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Enhancing knowledge management in the engineering design process through a communication platform

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Abstract

In today's competitive market, design firms are under pressure to enhance the speed of their decision-making processes to foster innovative products. Due to specialized nature of contemporary technology, enterprises are directed to consider Design for X factors during the product development process like environmental impact and production efficiency. This transformation leads to an increase in gaining knowledge from different fields. This paper presents a comprehensive framework for efficiently acquiring and applying knowledge, aimed at improving knowledge management and sharing practices.

Keywords: *design for x (DfX), knowledge management, product development, communication, knowledge acquiring*

1. Introduction

In today's business world, companies must balance exceptional product quality and creativity with increased operational efficiency to stay competitive. The design of technological products necessitates the integration of multiple factors, including serviceability, safety, quality, manufacturing, assembly, ergonomics and environmental impact. The complexity arises from global markets, changing customer preferences and advancing technology specialization (Masior, et al., 2020; Heimicke, et al., 2019).
In today's world, knowledge plays a crucial role for accomplishing tasks in an innovative environment and knowledge management involves storing, sharing and expanding knowledge within organizations. However, in development projects, effective communication can be challenging, especially when teams are located far apart. During a time when speed is essential, communication is vital, even with individuals outside the project. If we don't address above mentioned issues through communication and knowledge sharing, costs can increase. This implementation emphasizes the importance of strong knowledge management and communication within project teams. To succeed in product development, it's significant to not only gather and store knowledge but also promote its exchange and dissemination for better decision-making. This research introduces a framework for a communication software that aids engineering teams using Design for X (DfX) principles and knowledge. The aimed software focuses on continually improving knowledge application in early product development. The framework enables systematic acquisition, storage, transfer and utilization of empirical and explicit DfX knowledge, including codifying tacit expert knowledge across disciplines for the entire organization.
To enhance knowledge integration and retrieval, a hierarchical DfX structure is used. This concept includes keyword extraction and tagging supported by natural language processing (NLP) for organized knowledge access. Collaborative tagging facilitates efficient sharing of critical knowledge, aiding decision-making and fostering an innovative organizational culture among engineering teams.

The co-occurrence networks are important in bibliometric analysis, providing insights into academic literature and research connections. Co-occurrence networks uncover thematic relationships in research, aiding in visualizing the academic thematic landscape. Figure 1 presents a co-occurrence networks (word cloud) with a total of 50 nodes, featuring the most frequent 'DfX and engineering-related keywords' confirming the relevance of the search terms. Analysing the keywords selected and utilized by authors in their research is a significant tool for understanding trending topics in a specific domain. The most prominent keyword is 'product design' followed by other related design styles and concepts.

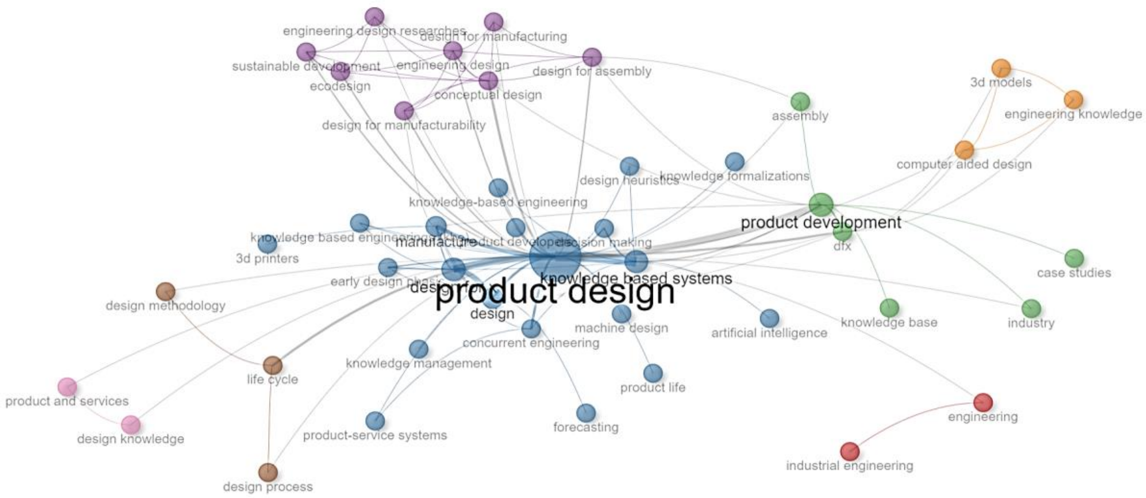

Figure 1. Cluster of co-occurrence of keywords

The main contribution of this paper lies in presenting a novel tool for knowledge management, which is shown through a concise use case. This tool represents a significant advancement in addressing the complexities and challenges associated with managing knowledge effectively within organizations. By introducing this innovative solution, the paper seeks to offer a practical and efficient means for capturing, organizing and utilizing knowledge assets to support decision-making and enhance organizational performance.

The paper begins with an overview of research background, followed by sections detailing the research approach, including a 3D printer use case, prototype implementation and software application example, ultimately concluding with discussions on findings and future research prospects.

2. Research background

The research aims to integrate Design for X (DfX) principles into a communication platform for engineering teams, focusing on product development, DfX, communication and knowledge management. This initiative lays the groundwork for an innovative communication software framework. Literature analysis highlights the substantial relevance of DfX-centered knowledge management in this context.

The product development process guides a product from its initial concept to market introduction, involving phases from conceptualization to detailed design, with initial stages emphasizing innovation, while later stages are practical and engineering-driven (Favi, et al., 2022). The engineering design phase identifies product component specifications, including geometry, materials, tolerances and many more. Solid modelling and drawing, core disciplines within engineering design, have evolved with CAD tools, progressing from basic electronic drawing boards to sophisticated 3D parametric design platforms. Over time, CAD systems have added specialized environments for tasks including environmental assessment (Tao, et al., 2018), kinematic analysis (Campi, et al., 2020) and ergonomic evaluation (Marconi, et al., 2018).

The challenge of formalizing Design for X (DfX) engineering knowledge has led to solutions like knowledge-based engineering systems, with research focusing on managing design knowledge and creating ontologies for specific design objectives like Design for Manufacturing (DfM) and Design for

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Assembly (DfA). Ontology-based knowledge processing is increasingly gaining traction in the field of DfX engineering as a valuable tool for managing and applying specialized design knowledge (Schmidt, et al., 2020).

In DfX, various methods play a crucial role in improving product development. They fall into two categories: product-oriented (e.g., Design for Manufacturing (DfM)) focused on enhancing product features and attributes and process-oriented (e.g., Design for Service (DfSv)) aimed at refining production and service efficiency. This categorization helps us understand DfX methods better. Each method is designed for specific aspects of designing and developing a product, working together to ensure the final product and its processes are excellent (Kremer, et al., 2023; Walid, et al., 2023; Mesa, 2023; Formentini, et al., 2023).

In response to the urgent need to address climate change, sustainability requirements for products have expanded significantly. The growing knowledge base on sustainability has given rise to various subtypes of 'design for sustainability'. To keep up with this evolving knowledge and the rapid shift toward sustainable product design, there is a critical need for continuous, open communication among product designers and researchers. This includes focusing not only on well-established and scientifically proven knowledge but also on practical, experience-based heuristics emerging among product designers (Kremer, et al., 2023).

Mesa discusses the growing importance of circular product design, involving strategies like reuse, repair, refurbishing, remanufacturing and upgrading. It highlights the potential of using Design for X (DFX) tools to improve circularity but notes that current DFX approaches are not aligned with the circular economy. To address this gap, the Mesa proposes a classification of DFX guidelines based on seven circular economy strategies aimed at promoting sustainability and reducing waste in product design (Mesa, 2023).

Design for disassembly approaches play a significant role in facilitating the transition to an industrial circular economy. Nevertheless, a noteworthy constraint in existing design for disassembly methods is their incapacity to model the consequences of a product's end-of-life status on the actual disassembly effort and the resulting implications for the applied circular design strategies (Formentini, et al., 2023).

In product development, designers have to access well-structured knowledge in a systematic approach, so that designers may be able to use organized knowledge to enhance their creativity during decision-making (Pahl, et al., 2006). A methodical gathering and application of knowledge from various fields must be provided to success an effective information retrieval. In this sense, gaining and organizing knowledge from many different DfX aspects or categories in a structured manner presents a fundamental need to build a knowledge management system throughout the early stages of product development processes. In earlier research, some of the most examined DfX approaches are Design for Assembly (DfA), Design for Manufacturing (DfM), Design for Quality (DfQ), Design for Cost (DfC) and Design for Environment (DfE), which are also applied in this research work to manage DfX based knowledge for the implementation of the proposed knowledge management and communication platform. DfA (Bouissiere, et al., 2019; Battaia, et al., 2018; Cabello, et al., 2018; Mattson and Sorensen, 2020; Remirez, et al., 2019) aims to reduce assembly lead time and costs within the restrictions set by the product`s other design elements, moreover, to facilitate long life cycle for the products that consists of large size parts. The main principles of DfA are, for example, reducing part count and types, self-locating features, modular design, top-down assembly and eliminate secondary operations. By using DfM (Mattson and Sorensen, 2020; Battaia, et al. 2018; Ji, et al. 2022; Doellken, et al., 2021; El Souri, et al., 2017), manufacturing guidelines and principles may be used to design and develop a product for an improved product quality and lower manufacturing costs. DfM approach covers using standardize components, avoiding unnecessary operations, preventing overusing of materials, defining material and process. Furthermore, DfM knowledge-based rules and principles for certain manufacturing processes, such primary forming, shaping, joining, cutting and coating, must be accessible to the engineering teams. Another approach is the DfC (Roy, 2003), which provides a wide range of ideas and guidelines to reduce costs during product development. Main aspects for a DfC analysis are manufacturing, logistics, material, maintenance, development, tool, training, testing and labour. The multifaced DfQ (Hoe and Mansori, 2018; Stylidis, et al., 2015; Sinclair, et al.,1993) aims to satisfy customer's needs and expectations to maintain competitive edge. Identifying and executing quality measures is vital in

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achieving customer satisfaction, which is a crucial aspect. DfQ includes dimensions such as performance, reliability, conformance, durability, serviceability, aesthetics and perceived quality. In addition, DfE (Fitzgerald, et al., 2007; Kolur, et al., 2020; Hauschild, et al., 2004; Telenko, et al., 2008; Mesa, 2023) has become a relevant design approach owing to public policy and government regulations. DfE comprises eliminating hazardous materials, minimizing energy demand in the manufacturing and usage, using environmentally friendly and recyclable materials, reducing emissions, minimizing disassembly time, optimizing transport operations.

DfX and knowledge management enable manufacturing companies to maintain and apply their own expertise and knowledge in a collaborative engineering area (Jari, et al., 2011). The generation and structuring of knowledge according to DfX aspects alone, however, cannot represent an effective knowledge management system. A robust knowledge management system must also enhance knowledge sharing, knowledge accessibility and knowledge use for a more informed and efficient decision-making, contributing to improved performance and productivity within the organization (Sokoh, et al., 2021). Technologies like tagging, keyword extraction, NLP and knowledge management software collectively contribute to more efficient and effective knowledge management processes by enabling the identification, organization, dissemination and utilization of valuable information and expertise within an organization (Gogineni, et al., 2019). Computer-supported tools help us learn how people collaborate in groups with the help of technology that connects them through computers. These tools make it easier to work together even when you're not in the same place (Schlichter, et al., 2001).

Frank and Echeveste introduce a method for diagnosing knowledge transfer (KT) issues within new product development (NPD) project teams, employing Quality Function Deployment (QFD) and Failure Mode and Effects Analysis (FMEA) to prioritize improvements. It emphasizes the practical application of knowledge management concepts in NPD, offering valuable insights for addressing KT barriers. However, challenges such as complexity of issues and conceptual understanding among engineers suggest the need for experienced facilitators and pre-application training. Despite limitations, the method aids in fostering discussions and enhancing KT mechanisms within companies, contributing to bridging the gap between theoretical knowledge management concepts and practical implementation (Frank and Echeveste, 2012).

Koners and Goffin examine how NPD professionals perceive post-project reviews (PPRs) and whether tacit knowledge is created during these reviews. Through five in-depth case studies in German companies, the research highlights the usefulness of PPRs and the role of social interactions and tacit knowledge in NPD learning. Limitations include the need for more robust methods to study tacit knowledge generation and transfer. The study emphasizes the importance of effectively disseminating PPR results to use the tacit knowledge generated, providing valuable insights into learning within NPD teams and underscoring the significance of interaction among professionals for knowledge transfer (Koners and Goffin, 2007).

3. Use case - Development of a 3D printer

Technische Universitaet Wien (Vienna) built the TU Wien Pilotfabrik Industrie 4.0 to do research on intelligent manufacturing systems. In the field of discrete manufacturing, the pilot factory focuses on novel ideas and approaches for various serial production scenarios (low volume - high mix). A realistic test environment is necessary for the improvement of new methods and solutions in the pilot factory, consequently, a 3D printer was selected as a sample product in many forms to explore innovative production techniques. The 3D printing industry continues to advance rapidly, therefore, this change, on the one hand, bring in new DfX consideration, but it also increases the quantity of information to take into account throughout the 3D printer development process. A practical use case may help to clarify the idea of the communication platform and can aid in a better understanding, which is why the 3D printer was selected as a use case for the intended concept founded on a knowledge management and communication system.

The product 3D Printer of the Pilot factory is based on the FDM (Fused Deposition Modelling) technology. In this technology, thermoplastic filament is heated and extruded through an extrusion head to print an object layer by layer. The main components of the 3D Printer are the extruder, print head, print bed, guide block, drive shaft, heater, cooler, motors (for X, Y, Z Axis), belt mechanism (for X, Y,

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Z Axis), filament spool holder and electronic control panel, which must be constantly adapted to technologies and requirements. In the pilot factory, the focus is put on chipping/cutting manufacturing technologies. Machining centres for milling and lathes are available to produce the 3D printer components that has a big influence on the generated design of the 3D printer.

4. Research approach

The principal concept of the current research work is presented and described by means of a potential scenario which is adapted from Henrich & Morgenroth (2006). How this DfX-based knowledge management and communication platform aims to support development teams in decision-making processes is also explained with respect to the example of 3D Printer product. Acquiring, storage and use of knowledge through a tagging or keyword extraction will be summarized for an understanding of the connection between generated knowledge and DfX principles.

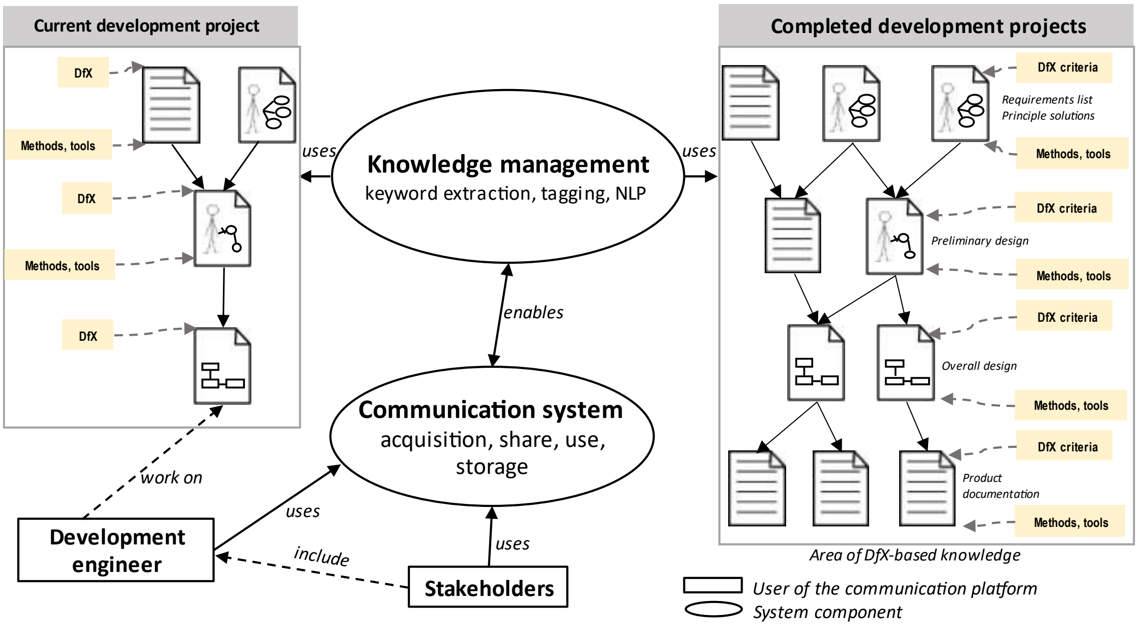

Figure 2. The basic concept modified from (Henrich & Morgenroth, 2006)

The primary components of this concept are basically communication, knowledge management and DfX-related database. Communication part support users to acquire particularly their implicit knowledge, moreover, provide presentation and use of the externalized DfX-based knowledge. Knowledge management part facilitates the creation and organization of the knowledge in a structured format by employing keywords or tagging mechanism related to DfX-based expertise during collaboration and communication of development teams. Knowledge management part realize basically an interface between communication and DfX section for an effective utilization of the generated knowledge in future projects. A 3D printer development use case, as detailed in Section 3, is used to explore the given scenario in Figure 2 to provide a greater awareness of the concept. Development team begin work on the overall design of the 3D Printer and communicate each other in the proposed software. If employees require DfX-based knowledge to complete current task, they can apply a query to search existing keywords and access DfX-based knowledge. For instance, to enhance the durability and reliability of 3D printing (Design for Quality), the drive shaft of a 3D printer needs to be designed from steel tube rather than aluminium. As a result, the primary focus for 3D printer optimization is on DfQ-related development activities at that time. For this reason, the knowledge management system identifies and uses keywords like 'missing layer, extrusion temperature, surface quality, layer thickness, printing accuracy' that are frequently addressed in the communication platform to acquire and store the necessary knowledge regarding DfQ. Furthermore, the representation and use of the stored DfQ knowledge in an upcoming project can be provided for the development team while stakeholders communicate and apply same keywords in the communication platform.

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5. Implementation of prototype

The core software requirements, main system components and a Java Model-View-Architecture for the aimed knowledge management and communication software are presented. For the realization of preliminary prototype following key requirements are defined. A communication panel must be provided to share information and text messages. A scan and tagging mechanism supported by keywords extraction and NLP is needed to acquire and use knowledge effectively since identifying keywords is the core function of proposed concept for the consciously externalization, organization and storage of implicit knowledge. Moreover, for the searching and application of the DfX based knowledge a query function is required. To ensure the generated knowledge from completed and current projects, user information as well as messaging history, a storage regarding DfX categories must be implemented. Furthermore, a knowledge retrieval function that basically consists of the creation, update and delete of knowledge must be planed.

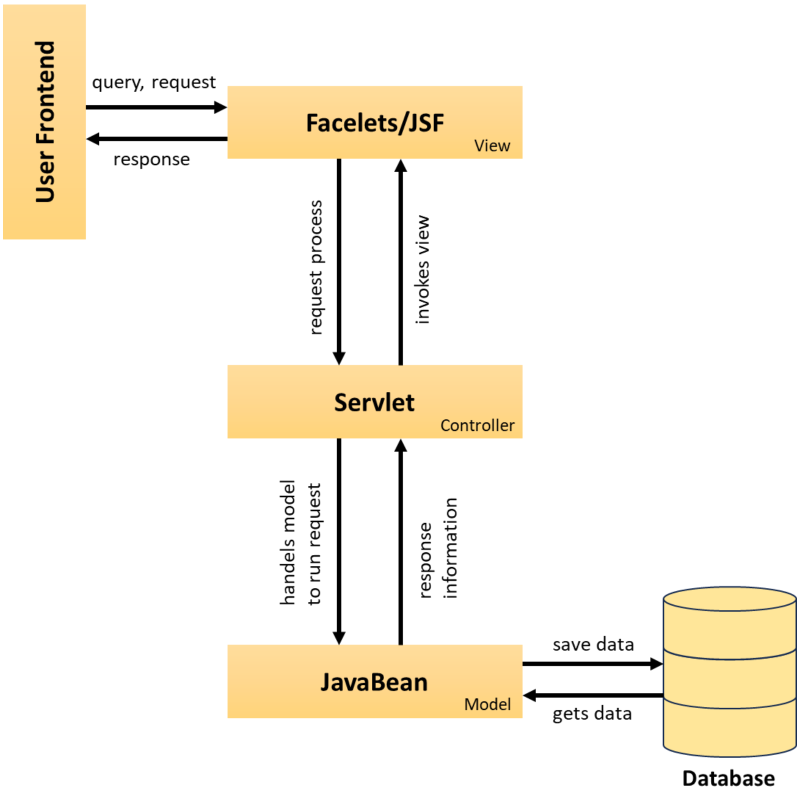

Figure 3. Model-View-Controller architecture pattern

In Figure 3 a Java MVC (Model-View-Controller) software design pattern is generated to present interaction between software technologies for the implementation of defined requirements into the prototype. Basically, user interface (UI), control logic and data processing are provided by model, controller and view components. The model component supports storage and management of data that is processed independently from the UI. The database is connected to the model, which allows information to be stored and extracted at the controller's request. The view part gives participants access to the communication platform's user interface so they may see the data that the model element of the software has gathered. User input from the view component is accepted by the controller, which uses pre-designed logic to transform the request into a model command. In short, following data update and reception into the model, data is processed and modified by the controller based on requests made by the user from the application to the browser, which then displays the result. To comprehend how the MVC software design pattern operates, 3D printer use case may be applied. Initially, the end-user can enter the communication platform through the query option or by interacting with the User-Frontend that is linked to the collaborative communication interface. A request may be in the form of a query or

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a keyword that is identified by keyword extraction with NLP assistance. For example, when a request for 'printing accuracy' is made, the Facelets/Java Server Faces (JSF) view component handles it. With the help of a Servlet, the controller component communicates with the model and uses logic to execute requests to obtain or save relevant data. JavaBeans models link to databases based on request data to store information about identified keywords 'printing accuracy' and DfX categories. The model also retrieves the required information from the database based on DfX and responds to the controller. Following the submission of the 'printing accuracy' request and information gathered from the model based on DfX, the view component shows the data to the user.

6. Application example

To provide an overview of the acquisition, structuring, storage and use of knowledge, an application example for the preliminary prototype of the communication platform is presented using a communication scenario between two different projects 'Project_01' and 'Project_02'. In Figure 4 a project manager and a designer are attending in a real-time communication for the development tasks of a 3D Printer in Project_01. When the project manager submits a text message in the Project_01 knowledge room, the system detects and underlines the keywords 'belt tension' to notify project manager to the most important key terms.

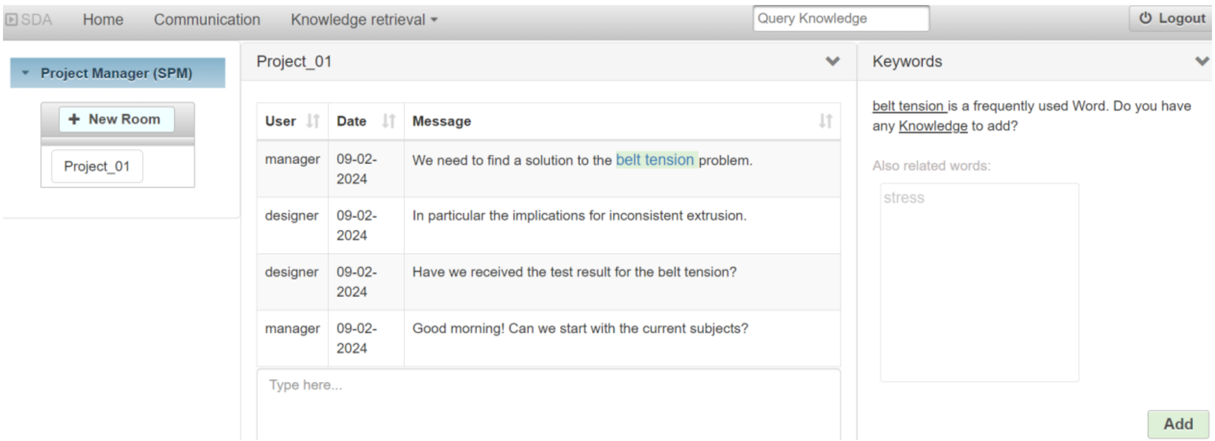

Figure 4. Extracting the keywords 'belt tension' for knowledge acquisition

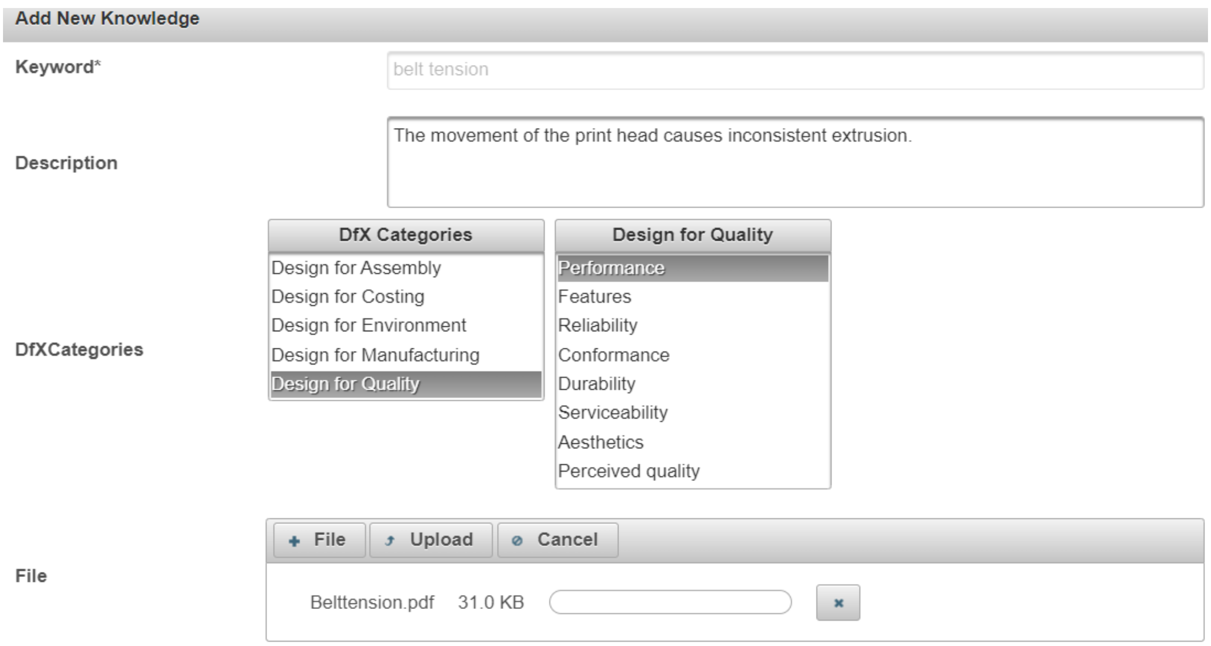

Figure 5. Acquiring, structuring and storage of knowledge using DfX categories

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In fact, identifying keywords take place through a tagging mechanism supported by NLP for both knowledge acquisition (see Figure 4) and use (see Figure 6). The fundamental method for keyword extraction or tagging is as follows: each word in the provided text or message will be analysed separately. To determine the most significant content single terms or groups of two words, the provided text is first scanned for phrase delimiters and words longer than two letters. Then, stop words from the remaining text are eliminated. After that, defined content terms are further reviewed using an API (Application Programming Interface) in relation to synonyms. For the knowledge acquisition, after elimination of stop words, remained content words in the current given text are compared additionally with the other content words from the previous messaging history based on frequency approach to recognize most repeated content words and to highlight in the provided text for the identification of the key concerns.

In Figure 5 project manager can specify knowledge in the system by activating the extracted keywords 'belt tension' and choosing the relevant DfX categories depending on the context of explicit or implicit knowledge. The project manager selects the appropriate DfX category 'DfQ' and the subcategory 'Performance' and sets the knowledge with a description in the system. The system automatically links selected DfX categories and previously extracted keywords. Corresponding files or attachments can also be provided to the storage.

Figure 6. Knowledge use by activating extracted keywords 'belt tension'

The Figure 6 presents a real-time communication between a development engineer and a quality engineer in the Project_02 knowledge room. The previously outlined keyword extraction process is applied to represent and use the acquired knowledge regarding the DfX categories this time. In Figure 6 'belt tension' is activated by the development engineer to access existing knowledge from the DfX related cloud-based storage. A brief description of the knowledge, related DfX category 'DfQ' and subcategory 'performance' are available for the development engineer to review. The presented communication scenario between Project_01 and Project_02 demonstrates how the acquisition, structuring, storage and representation of knowledge with keywords linked to DfX categories is provided. Users and system work together to realize the fundamental components of knowledge management, which enables users to access knowledge in real-time during product development.

The communication platform enables the presentation and utilization of externalized DfX-based knowledge. By utilizing the platform as a repository for DfX-related information, users can access and reference relevant knowledge resources during their interactions. This integration of DfX knowledge into the communication environment ensures that it is readily available and easily accessible to team members whenever needed. Additionally, the platform can facilitate the sharing of best practices, lessons learned and case studies related to DfX principles, further enriching the collective knowledge base of the organization.

7. Conclusion

Companies need diverse teams to generate new ideas, especially in design to compete globally. Effective teamwork and communication, with the use of collaboration tools, are key for successful product development. Clear communication prevents knowledge loss and costly mistakes, crucial for diverse teams. These teams can be close for informal interactions or work virtually for flexibility, but the right tools are essential for effective product development collaboration. To enhance and speed decision-

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making particularly in the engineering design process, an effective knowledge generation, storage, dissemination and use of implicit or explicit knowledge of experts from different areas are critical, therefore, this approach aims to develop a DfX-based knowledge management and communication tool. In today's interconnected world, effective management of knowledge is essential for organizations to remain competitive and innovative. Rapid advancements in technology and globalization have led to an exponential increase in the volume and complexity of information available to organizations. As a result, there is a growing need for tools and strategies that can help organizations efficiently capture, organize and utilize knowledge assets to drive decision-making, foster collaboration and facilitate learning. By addressing this critical need, the presented tool has the potential to significantly impact how organizations manage and utilize knowledge in the digital age. Furthermore, the required knowledge at the right time during decision-making is accessible by well-structured acquisition of expert tacit knowledge and team-level dissemination through keyword extraction. Therefore, highlighting the significance and relevance of the communication tool provides a solid foundation for this study.

In considering future recommendations, it is important to prioritize the user-friendliness and adaptability of the communication platform, which integrates artificial intelligence (AI), machine learning (ML), knowledge-based engineering and CAD integration to suit a diverse range of projects. Encouraging interdisciplinary collaboration among experts from various fields remains essential to foster innovation. Emphasizing data security, especially concerning critical design information, is of great significance. Developing training programs to optimize platform utilization is necessary, as is regarding continuous enhancement and real-world testing as integral to validate its effectiveness. Finally, the dissemination of acquired knowledge and best practices within the engineering and design communities through various channels is considered vital for the ongoing growth and improvement of the field.

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