* (2018) identified this feedback as *"[…] any response that the producer or its employees receive when they present their work to a stakeholder such as a customer, user, supplier or co-worker*". Employees that receive feedback include engineers, salespersons, service staff, quality managers, and product managers. Responses emerge for different reasons such as complaints, commendation, constructive critique, observation, and inspections. The employees can assess feedback information and use it to support decisions, for instance, about product design changes.

This paper focuses on the information coming from the market. From the lifecycle perspective above, the market equals the so-called "Middle of Life" or usage phase. Wellsandt *et al.* (2015) used the term **Product Usage Information** (PUI) for this information. They defined it as "*product-related information that is created after the product is sold to the end customer and before the product is no longer useful for a user*" (Wellsandt *et al.*, 2015). This term is similar to field data (Edler, 2001), in-service information (Jagtap and Johnson, 2011), and field feedback (Petkova, 2003), but it indicates where the information comes from in the product life cycle without constraining it to a specific data source, format, or content. This distinction is subtle but necessary, in our view, to better connect it to the extensive conceptual world of PLM.

Companies can acquire PUI through various communication channels, such as call centers, help desks, measurement systems, software logging, and various website and service types on the Internet. The latter include, for instance, weblogs, social networking services, product review services, and online marketplaces. The broad range of conventional and newer channels facilitates the rapid collection of PUI in large amounts. Table 1 provides an overview of relevant communication channels. This table is not comprehensive, but it outlines the complexity of PUI in product development.

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

Table 1. PUI channels usable in product development (Deng et al., 2019)

Channels	Typical contents	Data formats
Sensor data repository	Environmental information; performance	S / SS
Log file of embedded control system	Product behavior	SS
Service report	Maintenance, repair, and failure information; product condition	SS / US
Online discussion forum	Opinions; ratings; complaints; customer/user profiles; constructive critique	SS / US
Online customer review platform	Opinions; ratings; complaints; customer/user profiles; constructive critique	SS / US
Telephone	Opinions; complaints; customer profiles	US
Email	Opinions; complaints; customer/user profiles; constructive critique	US

S = structured ; SS = semi-structured ; US = unstructured

3 RESEARCH DESIGN

As discussed in the last section, we use the term PUI for information coming from the market. Many stakeholders benefit from PUI, such as users, service personnel, and product development teams. This study focuses on the values in product development, mainly for product development teams (e.g., product developer, and product manager). We then refine the research question posed in the introduction as: *How PUI contribute to a better understanding of users and products in product development?*
This paper uses a literature review to identify and analyze PUI application cases. (Paré *et al.*, 2015) outline nine types of literature reviews, such as systematic review, descriptive review, and scoping review. Each type has a specific approach and research goal. This study used a systematic review to examine the literature regarding the value of PUI in product development. Afterward, it takes the idea of descriptive review to form a sample subset related to this article's particular aim.
We used the search engine Scopus for the systematic review. It covers many important databases relevant to engineering and product development, such as Science Direct, IEEE, and Design Society. To make the research comprehensive and thematically limited, we divided the search field into two main categories: PUI and product development. We took the literature identified in Deng *et al.* (2019) as initial articles to discover new terms. We have afterward checked and compared the results in Scopus with different term combinations.
For the category PUI, we chose the term: *((use or usage or review or interaction or warranty or field or service or maintenance or feedback or customer or consumer or user or "social media") Pre/1 (data or information or content))*. Since literature often uses basic word variants to describe PUI, for example, warranty information rather than warranties information, we used searches without wildcards characters. The search term is a combination of synonyms and related phrases for "usage" and "information" (Table 2). "use" and "usage" are two general alternative terms for usage. Other words for usage, such as "field", "warranty", and "social media" are to search different types of information in the usage phases, and similar terms of PUI, for example, field data, warranty information, and social media data. As the words for "usage" must appear before that for "information", this study used the proximity operator "Pre/n" in the Scopus Search. We took "Pre/1" (maximum distance1) to cover the type of PUI that are otherwise difficult to find, such as customer complaints data, consumer satisfaction information, and user generated content. For the category product development, we used the term: *(product Pre/0 (design or development or improvement)*. As a result, the combination *((use or usage or review or interaction or warranty or field or service or maintenance or feedback or customer or consumer or user or "social media") Pre/1 (data or information or content)) and (product Pre/0 (design or development or improvement))* was finally selected for the systematic literature review.

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

Table 2. Search terms for PUI

Keyword	Synonyms and related phrases
Usage	use, usage, field, service, maintenance, warranty, customer, consumer, user, interaction, review, feedback, social media
Information	information, data, content

To eliminate the irrelevant publications, we have defined several inclusion and exclusion criteria. One of the most important criteria is that the published literature must have concrete product development scenarios/examples with PUI usage to illustrate PUI's benefits for product development. The literature should be in English and peer-reviewed from the last 10 years between 2011 and 2020. When multiple versions with similar content existed, only the most extensive version is included.

This research focuses on durable goods, which product development engineers and improves to satisfy users. The usage phase of these goods typically covers years or decades and during that time, many users can use the product under various conditions. Furthermore, expensive durable goods may contain software and measurement systems that create PUI automatically at low costs and with high precision. Since durable goods degrade, they require maintenance, repair, and overhaul services. These factors increase the amount and heterogeneity of PUI. We assume that the factors above create more opportunities for the exploitation of PUI compared to non-durable goods.

This study extracted and codified three types of information for the literature from the systematic review: product, PUI, and contribution to an understanding of users and products. We classified the "product" as consumer good (CG) or industrial good (IG), and codified the "contribution on users and products understanding" according to their contribution on different aspects: user, product, and usage context. In the end, we selected 12 papers to form a sample subset. The sample subset covers 1) both CG and IG, 2) multiple types of PUI, and 3) contributions to an understanding of the user, product, and usage context. We tried to select papers that contribute differently to achieve the best coverage. We acknowledge that the coding and selection is based on our interpretation of the papers. It is merely indicative, and not exhaustive, for an initial overview about the value of PUI on the understanding of users and products in product development. Fig. 2 gives an overview of the review process and the number of literature in individual filter steps.

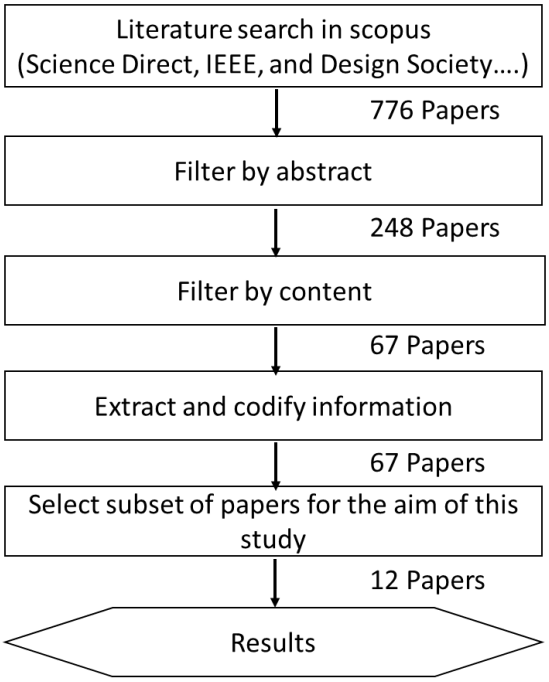

Figure 2. Review process and filtering steps

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

4 FINDINGS

Table 3 presents the representative sample that has concrete product development scenarios with the application of PUI. It gives an overview of PUI and its contributions to the understanding of users and products.

Table 3. Overview of selected use cases with the application of PUI

Product	PUI	Contribution on users and products understanding	Reference
Wire Electrical Discharge Grinding machine	MRO reports	Understand product failures, influence factors, and causes	(Abramovici *et al.*, 2017)
Automobile	Field data, user data, etc.	Understand current reliability performance, critical failure modes, and actual use scenarios, etc.	(Geiger and Sarakakis, 2016)
Kindle e-readers	Online reviews	Understanding how and in what condition customers use their products, how user preferences change, etc.	(Hou *et al.*, 2019)
Intelligent mobile phones	Opinion data, e.g., customer reviews	Understand consumer opinions on product features	(Jin *et al.*, 2016)
Front-loading washer	Customer reviews	Understand consumer complaints about products, satisfaction levels, product experience, and preferences	(Kim and Noh, 2019)
Washing machine	Sensor data	Understand product usage behaviors, i.e., bearing load during washing	(Klein *et al.*, 2019)
Refrigerator	Sensor data	Understanding user behaviors	
Locomotive braking system	Field data	Understand function performance degradation, and relevant design parameters	(Shin *et al.*, 2015)
Electric violin	Survey on customer and product usage	Understand customer and product usage in different settings	(Sotos *et al.*, 2014)
Highly reliable product (unnamed)	Field data and laboratory testing data	Understand product failures and reliability characteristics	(Tseng *et al.*, 2016)
Smartphone	Social media data	Identify lead users and latent features	(Tuarob and Tucker, 2014)
Medical imaging system	Sensor data and product usage logs	Discovery user behaviors	(van Eck *et al.*, 2019)
Handheld grinder	Sensor data about product usage	Understand product usage, assess deviation from the intended optimal use	(Voet *et al.*, 2019)

5 DISCUSSION

5.1 PUI for the understanding of users and products

Usage information in product development is by large about increasing the producer's understanding of the product, its users, and the context of usage. The following list outlines these three elements:

- **User**. A user is a human interacting with products to, for instance, achieve goals and satisfy needs. He or she has or develops preference regarding the product's characteristics. These preferences influence future interactions and purchase decisions of similar or related products. During interactions, users typically show specific behavior, such as holding, pressing, pulling, lifting, and turnig. This behavior affects how well they achieve goals or satisfy their needs. It also influ-

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

ences how the product responds in the current interaction or in future ones. The latter is relevant if inappropriate user behavior results in a product getting damaged. Besides, it is important to differentiate between users and customers. The latter pay for a product but are not necessarily the ones that use it. This difference is common for industrial products where an organization's legal representative is the customer and another employee is the user. Cantamessa *et al.* (2016) differentiate as well user and beneficiary. A beneficiary does not operate a product but directly benefited from the usage of a product. For instance, patients are beneficiaries of medical devices.

- **Product**. A product is the result of a production process. It possesses specific characteristics and satisfies the needs of one or more stakeholders - foremost the users' needs. From a design perspective, products possess functions, behavior, and structure. Some stakeholders expect that functions, behavior, and structures meet specific requirements during product usage. An example is that users want their products to remain usable for many years. The degree of meeting these expectations is the product's performance.
- **Usage Context**. (He *et al.*, 2012) define usage context of a product as "all aspects describing the context of product use that vary under different use conditions and affect product performance and/or consumer preferences for the product attributes". It may have a significant impact on product performances, user behavior, user preferences. Usage context is often named differently in various papers, such as use condition, usage situation, and usage environment.

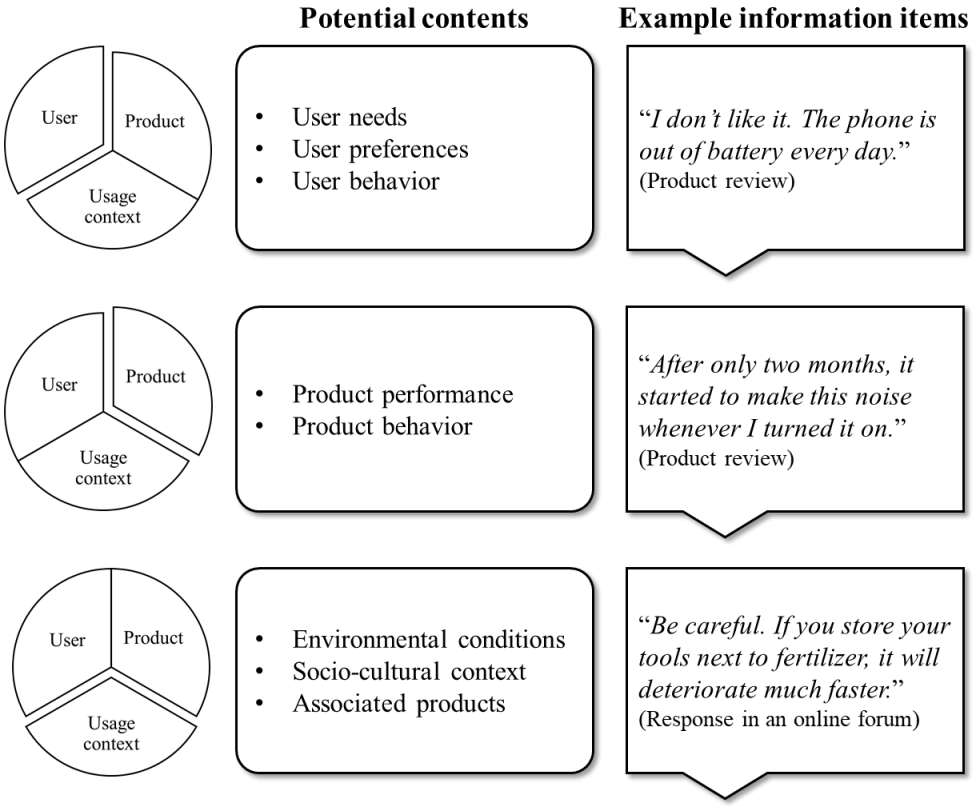

Figure 3. PUI for the understanding of users and products

As illustrated in Fig. 3, the application of PUI can provide producers an understanding on product usage, about how users interact with products in different usage contexts. In the real world, these three elements interact and are often difficult to differentiate. While, depending on the goal and focus of product development activities, product developers do have focus on certain aspects of product usage. PUI allows product developers to have a detailed understanding of product performances, e.g., failures, reality, and performance degradation. Field data is helpful, for example, to understand product failures and reliability characteristics (Tseng *et al.*, 2016). It enabled Shin *et al.* (2015) to evaluate product's function performance degradation. MRO reports supported Abramovici *et al.* (2017) to analyze influence factors and causes for failure-prone components. (Geiger and Sarakakis, 2016) have presented the usage of various data, including field data and actual user data, to understand the current reliability performance and critical failure modes of automobiles. In understanding product behaviors,

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

Klein *et al.* (2019) presented a use case using PUI from embedded sensors (i.e., spin value, load weight) to calculate the washing machine's bearing load during washings.

To understand user preferences and needs, PUI, for example, customer reviews and social media data, is often used. Opinion data has been applied to analyze users' complaints, preferences, experiences, and satisfaction levels on product and product features (Kim and Noh, 2019; Jin *et al.*, 2016). Tuarob and Tucker (2014) have used social media data to identify latent product features and lead users for smartphone development. User preferences and needs are closely related to user behaviors, product usage, and product usage context. (van Eck *et al.*, 2019) have taken sensor data and product usage logs to understand how users behave when using the medical imaging system in practice. (Voet *et al.*, 2019) have used sensor data to understand the usage profile of handheld grinder and assess deviation from the intended optimal use. Real-life PUI from sensors offers Klein et al. (2019) the opportunity to understand user interactions with the refrigerator. Around product usage context, (Hou *et al.*, 2019) have applied online reviews to understand how and in what condition customers use their products, and how user preferences change. Sotos *et al.* (2014) have used survey data to know better about users and their interaction frequency with the Viper in different settings.

5.2 Challenges

Producers need to address several challenges if they want to successfully apply PUI in product development. The following paragraphs outline these challenges.

Information quality. One of the most critical challenges is to identify PUI that is fit-for-purpose, i.e., PUI with the right characteristics for a development task. Addressing it requires that the producer develops a notion for relevant characteristics. Hight accuracy often is a desired information characteristic in development. It minimizes the risk that employees come to false conclusions, which may result in follow-up costs. Apart from accuracy, the producer may need to consider other characteristics, such as precision, timeliness, accessibility, availability, and credibility. A concise understanding of PUI quality could help producers to specify what PUI they need for their development process. It is not sufficient, though, to identify high-quality PUI among all available information. This is most evident for the vast information available in Social Media which is also highly heterogeneous in terms of quality. Addressing this part of this challenge requires a comprehensive understanding of quality-related factors, i.e., phenomena, mechanisms, and effects that influence PUI quality characteristics. Without this knowledge, it might be impossible to specify characteristics of information items, such as the accuracy of review reports. Relevant factors for this content type relate to the related communication channels (e.g. Amazon's online marketplace). For instance, it is important to understand channel user demographics, channel norms and rules, technical constraints, and the business model. Quality-related factors appear in all steps of the life cycle of PUI. Acquiring knowledge about them is, thus, a complex and time-consuming task for producers. Its complexity relates to the different disciplines that possess related knowledge, such as metrology, psychology, statistics, sociology, and computer science.

PUI acquisition. Another challenge is the acquisition and preparation of PUI according to the needs of product development tasks. Product developers can either capture new data with additional information channels or reuse existing data. When producers choose to add information channels, it could be very costly. They need to know clearly their goals and carefully select the required information channels, e.g., sensors installation on a specific product part. It may take a long period to get the needed information. Meanwhile, additional information channels, for instance, redesign and sensor installation on products for the improvement of product generations afterward, could be expensive. Reuse of existing data sounds like the right way for cost-saving but still a set of challenges. There are many different kinds of PUI distributed in departments or organizations along with product usage phases. It is a challenge for product developers to find out the right PUI relevant to the needs of their current or near-term product development tasks. Moreover, PUI with different semantic meanings can be structured or unstructured, scattered in multiple sources under various data schema. They are often originated from various stakeholders,e.g., service personal, that have different perspectives as product developers. It is not easy to interpret and integrate them properly from product developers' perspectives for problem-solving in product development tasks.

Personal data protection. PUI contains information about identifiable users or may be associated with real names in Social Media. In this case, producers must meet legal requirements resulting from data privacy regulations, such as the General Data Protection Regulation (GDPR) in Europe. A minimum requirement is to ask the users for their consent if one desires to process personal information.

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press

Furthermore, the GDPR requires making the goals and mechanisms of personal data processing transparent. A side-effect of this is that competitors may learn how a producer processes and applies PUI.
Knowledge discovery with PUI. Even with the appropriate PUI at hand, producers may still have difficulties discovering the required knowledge to solve specific problems. Existing tools are likely unfit for transfer to other problems and may require significant effort to customize (e.g., building machine learning training datasets for data mining).

6 CONCLUSION

This paper presented an initial overview of PUI's application for the understanding of users and products in product development. We conducted a combination of systematic and descriptive reviews to achieve this. The result indicates that PUI can provide an in-depth understanding of users and products, about the interaction between users, product, and usage context. This understanding would give valuable basis and benefits for various product development tasks, ranging from planning and task clarification to conceptual, embodiment, and detail design. As an example, knowledge about the interaction between users and products under certain use conditions provides evidence, rather than assumptions, for producers to improve simulation models, test profiles, and evaluate solution alternatives. The application of PUI complements the traditional product development approaches based on assumptions, estimations, and experience. Apart from the values, this research discusses several challenges that could hinder the widespread application of PUI in product development. An overview of these values and challenges would help other researchers to position their contributions better within the research domain, and inspire industry companies to reshape their product development strategy on the acquisition and application of PUI.
Although we use a combination of systematic and descriptive review to cover various aspects of the research questions as far as possible, the representative sample is still in risk of a sample bias. We will present the complete results of the systematic review in a forthcoming paper. It will discuss as well the concrete values of PUI in various product development tasks.

ACKNOWLEDGMENTS

The research presented in this paper is supported by the European Union's Horizon 2020 research and innovation programme, in the context of the LEVEL-UP project, under grant agreements number 869991.

REFERENCES

Abramovici, M., Gebus, P., Göbel, J.C. and Savarino, P. (2017), "Utilizing unstructured feedback data from MRO reports for the continuous improvement of standard products", *DS 87-6 Proceedings of the 21st International Conference on Engineering Design (ICED 17)*, Vol 6: D*esign Information and Knowledge*, Vancouver, Canada, 21-25.08.2017.

Cantamessa, M., Montagna, F. and Cascini, G. (2016), "Design for innovation – A methodology to engineer the innovation diffusion into the development process", *Computers in Industry*, Vol. 75, pp. 46–57. https://doi.org/10.1016/j.compind.2015.10.013.

Deng, Q., Wellsandt, S., Hribernik, K.A. and Thoben, K.-D. (2019), "Towards Understanding the Role of Product Usage Information in Product Design Improvement", *16th IFIP WG 5.1 International Conference on Product Lifecycle Management, PLM 2019*, IFIP AICT Vol. 565, Springer, Cham, pp. 369-378. https://doi.org/10.1007/978-3-030-42250-9_35.

Edler, A. (2001), *Nutzung von Felddaten in der qualitätsgetriebenen Produktentwicklung und im Service*. Dissertation, Technische Universität Berlin. https://doi.org/10.14279/DEPOSITONCE-370.

Geiger, C. and Sarakakis, G. (2016), "Data driven design for reliability", *2016 Annual Reliability and Maintainability Symposium (RAMS)*, Tucson, AZ, USA, 2016, pp. 1-6. https://doi.org/10.1109/RAMS.2016.7448023.

He, L., Chen, W., Hoyle, C. and Yannou, B. (2012), "Choice Modeling for Usage Context-Based Design", *Journal of Mechanical Design*, Transactions of the ASME, Vol. 134 No. 3. https://doi.org/10.1115/1.4005860.

Hou, T., Yannou, B., Leroy, Y. and Poirson, E. (2019), "An affordance-based online review analysis framework", *DS 94: Proceedings of the Design Society: 22nd International Conference on Engineering Design (ICED19)*, Delft, The Netherlands, pp. 2457–2466. https://doi.org/10.1017/dsi.2019.252.

Jagtap, S. and Johnson, A. (2011), "In-service information required by engineering designers", R*esearch in Engineering Design*, Vol. 22 No. 4, pp. 207–221. https://doi.org/10.1007/s00163-011-0107-8.

Jin, J., Liu, Y., Ji, P. and Liu, H. (2016), "Understanding big consumer opinion data for market-driven product design", *International Journal of Production Research*, Vol. 54 No. 10, pp. 3019–3041. https://doi.org/10.1080/00207543.2016.1154208.
Kim, H.-S. and Noh, Y. (2019), "Elicitation of design factors through big data analysis of online customer reviews for washing machines", *Journal of Mechanical Science and Technology*, Vol. 33 No. 6, pp. 2785–2795. https://doi.org/10.1007/s12206-019-0525-5.
Klein, P., van der Vegte, W.F., Hribernik, K. and Klaus-Dieter, T. (2019), "Towards an approach integrating various levels of data analytics to exploit product-usage information in product development", *DS 94: Proceedings of the Design Society: 22nd International Conference on Engineering Design (ICED19)*, pp. 2627–2636. https://doi.org/10.1017/dsi.2019.269.
Kotler, P. and Keller, K.L. (2012), *Marketing management*, 14th ed., Prentice Hall, Upper Saddle River, NJ.
Lindström, J. (2017), "Improving Functional Product Availability: Software-related Measures Planned and Taken", *Procedia CIRP*, Vol. 59, pp. 202–207. https://doi.org/10.1016/j.procir.2016.08.018.
Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.-H. (2007), *Engineering Design:A Systematic Approach*, Springer London, London. https://doi.org/10.1007/978-1-84628-319-2.
Paré, G., Trudel, M.-C., Jaana, M. and Kitsiou, S. (2015), "Synthesizing information systems knowledge: A typology of literature reviews", *Information and Management*, Vol. 52 No. 2, pp. 183–199. https://doi.org/10.1016/j.im.2014.08.008.
Petkova, V. (2003), *An analysis of field feedback in consumer electronics industry*, Dissertation, Eindhoven University of Technology, Netherlands.
Shin, J.-H., Kiritsis, D. and Xirouchakis, P. (2015), "Design modification supporting method based on product usage data in closed-loop PLM", *International Journal of Computer Integrated Manufacturing*, Vol. 28 No. 6, pp. 551–568. https://doi.org/10.1080/0951192X.2014.900866.
Sotos, C., Okudan Kremer, G.E. and Akman, G. (2014), "Customer needs based product family sizing design: The viper case study", *Advances in Product Family and Product Platform Design: Methods and Applications*, Springer New York, pp. 683–706. https://doi.org/10.1007/978-1-4614-7937-6_27.
Tseng, S.-T., Hsu, N.-J. and Lin, Y.-C. (2016), "Joint modeling of laboratory and field data with application to warranty prediction for highly reliable products", *IIE Transactions (Institute of Industrial Engineers)*, Vol. 48 No. 8, pp. 710–719. https://doi.org/10.1080/0740817X.2015.1133941.
Tuarob, S. and Tucker, C.S. (2014), "Discovering next generation product innovations by identifying lead user preferences expressed through large scale social media data", *ASME 2014 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. https://doi.org/10.1115/DETC201434767.
van Eck, M.L., Markslag, E., Sidorova, N., Brosens-Kessels, A. and van der Aalst, W. (2019), "Data-driven usability test scenario creation", *7th International Working Conference on Human-Centered Software Engineering, HCSE 2018*, Springer Verlag. https://doi.org/10.1007/978-3-030-05909-5_6.
VDI (1993), *VDI-Richtlinie 2221: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte*, VDI-Verlag, Düsseldorf.
Voet, H., Altenhof, M., Ellerich, M., Schmitt, R.H. and Linke, B. (2019), "A Framework for the Capture and Analysis of Product Usage Data for Continuous Product Improvement", *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, Vol. 141 No. 2. https://doi.org/10.1115/1.4041948.
Wellsandt, S., Hribernik, K. and Thoben, K.-D. (2015), "Sources and Characteristics of Information about Product Use", *Procedia CIRP*, Vol. 36, pp. 242–247. https://doi.org/10.1016/j.procir.2015.01.060.
Wellsandt, S., Thoben, K.-D. and Klein, P. (2018), "Information Feedback in Product Development: Analysing Practical Cases", *DS 92: Proceedings of the DESIGN 2018 15th International Design Conference*, University of Zagreb, Croatia, May, 21-24, 2018; The Design Society, Glasgow, UK, pp. 1745–1756. https://doi.org/10.21278/idc.2018.0379.

https://doi.org/10.1017/pds.2021.591 Published online by Cambridge University Press