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ANALYSIS OF EMPIRICAL STUDIES IN DESIGN RESEARCH

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1. Introduction

Design research is a relatively young discipline and the design research community has often been described as "multi-faceted" [McMahon 2011], [Eckert 2003]. Accompanying these "multiple facets" is a variety of research approaches, both in terms of study designs and data collection methods. This enables the researcher to choose from multiple ways of conducting his research but can also lead to a lack of orientation for choosing the most suitable one. Accordingly, Blessing and Chakrabarti [2002] observed a "lack of rigour" in design research and developed a design research methodology [Blessing and Chakrabarti 2009]. The methodology includes four research stages and provides an overview on possible research approaches. Two of the research stages are empirical and in case they are "comprehensive", include one or more empirical studies [Blessing and Chakrabarti 2009]. Empirical studies require data collection, as they are "based on observation or experience rather than theory or pure logic" [Oxford Dictionary 2013]. Since data collection requires considerable effort and often cannot be repeated, the (empirical) study design as well as the data collection methods have to be planned carefully. But how can the most suitable study designs and data collection methods be selected? In order to approach this question and identify best practices, we examined a collection of scientific publications describing empirical studies from different conferences and journals. As they were peer-reviewed, a certain quality of their choice of the study designs and data collection methods can be guaranteed. Moreover, the analysis can reveal existing gaps in research, i.e. study designs or data collection methods that are not often conducted and can possibly provide new, unexpected insights.

2. Literature review

In order to gain an understanding of the theme of design research pertaining to product development, a literature review was conducted. An empirical study involves a product development scenario, study design and data collection methods. Common product development scenarios are described in Section 2.1, while Sections 2.2 and 2.3 cover data collection methods and study design in detail.

2.1 Product development scenarios

For the classification of product development scenarios addressed by empirical studies, the 7 steps of the product development process of the Munich Procedure Model [Lindemann 2009] were used as a reference. During the analysis, some product development scenarios were found to have a relative infrequent occurrence. In order to facilitate the subsequent analysis and increase statistical validity, goal planning, goal analysis and task structuring were consolidated as "early stage", as they involve the analysis of the situation and the derivation of the focus of the product development, Properties assessment, decision making and ensuring goal achievement were combined as "late stage" since they cover evaluation and measures to prevent and reduce risk and error during the stage of detailed design, "Generate solution ideas" is renamed as "concept generation" as solutions and ideas can also be combined to form an overall concept. The analysis of the empirical studies also revealed product development scenarios that could not be classified unambiguously using the Munich Procedure Model since they do address more than one specific stage of the product development or design process. They could be classified under the categories: sustainability, variety and change management, user-centric design and collaboration. The category general product development was introduced for the remaining empirical studies that did not suit these categories. This approach takes into account the amount of empirical studies which can be classified under each category. Existing classifications of design research areas, e.g. by [Chakrabarti 2011], [Hovárth 2004] were not used, mainly because their level of detail would provide too many categories for this analysis.

2.2 Study design

Empirical studies can be characterised by various study designs. Table 1 presents a summary of the aspects relevant to the analysis and their respective possible configurations.
Pertaining to the nature of study, studies can either be observational or interventional and comparative or non-comparative. The strict definition of 'interventional studies' is to be noted: a study where pre-planned changes are introduced during the process is also considered to be observational. This may result in relatively few studies falling under the 'interventional' category. However, the aspects of setting, task and case dimensions (case size, total number of participants, repetitions per condition and number of conditions) are the focus of this publication as they influence the amount of effort required for data collection and the significance of the results yielded. A natural setting may complicate data collection as compared to a contrived setting, but the findings yielded may be more useful to the researcher. Similarly, realistic tasks may reduce the amount of effort required for the study but the results may not be as conclusive as that from real tasks. Studies conducted on a larger scale require more sources but are also more conclusive than small-scale studies. Hence, the design of the study is an important consideration for the researcher as it influences the choice of data collection methods.

Table 1. Aspects of study design (adapted from [Blessing and Chakrabarti 2009])

Aspect	Dimension configuration	Explanation
Nature of study	Observational	Circumstances are pre-determined
	Interventional	Deliberate changes are made to the existing circumstances in order to investigate their effects
	Comparative	Participants are divided into groups with different study designs
	Non-comparative	All participant groups are identical
Setting	Natural	Environment where participant carries out his normal routine
	Contrived	Environment has been modified for the purpose of the study
Task	Real	Normal routine or work of the participants
	Realistic	Simplified versions of real tasks where circumstances have been modified to facilitate the research
	Artificial	Work which participants do not normally carry out in their routine
Case size	1; 1-5; >5 participants/case	Participants work as individuals, in small groups or in large groups.
Total number of participants	<10; 10-50;>50 participants	Total number of participants directly performing the task, indicating the scale of the study
Repetitions per condition	1; 2-10; 11-50; >50	number of repetitions per condition (e.g. task)
Number of conditions	1; 2-5, > 5	Set of circumstances under which tasks are carried out

2.3 Data collection methods

Table 2 summarises the main characteristics of the main data collection methods used in empirical studies. Data collection methods can be distinguished between real-time and retrospective methods [Blessing and Chakrabarti 2009]. In the case of the former, application of the methods occur parallel to the events of interest, whereas in the latter case, the methods are applied after the events of interest. Real-time methods can generate “unadulterated, direct and potentially very rich descriptions of events and their context, because data is captured while the phenomena occur” [Blessing and Chakrabarti 2009]. While such methods can gather data in depth and big quantities, they require more effort in their application. Hence, the scale of the study can be limited. Real-time methods include observation, simultaneous verbalisation whereby participants are required to vocalise their thoughts as they carry out the tasks and introspection, where participants capture their reflections mainly in the form of diaries. On the other hand, retrospective methods “summarise events and rely upon memory or documentation, which may be very selective” [Blessing and Chakrabarti 2009]. Such methods are useful for large-scale studies, although they are vulnerable to manipulation due to selective memory and documentation and post-rationalisation where participants attempt to account for the observed events. The methods were summarized into 8 main data collection methods in order to facilitate the analysis of the publications. Collecting documents ranging from meeting protocols to idea sketches, collecting products such as prototypes, questionnaires, interviews and (interviews with) focus groups are methods falling under this classification.

Table 2. Summary of data collection methods (adapted from [Blessing and Chakrabarti 2009])

DCM	Description	Effort (Participant)	Effort (Researcher)	Time Factor	Data Quality
Observation	Researcher records occurring events	Low	High	Real-time	Average
Simultaneous Verbalisation (SV)	Participants voice out thoughts while working	High	Low	Real-time	High
Introspection	Participants record events and thoughts	High	Low	Real-time	High
Collecting Documents	Sketches, logs, meeting protocols	Low	Low	Retrospective	Low
Collecting Products	Gathering of objects such as prototypes and models	Low	Average	Retrospective	High
Questionnaires	Eliciting feedback in paper or electronic form	Low	Low	Retrospective	Low
Interviews	Face-to-face dialogue with an individual	Average	High	Retrospective	Average
Focus Groups	Discussion of a topic by a group of participants	Average	High	Retrospective	Average

3. Method of analysis

As highlighted in Section 2, when designing empirical studies, three aspects play a major role - the product development scenario, the study design and the data collection methods used. The relations between these 3 aspects are shown in Figure 1. In this publication, we present the most significant results from the separate three aspects (section 4.1, 4.2, 4.3) and the influence of the product development scenario on the (empirical) study design (section 4.4) and the selection of data collection methods (section 4.4). More details and the results of the other influences can be found in [Toh 2013]. For the analysis, publications from two different conferences and journals were selected:

- ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2011

- The 4th World Conference on Design Research organized by the International Association of Societies of Design Research (2011)
- Design Studies 2010, 2011, 2012
- Journal of Engineering Design 2011, 2012

In total, 81 publications from these two journals (several editions) and conferences included empirical studies. A list of these publications is presented in Annex A1. These publications yielded a total of 101 empirical studies because multiple empirical studies were documented in some publications.

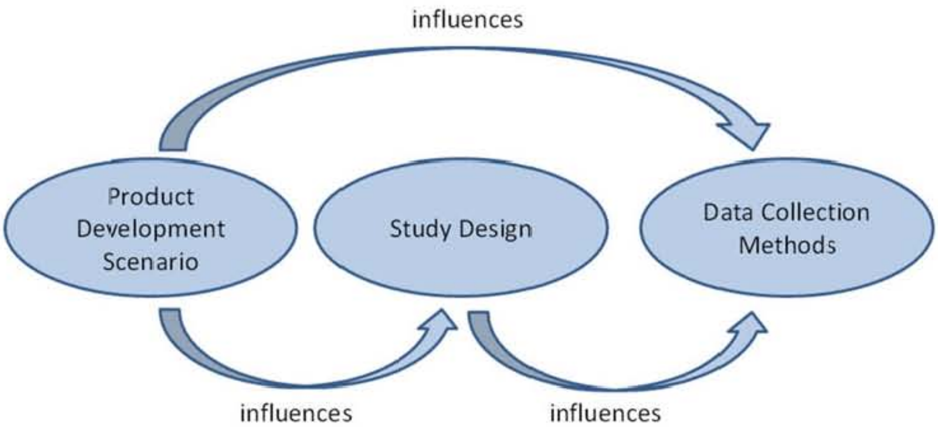

Figure 1. Relations within empirical studies

4. Results

4.1 Product development scenarios addressed by analysed empirical studies

Figure 2 shows the product development scenarios addressed by the empirical studies. As can be seen, approximately one-third of the studies examined product development methods used in the concept generation phase of product development. This indicates that researchers frequently use empirical studies to examine this phase of product development.

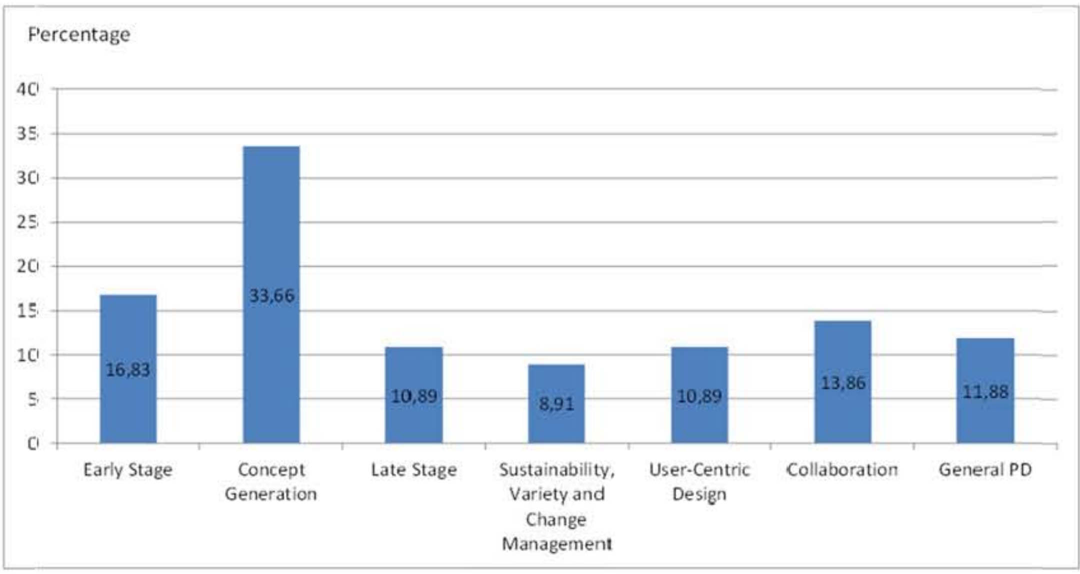

Figure 2. Product development scenarios addressed by the empirical studies

4.2 Study design of analysed empirical studies

Figure 3 presents an overview of the nature of the study, the setting and the task.

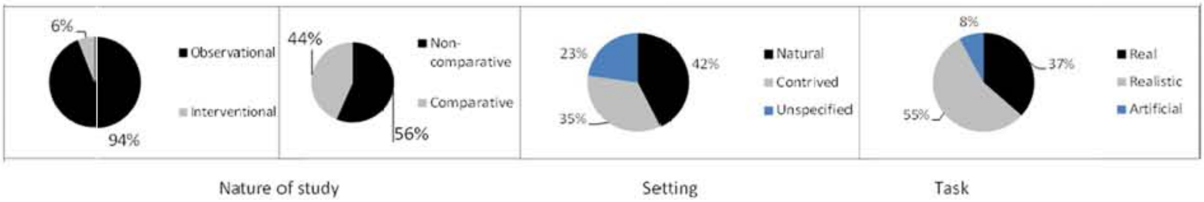

Figure 3. Overview of the nature of the study, the setting and the task

Most studies were observational in nature. As pointed out in 2.3, this can be explained by the strict definition of 'interventional studies'. There were slightly more non-comparative studies than comparative studies. There were also slightly more studies conducted in a natural setting than in a contrived setting, although the significant number of studies where the setting was unspecified can skew the result. According to Blessing and Chakrabarti [2009, p. 105], design research is dominated by studies in laboratory settings. Following this statement, it is likely that most of the studies with an unspecified setting were conducted in a contrived setting rather than in an industrial setting. Nevertheless, it is not possible to infer definitively due to the lack of detail in those studies.

The majority of the studies were found to have a realistic task rather than a real or artificial one. Only 8% of the studies involved an artificial task. This finding highlights the importance of the application of product development methods in realistic scenarios in product development research because these methods will be used in the field of product development, which is of a practical, rather than an abstract and theoretical nature. A real task, while potentially yielding more significant results, is generally more difficult to plan and execute than a realistic task, which can come in the form of a simplified real task, or consists of parts of a real task. Hence, this can explain the prevalence of realistic tasks among the studies analysed.

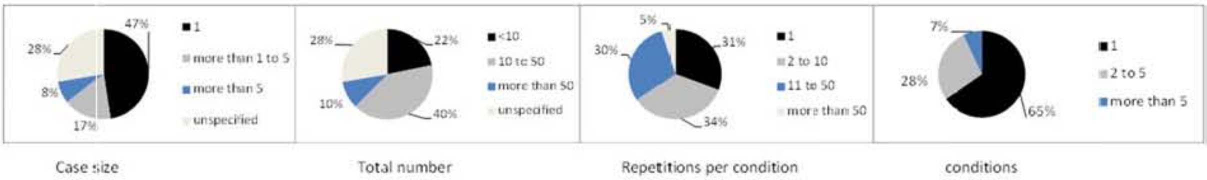

Figure 4. Overview of case dimensions

Figure 4 summarises the various case dimensions characterising the studies. Studies were characterized according to their case size, total number of participants, number of repetitions per condition and number of conditions. Case size categories of 1, between 1 and 5 and more than 5 were used in the analysis. A case size of 1 implies individual work, while group work is reflected in case sizes of between 1 and 5 and case sizes of more than 5. Case sizes for group work were further subdivided into these two categories because working in a small group is different from working in a large group. As such, these categories were deemed to be logical and of interest. Almost 50% of the studies had a case size of 1. This finding means almost half of the studies looked at the individual work of the participants. There are 2 possible reasons for this finding. First, the focus of the studies was not on teamwork; second, individual work simplifies the assessment of the method to be tested because synergy effects from teamwork do not have to be factored in. Thus, the effectiveness of the method can be entirely attributed to the method. On the other hand, in the studies where participants worked in teams, group dynamics were possibly deliberately being considered by the researchers. Nevertheless, a significant number of studies (28%) did not specify the case size and this can significantly alter the validity of the conclusions drawn with regard to the case size. This was also the case with the total number of participants. This large number of studies with unspecified participant strength can alter the strength of the conclusion to be made.

The results from the analysis of the case dimensions show two main issues in the characterisation of empirical studies. Firstly, the definition of dimensions can affect the characterisation of empirical studies as in the case of interventional studies. Definitions that are neither too broad nor too narrow are necessary in order to classify studies properly. Secondly, in the 3 aspects setting, case size and total participants, at least 20% of the studies are classified as unspecified. This finding indicates a weakness in some of the publications in documenting their empirical studies. It is important to document the setting, case size and the total participants involved so as to provide a context in the review of the empirical study. It is possible that in some of the empirical studies, the product development methods were applied by the researchers themselves as a validation of the method. While this can demonstrate the workings of the method, conducting an empirical study where the method is applied by test participants enables a more rigorous and credible validation of the method.

4.3 Data collection methods used in analysed empirical studies

The analysis showed that 34% of the studies used observation, 24% collected products, 35% carried out questionnaires, 24% conducted interviews and 12% conducted used focus groups to collect data. Collecting documents was the most frequently used data collection method (83%). 'Documents' is a broad term and encompasses anything from sketches to protocol logs. Moreover, documents are commonly produced during the design process and are thus a readily available source of information for the researcher. Hence, it is the dominant data collection method used.

On the other hand, simultaneous verbalisation and introspection were the least frequently used data collection methods (8% and 4% respectively). This can be due to the two methods being difficult to implement in terms of effort and facilitation. Simultaneous verbalisation is not natural and participants either have to be trained in it or make a conscious effort to execute it. This requires considerable effort and the results obtained can be incomplete because the participant misses out on something. Introspection is time-consuming and requires discipline and motivation on the part of the participants, which cannot be guaranteed. Thus, for both methods, while they can certainly provide additional insights, the obtainable results may not be justified by the effort required, resulting in them being less popular data collection methods. Due to the sample sizes for these two methods from this analysis being relatively small, the findings regarding introspection and simultaneous verbalisation can at most be used to provide a general idea since they are statistically insignificant to enable the drawing of conclusions.

As the next part of the analysis, the most common data collection method pairs (i.e. both methods were applied in the study) of the 101 empirical studies analysed were identified. Given that there were 8 data collection methods, 28 pairings were possible. The 10 most common pairs can be seen in Table 3.

Table 3. Most common data collection method pairs

Rank	Data Collection Method Pair	Usage (100%)
1	Observation- Collecting Documents	28.7
2	Collecting Documents- Questionnaires	22.8
3	Collecting Documents- Collecting Products	18.8
4	Collecting Documents- Interviews	17.8
5	Observation- Collecting Products Observation- Interviews	13.9
7	Collecting Products- Questionnaires	12.9
8	Collecting Documents- Focus Groups Observation- Questionnaires	11.9
10	Observation- Focus Groups Collecting Products- Interviews	6.9

While observation and collecting questionnaires are almost on par in terms of frequency of use when considered individually (used in 34 and 35 of the studies respectively), when used in conjunction with collecting documents, observation-collecting documents was used in around 6% more studies. This implies that observation-collecting documents is seen as a more compatible pairing than collecting documents-questionnaires by researchers. Observation and collecting documents complement each other because observation is a real-time, continuous method and takes place parallel to the study while collecting documents is retrospective. Hence, comprehensive data collection can be ensured. Moreover, observation can provide context to the data present in the documents collected. The relative ease of collecting documents also makes it a good secondary data collection method to support observation since it offsets the resources required for observation. Therefore, the two methods are often used together. On the other hand, collecting documents and questionnaires are relatively similar data collection methods in that both are not resource-intensive and are suitable for collecting a large amount of data, since documents are mostly available and questionnaires can be scaled up. Nevertheless, both methods are retrospective and their data quality is often low. As such, it might not be as useful for the researcher to use both methods since there is not much additional value in terms of collected data to be obtained. Instead of questionnaires, interviews can be used in conjunction with collecting documents, which is also a relative frequent pairing (4th most common). Interviews and questionnaires are similar retrospective methods, differing primarily in execution and form. Interviews, while requiring more effort, are more flexible and can therefore provide a deeper understanding of the participant's answer. Nevertheless, the amount of effort required may be a deterrent for researchers, explaining why it is less frequently used compared to questionnaires.

4.4 Influence of product development scenarios on study design

Figure 5 shows the setting and task of early stage, concept generation, late stage and collaboration empirical studies.

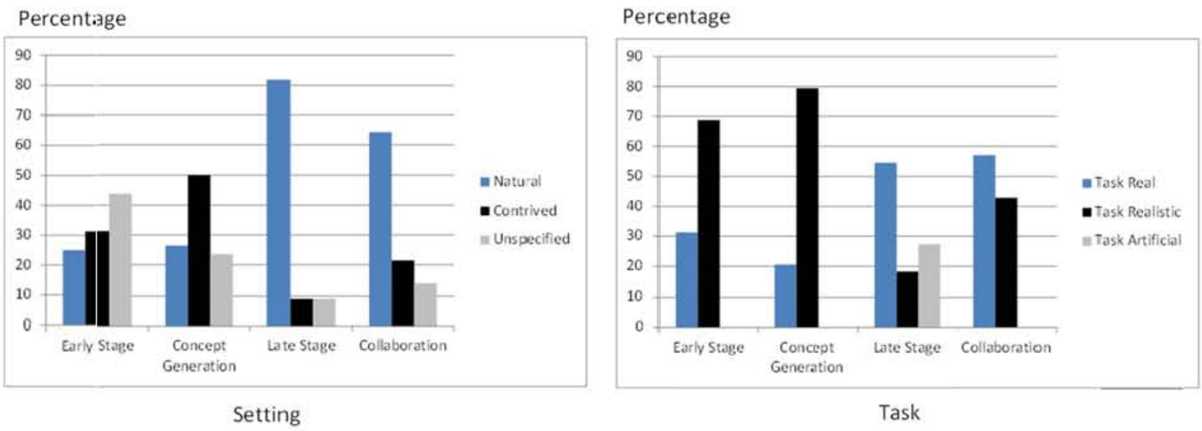

Figure 5. Setting and task of early stage, concept generation, late stage and collaboration studies

Late stage and collaboration studies were conducted predominantly in a natural setting with real tasks. The conditions of an industrial setting can reduce the effort to conduct empirical studies in these scenarios. For example, a tool developed to analyse the characteristics of a concept can be directly applied to existing concepts. Likewise, a tool that helps in the evaluation of generated concepts can also be directly applied to prototypes from earlier phases of a project, thus saving the researcher the work of having to generate such prototypes as part of the empirical study. Likewise, the performance of interdisciplinary teams can be directly evaluated to assess the support tested.

On the other hand, empirical studies on early stages and concept generation tend towards a contrived setting with realistic tasks. One explanation is that design supports developed for these scenarios tend to be indirect methods. This means that they do not directly generate ideas, but serve to aid the user by stimulating the thought process and creativity. The evaluation of such support is challenging in the context of real design projects. One reason can be that specific objectives and deadlines have to be met when real products are being developed. As a result, it is less probable that researchers have the opportunity to test the support in an industrial setting. The alternative is to devise simplified tasks to be carried out by test participants. However, empirical studies in natural setting with real tasks can provide additional insights. If a support is tested, they enable a more valid evaluation, possibly after an initial evaluation in a contrived setting with realistic tasks.

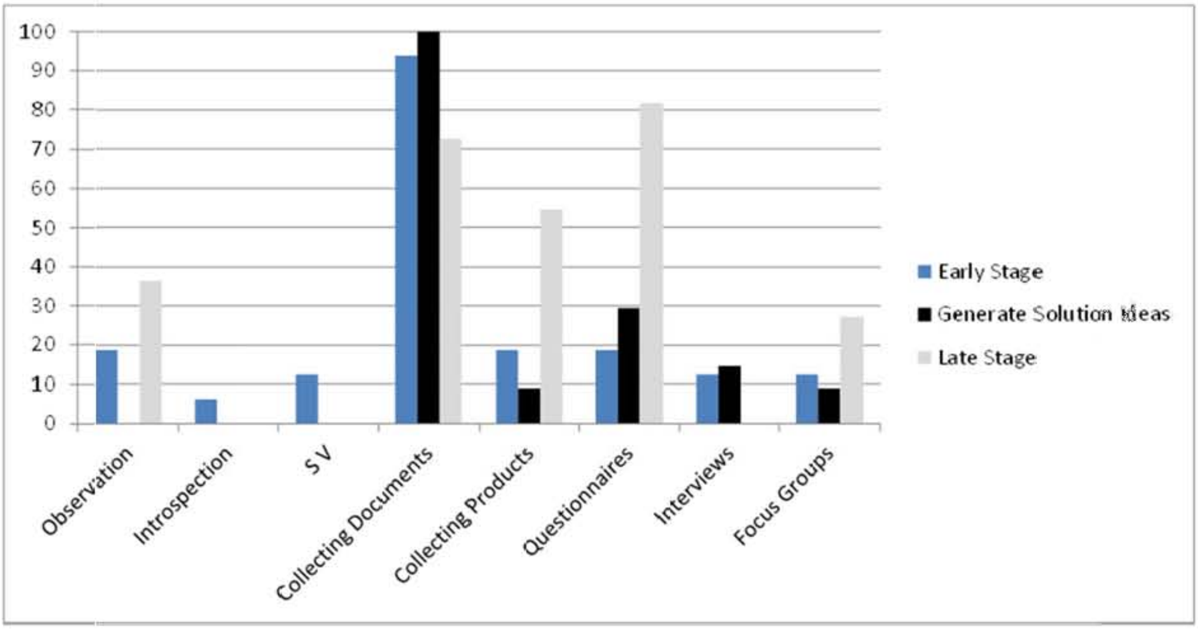

Figure 6. Data collection methods used in early stage, concept generation and late stage

4.5 Influence of product development scenarios on data collection methods

Figure 6 shows the percentage of empirical studies in early, concept generation and late stage using a specific data collection method. No real-time data collection method was used in concept generation studies. Instead, 100% of these empirical studies collected documents. This is probably down to the nature of this step in the product development process, where quantity, novelty and creativity are important. An efficient means to collect data in this stage is to evaluate sketches for example. However, using real-time data collection methods provides different and useful insights also in this stage. Collecting documents, questionnaires and collecting products are the preferred data collection methods in the later stages of the product development cycle. Each method was used in more than half of the empirical studies. In this phase of product development, prototypes are available and evaluations are made. In particular, collecting documents and products is an efficient means of gathering data in this stage.

5. Discussion

The validity of the findings of this study is restricted due to two main reasons: First of all, the study was conducted with a selection of 81 publications from two conferences and two journals (several editions). The conferences were selected due to their slightly different scope, the journals with regards to their reputation. However, there are numerous other conferences and journals which can be analysed to increase the scope of analysis. Another factor that decreases the validity of the findings is the lack of standardization and detail in the documentation of the empirical studies. Different publications had differing levels of detail of specification in various aspects. For example, a publication can have an ambiguous description of the setting while another publication does not give a clear indication of the number of participants. In some cases, the characteristics can still be reasonably inferred despite the lack of detail. In most cases, however, it was impossible to do so.

6. Conclusion

In this study, we selected and analysed 101 empirical studies from 81 publications with regards to the product development scenario, the study design and the data collection methods. Moreover, we analysed the impact of the product development scenario on both study design and data collection methods. The aim of the study was to identify best practices from peer-reviewed publications as to the design of empirical studies and the selection of data collection methods. The main findings are:

- The use of realistic tasks provides a useful compromise between using artificial or real tasks
- A combination of real-time and retrospective data collection methods (e.g. observation and collecting documents) can provide comprehensive data.
- Collecting documents in the stage of concept generation and collecting documents and products in the late stages of product development are efficient means of data collection.

In addition, we observed gaps of infrequently used study designs and data collection methods:

- Few empirical studies regard early stages of product development and concept generation in natural settings with real tasks.
- Few empirical studies in the stage of concept generation use real-time data collection methods.

Future empirical studies addressing these gaps can provide new, useful insights for design research. As a general outcome, we noted the lack of standardized documentation in empirical studies. This indicates a need for discussion in design research: What is the most important information on empirical study design and data collection methods and how should it be documented? Regarding documentation, we suggest a table summarizing the most important aspects of the study being presented in the publication, with clear instructions and explanations and examples of the various terms to aid the researcher in filling up the table without too much effort and ambiguity. This not only provides the most important details regarding the study in a concise manner, but also serves as a basis for comparison and the planning of future work for the researcher.

Annex A1

	Design Studies Volume 31 (2010)
1	Collado-Ruiz, D.; Ostad-Ahmad-Ghorabi, H.: Influence of environmental information on creativity.
2	Jung, E.; Kato, S.: Methodology for context-sensitive system design by mapping internal contexts into visualization mechanisms.
3	Lemons, G.; Carberry, A.; Swan, C.; Jarvin, L; Rogers, C.: The benefits of model building in teaching engineering design.
4	Shen, Y.; Ong, S.K.; Nee, A.: Augmented reality for collaborative product design and development.
5	Wilson, J.; Rosen, D.; Nelson, B.; Yen,J.: The effects of biological examples in idea generation.
	Design Studies Volume 32 (2011)
1	Berends, H.; Reymen, I.; Stultiëns, R.; Peutz, M.: External designers in product design processes of small manufacturing firms.
2	Goldschmidt, G.; Sever, A.: Inspiring design Ideas with text.
3	Lehoux, P.; Hivon, M.; Williams-Jones, B.; Urbach, D.: The worlds and modalities of engagement of design participants: a qualitative case study of three medical innovations.
4	Miaskiewicz, T.; Kozar, K.: Personas and user-centered design: How can personas benefit product design processes?
5	Reed, N.; Scanlan, J.; Wills, G.; Halliday, S.: Knowledge use in an advanced manufacturing environment.
6	Yilmaz, S.; Seifert, C.: Creativity through design heuristics: A case study of expert product design.
7	Youmans, R.: The effects of physical prototyping and group work on the reduction of design fixation.
	Design Studies Volume 33 (2012)
1	Cash, P.; Elias, E.; Dekoninck, E.; Culley, S.: Methodological insights from a rigorous small scale design experiment.
2	Koutsabasis, P.; Vosinakis, S.; Malisova, K.; Paparounas, N.: On the value of virtual worlds for collaborative design.
3	Smith, S.; Smith, G.; Shen, Y.: Redesign for product innovation.
	Journal of Engineering Design Volume 22 (2011)
1	Azkarate, A.; Ricondoa, I.; Perez, A.; Martinez, P.: An assessment method and design support system for designing sustainable machine tools.
2	Corremans, J.: Measuring the effectiveness of a design method to generate form alternatives: an experiment performed with freshmen students product development.
3	Eckert, C.; Alink, T.; Ruckpaul, A.; Albers, A.: Different notions of function: results from an experiment on the analysis of an existing product.
4	Garneaua, C.; Parkinson, M.: A comparison of methodologies for designing for human variability.
5	Howard, T.; Culley, S.; Dekoninck, E.: Reuse of ideas and concepts for creative stimuli in engineering design.
6	Kwong, C. K.; Chen, Y.; Chen, K. Y.: A methodology of integrating marketing with engineering for defining design specifications of new products.
7	Lopez-Mesa, B.; Mulet, E.; Vidal, R.; Thompson, G.: Effects of additional stimuli on idea finding in design teams.
8	Nagel, R.; Hutcheson, R.; McAdams, D.; Stone, R.: Process and event modelling for conceptual design.
9	Spitas, C.: Analysis of systematic engineering design paradigms in industrial practice: A survey.
10	Spitas, C.: Analysis of systematic engineering design paradigms in industrial practice: Scaled Experiments.
11	Sung, R.; Ritchie, J.; Rea, H.; Corney, J.: Automated design knowledge capture and representation in single-user CAD

	environments.
12	Unger, D.; Eppinger, S.: Improving product development process design: a method for managing information flows, risks, and iterations.
	Journal of Engineering Design Volume 23 (2012)
1	Brace, W.; Cheutet, V.: A framework to support requirements analysis in engineering design.
2	Cardoso, C.; Clarkson, P.: Simulation in user-centred design: helping designers to empathise with atypical users.
3	Chiu, I.; Shu, L.: Investigating effects of oppositely related semantic stimuli on design concept creativity.
4	Chulvi, V.; Mulet, E.; Chakrabarti, A.; Lopez-Mesa, B.; Gonzalez-Cruz, C.: Comparison of the degree of creativity in the design outcomes using different design methods.
5	Eckert, C.; Stacey, M.; Wyatt, D.; Garthweite, P.: Change as little as possible: creativity in design by modification.
6	ElMaraghy, H.; Algeddawy, T.: New dependency model and biological analogy for integrating product design for variety with market requirements.
7	Emmatty, F.; Sarmah, S.P.: Modular product development through platform-based design and DFMA.
8	Hannah, R.; Joshi, S.; Summers, J.: A user study of interpretability of engineering design representations.
9	Ingeneer, L.; Mathieux, F.; Brissaud, D.: A new 'in-use energy consumption' indicator for the design of energy efficient electr(on)ics.
10	Jankovic, M.; Holley, V.; Yannou, B.: Multiple-domain design scorecards: a method for architecture generation and evaluation through interface characterisation.
11	Morkos, B.; Shankar, P.; Summers, J.: Predicting requirement change propagation, using higher order design structure matrices: an industry case study.
12	Mugge, R.; Schoormans, J.: Newer is better! The influence of a novel appearance on the perceived performance quality of products.
13	Nunez, M.; Datta,V.; Molina-Cristobal, A.; Guenov, M.; Riaz, A.: Enabling exploration in the conceptual design and optimisation of complex systems.
14	Onarheim, B.: Creativity from constraints in engineering design: lessons learned at Coloplast.
15	Onarheim, B.; Christensen, B.: Distributed idea screening in stage–gate development processes.
16	Remery, M.; Mascle, C.; Agard, B.: A new method for evaluating the best product end-of-life strategy during the early design phase.
17	Vianello, G.; Ahmed-Kristensen, S.: A comparative study of changes across the lifecycle of complex products in a variant and a customised industry.
18	Yang, X.; Dong, A.; Helander, M.: The analysis of knowledge integration in collaborative engineering teams.
	ASME 2011, IDETC/CIE 2011, Washington DC, USA, August 28-31, 2011.
1	Cabrera, A.; Foeken, M.; Woestenenk, K.; Stoot, G.; Tomiyama, T.: Modeling and using product architectures in industrial mechatronic product development: experiments and observations.
2	Chiriac, N.; Hölttä-Otto, K.; Lysy, D.; Suh, E.S.: Level of modularity at different levels of system granularity.
3	Christophe, F.; Wang, M.; Coatanea, E.; Zeng, Y.; Bernard, A.: Grammatical and semantic disambiguation of requirements at elicitation and representation stages.
4	Dinar, M.; Shah, J.; Hunt, G.; Campana, E.; Langley, P.: Towards a formal representation model of problem formulation in design.
5	Dong, G.; Ma, Z.; Vunnam, S.; Lou, K.: Variable Screening using restricted maximum likelihood Kriging Method with

	application to gunner joint stiffness variables.
6	Eng, N.; Aurisicchio, M.; Bracewell, R.; Armstrong, G.: More space to think: eight years of visual support for rationale capture, creativity and knowledge management in aerospace engineering.
7	Genco, N.; Johnson, D.; Hölttä-Otto, K.; Seepersad, C.: A study of the effectiveness of empathic experience design as a creativity technique.
8	Hallihan, G.; Shu, L.: Creativity and long-term potentiation: implications for design.
9	Jorgensen, J.; Havens, D.; Salvatore, P.; Arciniegas, A.; Esterman, M.: Identifying enablers and barriers to successful platform-based product development: a case study from business-to-business products.
10	Lopez, R.; Linsey, J.; Smith, S.: Characterizing the effect of domain distance in design-by-analogy.
11	Macomber, B.; Yang, M.: The Role of Sketch Finish and Style in User Responses to Early Stage Design Concepts..
12	Nagel, J.; Stone, R.: A systematic approach to biologically-inspired engineering design.
13	Nix, A.; Sherrett, B.; Stone, R.: A function based approach to TRIZ.
14	Oehlberg, L.; Roschuni, C.; Agogino, A.: A Empirical Study of Designers' Tools for Sharing User Needs and Conceptual Design.
15	O'Halloran, B.; Stone, R.; Tumer, I.: Early design stage reliability analysis using function-flow failure rates.
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