A MODEL-BASED APPROACH TO IDENTIFY BARRIERS IN DESIGN KNOWLEDGE REUSE

Jordan, Thomas (1,2); Bender, Beate (1); Herzog, Michael (1); Song, Young-Woo (1)

1: Chair for Product Development, Ruhr University Bochum, Germany; 2: Komatsu Germany GmbH

ABSTRACT

Today, information and knowledge as competitive factors influence the success of companies as much as traditional production factors like human resources or physical capital. However, the reuse of design knowledge still represents a major challenge for engineering organizations. That is, because barriers exist hindering a successful knowledge reuse. On the basis of a literature review, the research depicted in this paper analyses the relation between single information conveying design knowledge and barriers hindering a successful knowledge reuse. Developing a model-based approach, we propose a micro logic containing three steps and underlying methods enabling practitioners to identify situation-specific barriers within their organization. We illustrate the industrial application of the approach in a case study at a mining machinery OEM.

Keywords: Knowledge management, Information management, Design management, Knowledge barriers, Design knowledge reuse

Contact:
Jordan, Thomas
Ruhr-University Bochum; Komatsu Germany
Chair for Product Development
Germany
thomas.jordan@komatsu-mining.de

Cite this article: Jordan, T., Bender, B., Herzog, M., Song, Y.-W. (2019) 'A Model-Based Approach to Identify Barriers in Design Knowledge Reuse', in *Proceedings of the 22nd International Conference on Engineering Design (ICED19),* Delft, The Netherlands, 5-8 August 2019. DOI:10.1017/dsi.2019.249

1 INTRODUCTION

Today, information and knowledge as competitive factors influence the success of companies as much as traditional production factors like human resources or physical capital (Gaag, 2010). Although an organization's knowledge base may be its single most important asset, its very intangibility makes it difficult to manage systematically (Bohn, 1998). Specifically, in product development the reuse of knowledge is an essential need driven by the design challenge: to produce the right product in minimum time with minimum cost (Baxter *et al*., 2008). The aim is to increase the awareness of existing solutions when investigating design problems (Ling *et al*., 2008) and to prevent "reinventing the wheel" as well as repeating past mistakes (König, 2012). Even though companies are reasonably successful in acquiring knowledge, this competitive factor is often neglected due to an ineffective dissemination and low reuse level (McShane and Von Glinow, 2010). These findings are supported by experience obtained from an industrial use case of an OEM in the machinery engineering sector. The case study implies that knowledge exchange is often inefficient. This becomes apparent in recurring product failures (Jordan *et al*., 2017). Therefore, still today the challenge for companies to reuse documented knowledge is a broad field in engineering design research (c.f. Holland *et al*., 2018; Carro Saavedra & Lindemann, 2017).
We conducted the research in this paper starting with a literature review. This allows to examine the difficulties of design knowledge reuse and furthermore to understand why current methods and tools are not enough to bridge the gap. Based on that, we propose a model-based approach to identify company-specific barriers hindering the reuse of design knowledge and apply it within a case study. Identified barriers can be an input variable to choose suitable knowledge management systems as a countermeasure.

2 RESEARCH METHODOLOGY

As stated by Ponn (2007), scientific perceptions are highly related to the used methods under which these perceptions have been obtained. To allow for a discussion about the validity of the findings, we followed the Design Research Methodology (DRM) of Blessing & Chakrabarti (2009). The DRM comprises four stages. In the following paragraph we introduce the individual stages and explain their objectives with regard to our specific case, as well as methods we have used to obtain our perceptions:

- Research Clarification (RC): In the first stage of the DRM, the researchers are supposed to introduce the topic and to emphasize the need to develop support. In our case, we combine observations from industry with a first literature review to explain the findings in chapter 1.
- Descriptive Study I (DS I): In the second stage of the DRM, the researchers depict the field of research in greater extent to gain an understanding of the phenomenon they aim to support in the subsequent stage. In our case, we underline the research gap based on an extensive literature analysis in chapter 3 and formulate the major research question as the central input parameter to develop support.
- Prescriptive Study (PS): Within the prescriptive study the supporting approach is developed. Based on a synthesis of the findings from the descriptive study, we propose a model-based approach to identify barriers in design knowledge reuse. This approach is presented in chapter 4.
- Descriptive Study II (DS II): The fourth stage of the DRM emphasises the evaluation of the supporting approach developed in the prescriptive study. In our case, we evaluate the proposed model-based approach in a case study. For this purpose, we illustrate the application of the approach parallel to the PS in chapter 4 by means of an industrial use case of design knowledge reuse from product maintenance to product generation development. Further evaluation is part of the conclusion and outlook in chapter 5. Here, the research question as initially raised in chapter 3 is answered.

3 STATE OF THE ART

3.1 Knowledge reuse

In the context of knowledge management, there are many different terms widely used synonymously or are considered to describe overlapping content (Paulin & Suneson, 2012). One of these terms is "knowledge reuse". To define this term in the context of this paper, we distinguish between two different interpretations according to Carro Saavedra & Lindemann (2017). The first one as defined by

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

Probst (1998) relates to the point in time of knowledge usage, in which an individual performs the usage. Chhim *et al*. (2018) extend this interpretation to a process by which an individual or entity can locate and use shared knowledge. Markus (2001) describes this process in four steps: 1) defining search question, 2) locating experts or expertise, 3) selecting an appropriate expert or expertise, and 4) applying the knowledge in new context.

According to Hicks *et al*. (2002), the reuse of knowledge in engineering design typically aims to make the experiences of individual knowledge or organisational knowledge from previous design activities available. Furthermore, it supports to better inform and enable future design activities. This aim of knowledge reuse correlates with the second common interpretation of the term in literature. It considers the whole knowledge cycle from capturing to actual reuse instead of only considering the concrete moment of knowledge reuse (Carro Saavedra & Lindemann, 2017). Marcus (2001) describes the knowledge reuse cycle in four stages where the last stage is also called reuse: 1) capturing or documenting knowledge; 2) packaging knowledge; 3) distributing or disseminating knowledge, and 4) reusing knowledge.

Following the aim of knowledge reuse in engineering design by Hicks *et al*. (2002), we apply the definition in our paper as the whole knowledge cycle from capturing to reusing it.

3.2 Barriers hindering knowledge reuse

Even though knowledge reuse is considered to be highly beneficial in engineering design, observations from industry indicate “practitioners are still struggling in managing what they know” (Schacht & Maedche, 2016). That is, because barriers exist hindering a successful knowledge reuse. Paulin & Suneson (2012) postulate three different views to investigate knowledge barriers: 1) lack of knowledge about something depending on barriers for knowledge sharing or transfer; 2) not enough knowledge depending on the level of education in a certain area or about a particular topic; and 3) the perceptual system in a specific human or group of humans does not contain enough contact points, or does not fit incoming information to utilize it and convert the information to knowledge.

Yih-Tong-Sun & Scott (2005) on the other hand, divide knowledge reuse barriers in an organization by the levels of learning and conclude on level-specific barriers: a) individual level barriers (i.e. knowledge perceived as a threat); b) team level barriers (i.e. knowledge competition with other teams); and c) organizational level barriers (i.e. organizational culture). Riege (2005) extends these individual and organisation levels based on the “triad of knowledge-sharing barriers” by technological barriers (e.g. lack of integration of IT systems with processes).

3.3 Knowledge reuse support by knowledge management

To support knowledge reuse, methods and findings from knowledge management can be applied. Generally, most research in this field can be traced back to two basic foundations of knowledge management (Laukemann *et al*., 2018). One is the knowledge spiral after Nonaka and Takeuchi, which explains how knowledge is created, used and distributed in industrial practice. The other essential foundation by Probst *et al*. (2012) explains the core activities of knowledge management comprising the preservation, identification, acquisition, development, sharing and use of knowledge.

These two foundations are the base of most knowledge management methods and support tools. These differentiate between codified approaches to manage documented knowledge on the one hand, and personalization approaches focussing on the transfer of non-documented knowledge between persons on the other hand.

3.4 Research gap & research question

Even though there is abundant literature for the implementation available and knowledge management methods and tools are widespread in industry (Zieba *et al*., 2016), it can be observed that there is still inefficient reuse of available knowledge in engineering design of many organizations. Carro Saavedra & Lindemann (2017) conclude that the reasons for the insufficient knowledge reuse may be various and often unclear. Besides, the variety of potential barriers mentioned in section 3.2 is different from organisation to organisation and may even vary within individual processes of an organisation (Kern *et al*., 2009). Successful knowledge management, however, requires a deep understanding of the barriers involved (Storey & Barnett, 2000).

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

Therefore, the underlying hypothesis of our research is that the identification of situation-specific barriers in knowledge reuse is a compelling requirement to select suitable knowledge management support systems in engineering design. Based on this hypothesis, the paper's objective is to answer the research question: *How can situation-specific barriers during design knowledge reuse in an organization be identified?*

3.5 Case study

Following this question, we developed a model-based approach to support knowledge reuse in engineering design. The approach was partially applied to a mining machinery OEM to evaluate the utilization and results of this support in design challenges. The organisation develops and manufactures cost-intensive mining machines in very small lot sizes. Therefore, continuous design activities after market introduction, so called product maintenance activities, are necessary to improve the product maturity, e.g. by eliminating product failures or improving the machine performance. As a side effect, valuable design knowledge is generated during these activities, which can be reused for the development of next product generations. However, the organisation's experiences imply that the reuse of design knowledge is often inefficient.
In the next section of our paper we introduce the methodical representation of our model-based approach and the application of its micro logic in the case study to understand the root cause of the inefficiency and to identify barriers during the reuse of design knowledge.

4 A MODEL-BASED APPROACH TO IDENTIFY BARRIERS IN DESIGN KNOWLEDGE REUSE

4.1 General framework

According to Pahl *et al*. (2007), design support in the form of methods and guidelines should always follow a systematic, problem-oriented approach compatible with concepts, methods and findings from other disciplines. Following this requirement, we focussed on the application of commonly used methodologies as a general framework.
The identification of barriers in design knowledge reuse with regard to the selection of suitable knowledge management support is a typical problem-solving task. It comprises an undesirable initial state, a desirable goal state and obstacles preventing a transformation from initial to desirable state. For such purposes, a wide range of models and methodologies is described in literature. In our case, we base on the system-analysis-cycle of Ehrlenspiel (2013) to create the meta model of our approach. Figure 1 (left) depicts the general sequence of the cycle which has been created to perform a system analysis from which one can gain an understanding of system properties. Based on a task or problem, three major steps are subsequently following in this cycle: 1) task clarification in which the task is analysed, formulated and structured; 2) search for hypothesis in which various possible cause-and-effect analysis are formulated as different hypothesis; and 3) selection of the most suitable hypothesis by analysing and evaluating each single hypothesis.

4.2 Meta model: basic structure of the approach

Following the system-analysis-cycle of Ehrlenspiel, we based the structure of our supporting approach to identify barriers in design knowledge reuse on this three-step-approach. Starting with the task clarification, we divide this step into two different partial models which relate to a retrospective investigation of an organization's experience of design knowledge reuse. As already outlined in section 3.4, the representation of the organization's former experience is key to identify situation-specific barriers. Therefore, the first partial model deals with the determination of a set of significant information I conveying this design knowledge which has not been reused in the past. In parallel, the second partial model aims to determine a set of potential barriers B which can hinder the design knowledge reuse.
In the second step these two partial models are linked by formulating a set of hypotheses. For this purpose, each significant information I is correlated with a potential barrier B leading to a hypothesis H which implies that the potential barrier hindered the reuse of information I as depicted in Equation 1. Mathematically, the number of hypotheses is therefore the product of the two factors significant information I and potential barriers B.

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

$$H_i = B_i \cdot I_i \tag{1}$$

In the third step the hypotheses are tested by combining both partial models by an associative correlation within a correlation model to verify, or falsify each single hypothesis and select the "most likely hypothesis" (Ehrlenspiel, 2013). Figure 1 (right) shows our meta model.

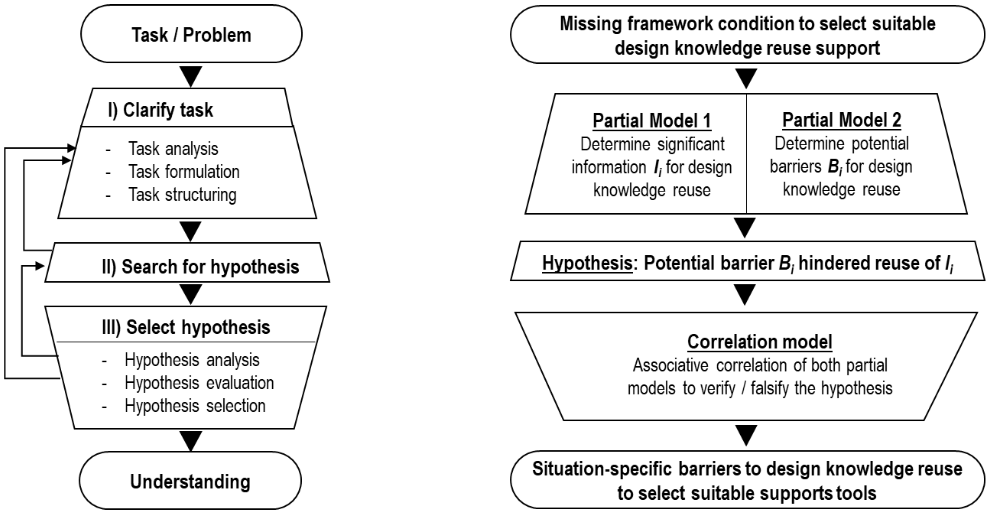


Figure 1. left) system-analysis-cycle (Ehrlenspiel, 2013); right) meta-model to identify barriers in design knowledge reuse

Based on this information, it is possible to gather an understanding for the key barriers of design knowledge reuse, which support to select suitable knowledge management methods and tools counteracting these barriers.

4.3 Micro logic: model-based support within the approach

Utilizing the above-mentioned approach, we partition the problem-solving task in single, less complex models. Hence, it allows us to determine situation specific barriers in design knowledge reuse. In the remainder of this sub-section we will explain the inherent logic within the three models of the approach. In addition, we describe the set of methods and their application within our case study to generate the needed information.

As a general method for all models, we use matrix representations based on Design Structure Matrix (DSM) methods as they emerged to represent the relations between information in processes. These methods were successfully proven in several situations of process analysis (c.f. Neumann & Bender, 2016; Lindemann *et al*., 2009) which are comparable to our framework.

4.3.1 Partial model 1: determine significant information

Partial model 1 is based on the retrospective investigation of significant information conveying design knowledge which has not been reused in subsequent design stages or following design processes. Therefore, a Domain Mapping Matrix (DMM) can be created to depict the relation between these two domains *information* and *design stage*/*design processes*. The needed information can be acquired by following process within an analysis of existing data bases, project documentations and interviews with involved designers in an organization: 1) selection of representative projects; 2) isolation of single information containing design knowledge not reused; 3) correlation of single information to beneficial design stage/design process; 4) valuation of the information significance (e.g. by impact or failure probability); and 5) clustering of most relevant/most significant information *I*.

The binary relation of the two domains allows for the identification of a cluster with highest information significance. Here, the most important design knowledge to be reused. Interviewing the involved stakeholders (e.g. "knowledge generators" and "knowledge users") allows to evaluate the information significance. It can be done by assessing the importance of a single knowledge chunk, as well as the expected probability of design flaws or time waste in case this knowledge chunk is not reused. A grading system for the parameters importance and perceived probability suitable to the organization's characteristics (e.g. 1 = safety-relevant; 0.8 = product quality-relevant; 0.5 = process quality-relevant) is

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

suggestive. Figure 2 (left) summarizes the methodical approach to create the partial model 1 which is denoted as the Knowledge DMM.

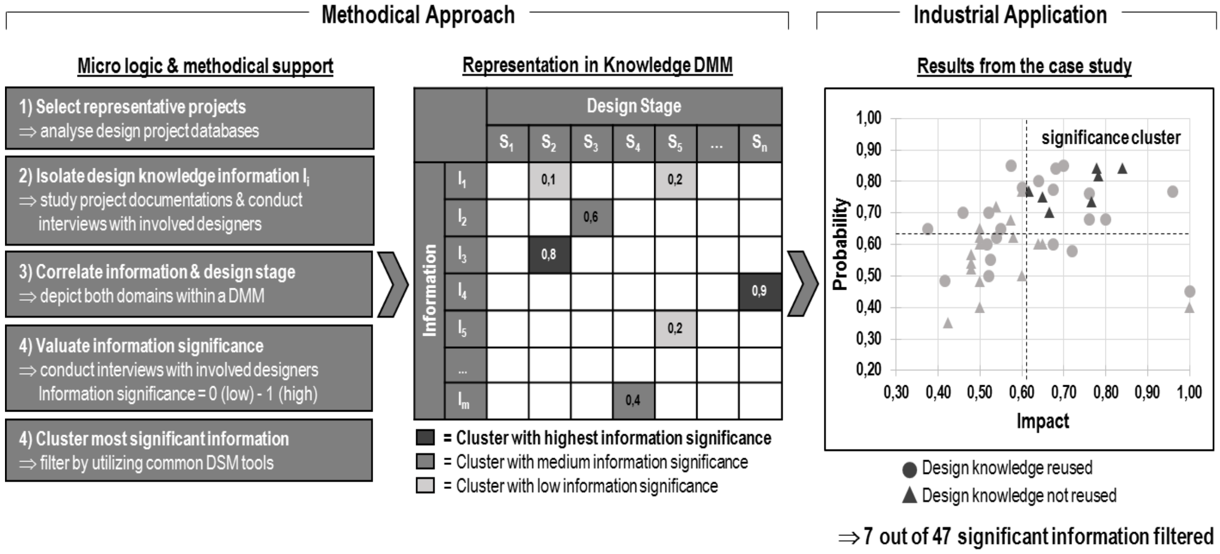


Figure 2. Micro logic to determine the knowledge DMM in partial model 1 & results from application in the case study

We applied our micro logic and its methods within the case study. To acquire the necessary data, we followed the above described process and interviewed 18 designers from the two main stakeholder groups “knowledge generators” (product maintenance team; n=7) and “knowledge seekers” (product development team; n=11). Additionally, we analysed project reports and databases. In total, we considered information from 20 typical product maintenance projects dealing with the remediation of product failures during machine usage. Studying the project documentation and interviewing the designers enabled us to identify a total pool of 47 chunks of design knowledge information *I*. Furthermore, we depicted the respective design stages in which these information are beneficial to be reused during product generation development. Concurrently to this, we evaluated the information significance with the involved designers through a numerical representation characterising on the one hand the impact of the information. This was done based on the companies SLQDC philosophy, which is an acronym for Safety (1 = safety and health), Law (0.9 = general compliance with the law/environmental regulations), Quality (0.8 = quality and reliability), Delivery (0.5 = timing/risk for iterations), and Cost (0.3). On the other hand, we evaluated the perceived probability for a failure recurrence distinguishing between a high (1), middle (0.7) and low (0.3) probability. Based on clustering the data set with a total pool of 47 information, we could determine the seven most significant information conveying design knowledge which have not been reused in past product generation development activities. Figure 2 (right) depicts the graphical representation of the Knowledge DMM in the organisation analysed within the case study.

4.3.2 Partial model 2: determine potential barriers

Partial model 2 is the representation of potential barriers which might hinder a successful design knowledge reuse in the observed process/organization. Based on a company audit, we propose to conduct semi-formal interviews with the stakeholders involved. For that purpose, a general morphology was created, in which the potential barriers are characterised by two different parameters. On the one hand, they address the stages during the knowledge cycle from capturing until reusing of knowledge. On the other hand, these barriers are differentiated by the triad of barrier levels in terms of individual, organisational and technical barriers. Figure 3 shows the representation within a matrix. Utilizing this morphology, potential barriers can be identified and assigned to each cell of the matrix during the interviews with the relevant practitioners by retrospective analysis of former experiences during design knowledge reuse.

In the case study, we conducted semi-formal interviews with the product maintenance and the product development teams utilizing the knowledge barrier morphology to share their past experiences and

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

collect potential barriers when supporting a reuse of the design knowledge-related information. From this approach eleven potential barriers *B* were identified.

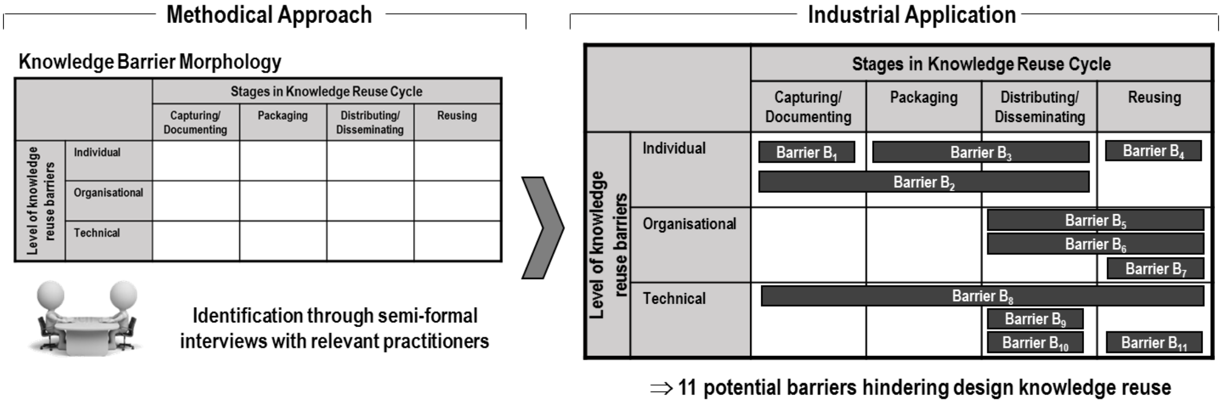


Figure 3. Representation to determine potential barriers & results from application in the case study

Generally, this matrix contains useful information that can be utilized to determine support tools to improve the knowledge reuse. However, to identify the actual impact of each barrier within the knowledge reuse process of the most significant information we aim to correlate these barriers from partial model 2 with the identified significant information from partial model 1. Thus, we formulate hypotheses implying that each barrier *B* hindered the reuse of knowledge from each significant information *I*. The target by this means is to finally identify and highlight the most important barriers that are specific for a certain situation through evaluation of each hypothesis.

4.3.3 Correlation model: verification/falsification of hypotheses

The selection of suitable hypothesis from the complete set of hypotheses is performed by analysis and evaluation in a further step. This correlation model links the significant information from partial model 1 with the potential barriers from partial model 2 by associative characteristics. In literature, several approaches exist to categorize knowledge, respectively each chunk of information conveying knowledge. In most cases these approaches base on dichotomic classifications. An example of these dichotomic classifications even can be found in ancient Greece. Philosophers separated knowledge in practical knowledge, acquired through experience, and theoretical knowledge, which is generated through theorization. Romhardt (1998) collected 40 pairs of knowledge dichotomies (e.g. implicit vs. explicit, codable vs. non-codable, declarative vs. procedural) from various scientific disciplines. We utilize these dichotomies to characterise the identified significant information based on their specific shape within our approach.

Additionally, these knowledge dichotomies can be harnessed to describe knowledge reuse barriers. Based on single dichotomies, one can define verification (must/can) or falsification criteria for each barrier and denote the resulting annotation as the characterisation vector *βi* of a specific barrier *Bi*.

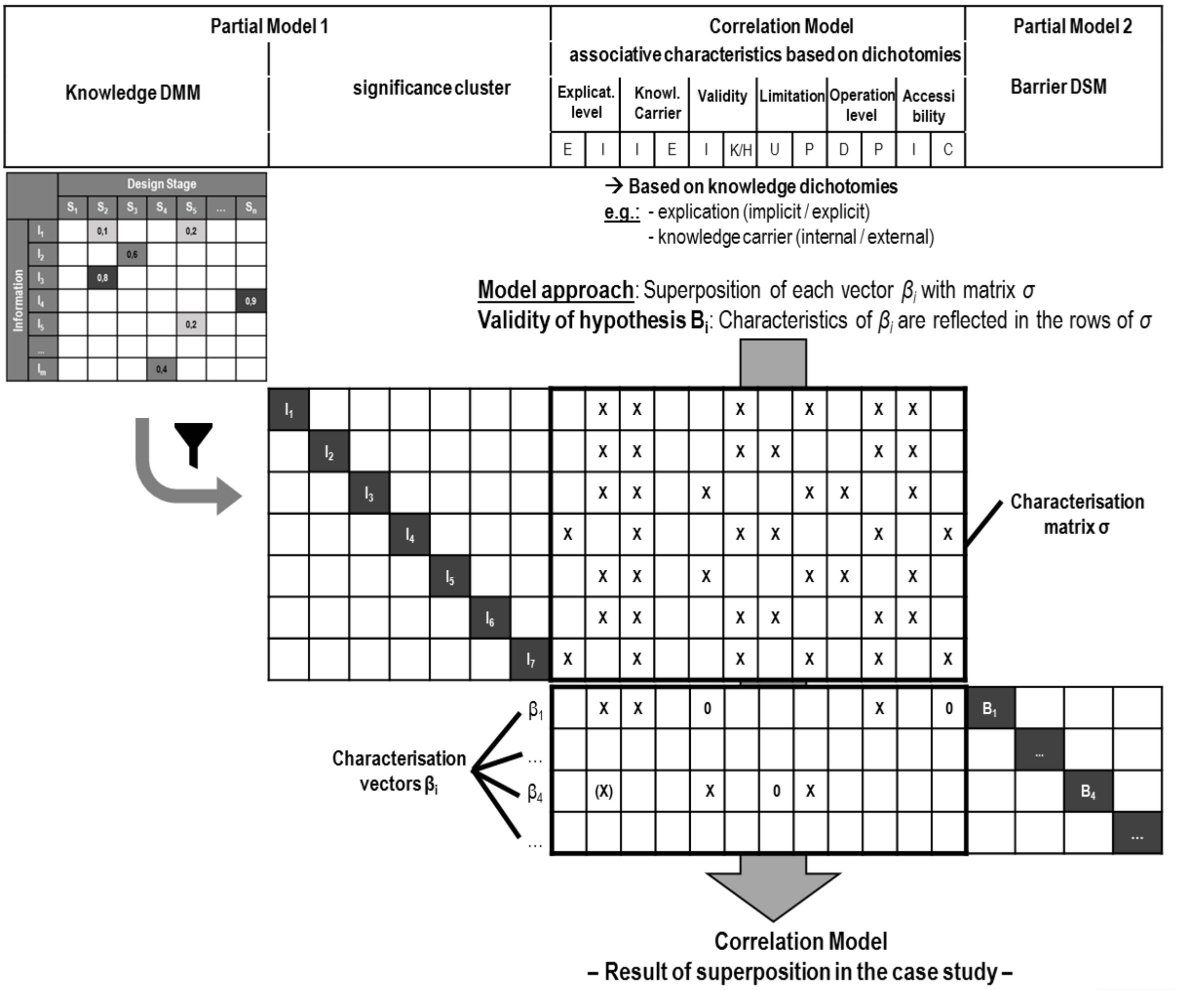
Knowledge Reuse Barrier	Associative characteristics based on knowledge dichotomies												
	Level of explication		Knowledge carrier		Validity		Limitation		Level of operation		Accessibility		
	Explicit	Implicit	Internal	External	Information	Know-How	Universal	Particular	Declarative	Procedural	Individual	Collective	
B1: Validation knowledge is not documented		X	X		0					X		0	β_1
…													
B4: Relevance of knowledge is not clear		(X)			(X)		0	X					β_4
…													

X = verification criteria (must)
(X) = verification criteria (can)
0 = falsification criteria

Figure 4. Example of utilization of dichotomies to describe knowledge reuse barriers

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

Figure 4 shows two examples how dichotomies can be used to describe typical design knowledge reuse barriers. These examples are potential barriers identified in the case study. The first potential barrier (*B1*) "validation knowledge (how to test?) is not documented" reflects a potential discrepancy between the information needs from the knowledge seeker and the information typically documented by the knowledge generator. The second potential barrier (*B4*) "relevance of knowledge is not clear" is a typical knowledge reuse barrier for knowledge seekers who are confronted with design solutions from past development projects and need to evaluate whether it is suitable for their problem. Their characterisation was analysed based on the 40 knowledge dichotomies. However, not all but six dichotomic pairs were sufficient and chosen to describe the potential barriers within the case study.
Utilizing a DMM, the table in Figure 4 can be transformed to describe the characterisation vectors β for each potential knowledge reuse barrier B from partial model 2. Additionally, a second DMM can be created to depict the relation between significant information *SI* and the form of the associative characteristics which we denote as the characterisation matrix σ. Combining both DMMs, we form our correlation model.



		Accordance check with significant information							Total
		I_1	I_2	I_3	I_4	I_5	I_6	I_7	
Barrier	B_1	X	X	0	0	0	X	0	3
	...								
	B_4	0	0	X	0	X	0	0	2
	...								

Figure 5. Correlation model with the micro logic of the approach & results of application in the case study

It is the base to analyse, evaluate and select the right hypothesis. By superposition of both DMMs, we can compare the characteristics of every potential barrier's characterisation vector βi with each row of the information characterisation matrix σ. It allows to validate the single hypotheses. If the verification

https://doi.org/10.1017/dsi.2019.249 Published online by Cambridge University Press

criteria of vector βi are in accordance with the entries in a single row of the matrix σ, it can be postulated that the underlying potential barrier B hindered the design knowledge reuse of the specific information *I*. Vice-versa, if a falsification criterion is contradicting the superposition of a vector with the entries within the matrix, the hypothesis can be falsified, and the potential barrier did not act to hinder the knowledge reuse. Figure 5 illustrates the methodical approach and the results of its application in the case study.

Based on the superposition of each vector βi with the matrix σ, the barriers can be mapped to the actual information to understand the specific barrier hindering each knowledge reuse. In the case study we formulated 14 hypothesis based on the seven most significant information *I* and the two potential barriers *B*. Applying the methods of the correlation model, we found out that the dichotomous characteristics of potential barrier *B1* are reflected within three information chunks (*I1*, *I2*, *I6*) conveying design knowledge and might be the root cause why this knowledge could not be reused. Additionally, we concluded that this barrier did not influence the knowledge reuse of the other information chunks (*I3, I4, I5, and I7*). Either not all verification criteria were met, or a falsification criterion was affected. Furthermore, we validated that the potential barrier B4 acted on two information chunks (*I3*, *I5*). Hence, we postulate that both barriers are evidently specific in the context of the organization's design process and need to be considered to improve the design knowledge reuse process.

5 CONCLUSION AND FUTURE WORKS

Considering the research question posed at the beginning of the paper, we can state that the model-based approach suggested in this paper supports to link information conveying design knowledge from past development projects with barriers hindering a successful knowledge reuse. Consequently, situation-specific barriers can be identified. Through our case study, we can show that it is possible to gather this key information in an industrial surrounding. It can be used as highly relevant requirement and input variable to select suitable knowledge management tools and methods, while considering the individual circumstances of an organization, respectively a specific process within an organization.

Even though we successfully tested the general application of our approach in an industrial case, however, there are further steps that need to be considered to further improve the method itself. On the one hand, the current approach is limited to very specific circumstances under which it can be deployed. Some general requirements are the quality, availability and accessibility of the organization's data to acquire the necessary input for the two partial models. Additionally, the characterisation of knowledge reuse barriers by knowledge dichotomies is a simple process, however, it needs a specific, granular formulation of the knowledge barrier as general barriers do not always have an explicit and distinct shape of each dichotomy.

On the other hand, our approach is currently a stand-alone solution for the specific problem of identifying barriers in design knowledge reuse. It must be considered, how to integrate this approach into general design methodologies and to connect it with frequently used methods by practitioners to simplify its application and support its acceptance in the industry.

Our next step therefore is to continue the evaluation of the approach following the guidelines within the Prescriptive Study II of the DRM. The industrial application of this approach will be focussed to conclusively formulate the framework under which this approach can be anchored in the scientific discourse of methodologies and how it can be further utilized in industry.

REFERENCES

Baxter, D., Gao, J. and Roy, R. (2008), "Design Process Knowledge Reuse Challenges and Issues", In: *Computer-Aided Design and Applications*, Vol. 5 No. 6, pp. 942–952. https://doi.org/10.3722/cadaps.2008.942-952

Blessing, L.T.M. and Chakrabarti, A. (2009), *DRM: A Design Research Methodology*, Springer, London. https://doi.org/10.1007/978-1-84882-587-1_2

Bohn, R.E. (1998), "Measuring and managing technological knowledge", In: Neef (Ed.), *The Economic Impact of Knowledge*, Elsevier, Amsterdam, pp. 295–314. https://doi.org/10.1016/B978-0-7506-7009-8.50022-7

Carro S.C. and Lindemann, U. (2017), "K-more - a methodology to manage documented knowledge for reuse", In: *Proceedings of the 21st International Conference on Engineering Design* (*ICED17*), Vol. 6: Design Information and Knowledge, Vancouver, Canada, pp. 151–160

Chhim, P.P, Somers, T.M. and Chinnam, R.B. (2017), “Knowledge reuse through electronic knowledge repositories”, In: *Journal of Knowledge Management*, Vol. 21 No. 4, pp.741–764. https://doi.org/10.1108/JKM-03-2016-0126
Ehrlenspiel, K. (2013), *Integrierte Produktentwicklung - Denkabläufe, Methodeneinsatz, Zusammenarbeit,* Hanser, München. https://doi.org/doi.org/10.3139/9783446436275
Gaag, M. (2010), *Entwicklung einer Ontologie zur funktionsorientierten Lösungssuche in der Produktentwicklung,* Doctoral Dissertation, Technische Universität München.
Holland, D.P., Walsh, C.J. and Bennett, G.J. (2018), “A qualitative investigation of design knowledge reuse in project-based mechanical design courses”, In: *European Journal of Engineering Education*, Vol. 9 No. 6, pp. 1–16. https://doi.org/10.1080/03043797.2018.1463196
Hicks, B.J, Culley, S.J., Allen, R.D. and Mullineux, G. (2002), “A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design”, In: *International Journal of Information Management*, Vol. 22 No. 4, pp. 263–280.
Jordan, T., Herzog, M., Neumann, M. and Bender, B. (2017), “A matrix-based concept to analyse the reuse of product maintenance information in future product developments”, In: *Proceedings of the 17th International Dependency & Structure Modeling Conference*, Espoo, Finland, pp. 83–94.
König, M. (2012), “Why KM - the importance of knowledge management”, www.kmworld.com (accessed on 2018-11-04).
Kern, E.M., Sackmann, S. and Koch, M. (2009), “Wissensmanagement in Projektorganisationen - Instrumentarium zur Überwindung von Wissensbarrieren”, In: Keupr (Ed.), *Wissens- und Informationsmanagement,* Gabler, Wiesbaden, pp. 54–69.
Laukemann, A., Roth, D., Binz, H. (2018), “How much knowledge management is hidden in design methods?”, In: *Proceedings of the International Design Conference - Design 2018*, Dubrovnik, Croatia, pp. 1607–1618. https://doi.org/10.21278/idc.2018.0406
Lindemann, U., Maurer, M., Braun, T. (2009), “Structural complexity management: an approach for the field of design”, Springer, Berlin. https://doi.org/10.1007/978-3-540-87889-6
Ling, T.N., Yih, G.C., Eze, U.C., Gan, G.G. (2008), “Knowledge Management drivers for organisational competitive advantages”, In: *Proceedings of Applied Int. Business Conference*, pp. 501–510.
Markus, L. M. (2001), “Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success”, In: *Journal of management information systems*, Vol. 18 No. 1, pp. 57–93.
McShane, S. L., Von Glinow, M. A. (2010), *Organizational Behaviour: Emerging Knowledge and Practice for the Real World,* McGraw-Hill/Irwin, New York.
Neumann, M., Bender, B. (2016), “Risk-oriented development of innovative products: a model-based approach”, In: *Proceedings of NordDesign* 2016, pp. 350–359.
Pahl, G., Beitz, W., Feldhusen, J. and Blessing, L. (2007), *Engineering design: A systematic approach*, 3rd ed., Springer, London. https://doi.org/10.1007/978-1-84628-319-2
Paulin, D., Suneson, K. (2012), “Knowledge Transfer, Knowledge Sharing and Knowledge Barrier - Three Blurry Terms in KM”, In: *Electronic Journal of Knowledge Management*, Vol. 10 No. 1, pp. 81–91.
Ponn, J. (2007), *Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte*, Doctoral Dissertation, Technische Universität München.
Probst, G. J. B. (1998), *Practical Knowledge Management: A Model that Works*. Arthur D Little PRISM, Second Quarter, pp. 17–29.
Probst, G. J. B., Raub, S.P., Romhardt, K. (2012), *Wissen managen - Wie Unternehmen ihre wertvollste Ressource optimal nutzen,* Springer-Gabler, Wiesbaden. https://doi.org/10.1007/978-3-8349-4563-1
Riege, A. (2005), “Three-dozen knowledge-sharing barriers managers must consider”, In: *Journal of Knowledge Management*, Vol. 9 No. 3, pp. 18–35. https://doi.org/10.1108/13673270510602746
Romhardt, K. (1998), *Die Organisation aus der Wissensperspektive: Möglichkeiten und Grenzen der Intervention*, Gabler, Wiesbaden. https://doi.org/10.1007/978-3-322-94610-2
Schacht, S., Maedche, A. (2016), “A Methodology for Systematic Project Knowledge Reuse”, In: Razmerita, L. (Ed.), *Innovations in Knowledge Management,* Springer, Berlin, pp. 19–44. https://doi.org/10.1007/978-3-662-47827-1_2
Storey, J., Barnett, E. (2002), “Knowledge management initiatives: learning from failure”, In: *Journal of Knowledge Management*, Vol. 4 No. 2, pp. 145–156. https://doi.org/10.1108/13673270010372279
Yie-Thong Sun, P., Scott, J.L. (2005), “An investigation of barriers to knowledge transfer”, In: *Journal of Knowledge Management*, Vol. 9 No. 2, pp. 75–90. https://doi.org/10.1108/13673270510590236
Zieba, M., Bolisani, E., Scarso, E. (2016), “Emergent approach to knowledge management by small companies: multiple case-study research”, In: *Journal of Knowledge Management*, Vol. 20 No. 2, pp. 292–307. https://doi.org/10.1108/JKM-07-2015-0271