Supplementary Material

# Appendix A. Guiding questions at semi-structured interviews.

“As-Is” state

-Early process or activities to realize resource-efficient and effective offerings.

* Describe the process of how you develop an offering?
  + From where does requirements originate
  + What actors are involved in the process? (internal and external) (E.g. buyers, users, suppliers, service technicians, legal experts?)
  + What are their roles/responsibilities?
  + When in the process are they involved?
  + What actors are perceived as the most important?

-Support used

* What support is used early in the realization process?
  + Describe the purpose of the methods?
  + Who uses them?
  + What input is required?
  + How are the methods perceived to work with?
  + What type of training is offered to the users of the methods?
* What are the biggest challenges with current methods available?
* Who makes decisions?
* How different actors interact?
* How are environmental factors addressed?
* How are economic factors addressed?
* How are risk and uncertainties addressed?

“To-Be” state

* What changes of product/service design would make your offerings more resource efficient and effective?
  + What would you say are the biggest challenges in the current design of offerings?
  + Where in the process do you see possibilities for improvements?
  + What should be changed in the process?
  + How should it be changed?
* What actors do you think should be included in the development process that currently isn’t?
* When in the process should these be involved?
* What should their roles/responsibilities be?
* How would you like to improve cooperation between actors?

-Support needed

* What support (both existing and non-existing) should in the realization process?
* How should uncertainties be addressed offerings? (e.g. customer requirements’ change, market trends, new regulations, etc.)
* How should decisions be ensured to be “the right one”?
* How should risks be managed in decision-making?
* Which actors should be involved in the decision-making process?
* What would be the most useful outcome from a method?

# Appendix B. E-mail sent before interviews after pilot study

* Dear interviewee, please find below important points prior to the upcoming interview. Question areas in the interview. During the interview we would like to identify how the early stage of design currently works at your company (As-is) and how it could be improved (To-be). Of special interest to us is:
* Activities: The steps to develop resource efficient and effective products and services.
* Actors: Internal and external persons (groups) involved in the design process (E.g. buyers, product users, suppliers, service technicians, legal experts).
* Performance evaluation: How to evaluate performance in the design process.
* Requirement specification: How requirement specification is performed in the early design.
* Conceptual design: How different concepts are developed in the early design.
* Analysis and evaluation: How different concepts are analysed and evaluated in the early design.
* Design methods.
* Interview procedure: The interview will follow the steps below.
* Brief introduction of the participants (all).
* Clarifying the interview, if needed (all).
* Presentation of the material to be used, if any (company).
* Interview about the “As-is” addressing the question areas in Section 1 (all).
* Interview about the "To-be” (This part will be carried out either during the planned interview or in another future interview depending on time available) (all).
* Book another interview, if needed (all).
* Materials to study
* Finally, it would be of great support for us if you could provide us with the results of previous work carried out at your company related to design of resource efficiency and effective solutions. This is useful for us to learn from previous experiences and to deepen our discussion.

We look forward to the interview with your support.

Sincerely,

XXXX

-Additionally, researchers prepared definitions of key concepts as follows in case they were necessary:

* Definitions
* Actor - An individual, group or organization that plays a specified role in interacting with a solution. (Based on: BABOK, V3, A Guide to the business analysis body of knowledge, 2015, pp.441)
* Method - A predefined description that support achieving a specific goal.
* Tool - An instrument that enables performing a certain task. (Based on: CIRP Encyclopaedia of Production Engineering, 2014, pp 386-388)
* Solution - A specific way of satisfying one or more needs with product and/or service in a defined context. (Based on: Beyond Requirements: Analysis with an Agile Mindset, AvKent J. McDonald, 2015)
* Offering - A suggestion of a solution.
* Product - A physical entity with value in a defined context. (including software)
* Service - An activity with value in a defined context.
* Design process - A set of activities to achieve an offering to be realized.
* Uncertainty - A state of deficiency of information related to a future event.

# Appendix C Templates to capture data

**Table 1 Template to capture data**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company name |  |  |  |  |
| Interviewee name: |  |  |  |  |
| Interviewee role: |  |  |  |  |
| Interview date: |  |  |  |  |
| Early realization process | Main question (ex: Describe the process of how you develop an offering? ) | Summary of answer AS-IS | Summary of answer TO-BE | Quote(s) |
| Requirements | From where does requirements originate? |  |  |  |
| Conceptual Design | Who is involved in the process? |  |  |  |
| Analysis and Evaluation | How are risk and uncertainties addressed? |  |  |  |
| Other relevant information |  |  |  |  |
|  |  |  |  |  |

# Appendix D Current support used by companies (as-is)

Large companies are labelled A, B and C. Small and medium sized enterprises are labelled D to H. The support (methods, and tools) is classified into 1) planning, 2) analysis, and 3) evaluation (see Stempfle & Badke-Schaub, 2002). The original report can be found in Brambila-Macias & Sakao (2019).

**Table 2 Support used for planning**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Design support | Large | | | SMEs | | | | |
| **Methods** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| Comparison to / use of previous versions of the product /cases | X | X | X |  |  |  |  |  |
| GAP- analysis to compare products with competitors | X |  | X |  |  |  |  |  |
| Customer meetings |  |  |  |  |  |  | X |  |
| Checklist to address environmental impacts of the product | X |  |  |  |  |  |  |  |
| User Requirement Specification (URS) | X |  |  |  |  |  |  |  |
| Quality Function Deployment (QFD) | X | X |  |  |  |  |  |  |
| Checklist for requirement specification |  | X | X | X |  |  |  |  |
| NÖHRA to define current situation, etc. |  |  |  |  | X |  |  |  |
| Process steps: 1. Architect 2. External expert consultant (e.g. env.) 3. Approval |  |  |  |  |  | X |  |  |
| Benchmarking competitors and other markets |  | X | X |  |  |  |  |  |
| Product guide to prioritize base requirements |  | X |  |  |  |  |  |  |
| PULSE meetings |  |  |  | X |  |  |  |  |
| Flexible and agile development process |  |  |  |  | X | X |  |  |
| Pluses, potentials, concerns, overcome PPCOs |  | X |  |  |  |  |  |  |
| Brainstorming |  | X |  |  |  |  |  |  |
| Need finding techniques |  | X |  |  |  |  |  |  |
| Axiomatic design |  | X |  |  |  |  |  |  |
| Virtual development |  | X | X |  |  |  |  |  |
| Systems engineering |  | X |  |  |  |  |  |  |
| Physical development |  |  | X |  |  |  |  |  |
| Remanufacturing |  |  | X |  |  |  |  |  |
| Design for assembly |  |  | X |  |  |  |  |  |
| **Design support** | **Large** | | | **SMEs** | | | | |
| **Tools** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| Break down general requirements to lower divisions, subsystem, components |  | X | X |  |  |  |  |  |
| Strategic exchange (remanufacturing) list, update/year |  |  | X |  |  |  |  |  |
| Relation matrix with different products and requirements |  | X |  |  |  |  |  |  |
| Blacklist of forbidden materials |  | X | X |  |  |  |  |  |
| Excel sheet for identified ideas |  |  | X |  | X |  |  |  |
| Stakeholder list |  |  |  |  | X |  |  |  |
| Project templates |  |  | X |  | X |  |  |  |
| Business case description | X |  |  |  |  |  |  |  |
| Documentation of requirements |  | X | X |  |  | X |  |  |
| Gate - meetings to process the requirements | X |  |  |  |  |  |  |  |
| Checkpoints | X |  |  |  |  |  |  |  |
| Gate system through the development process |  | X | X |  |  |  |  |  |

**Table 3 Support used for analysis**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Design support | Large | | | SMEs | | | | |
| **Methods** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| Environmental impact description for projects (MKB) | X |  |  |  |  |  |  |  |
| Test of concept based on ISO standards | X |  |  | X |  |  |  |  |
| FMEA |  | X | X | X |  |  |  |  |
| Risk analysis |  |  | X | X |  |  |  |  |
| Statistic analyzing tools |  | X |  |  | X |  |  |  |
| Economic analysis with gathered data |  |  |  |  |  |  | X |  |
| Risk identification in collaboration with the customer |  |  |  |  |  |  |  | X |
| Simulations and calculations |  | X |  |  |  |  |  |  |
| Verification: 1. Plausibility assessment by engineer, 2. CAE calculation model/comparison, 3. physical tests |  | X |  |  |  |  |  |  |
| Checklists to evaluate construction requirements & product functionality & compare |  | X |  |  |  |  |  |  |
| Pugh matrix |  |  | X |  |  |  |  |  |
| LCA / LCC |  | X | X |  |  |  |  |  |
| QTCF, quality, time cost, feature |  |  | X |  |  |  |  |  |
| Tests on actual hardware |  | X |  |  |  |  |  |  |
| System dynamics |  | X |  |  |  |  |  |  |
| Value analysis |  | X |  |  |  |  |  |  |
| **Design support** | **Large** | | | **SMEs** | | | | |
| **Tools** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| V-model for verification of requirements |  | X | X |  |  |  |  |  |
| Blacklist of forbidden materials |  | X |  |  |  |  |  |  |
| CAD and software programs |  |  | X |  |  |  |  |  |

**Table 4 Support used for evaluation**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Design support | Large | | | SMEs | | | | |
| **Methods** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| Validation and evaluation of the project and requirements | X | X |  |  |  | X |  |  |
| User/ customer evaluation and feedback of solutions | X | X | X |  |  |  |  | X |
| A3 report | X |  |  |  | X |  |  |  |
| Asses societal changes and attitudes |  | X | X |  |  |  |  |  |
| Verifications at suppliers |  | X |  |  |  |  |  |  |
| Business evaluation |  | X |  |  |  |  |  |  |
| Checklists to evaluate construction requirements & product functionality & compare |  | X |  |  |  |  |  |  |
| **Design support** | **Large** | | | **SMEs** | | | | |
| **Tools** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** |
| Follow-up one year after finished project | X |  |  |  |  |  |  |  |
| ISO 14001 Quality Certification | X |  |  |  |  |  |  | X |
| CE/ UL-labelling |  |  |  | X |  |  |  |  |
| Knowledge sharing seminars |  |  | X |  |  |  |  |  |
| Matrix based evaluation |  | X |  |  |  |  |  |  |

# Appendix E Coding scheme for support needs (to-be)

**Table 5 Coding scheme for support needs**

|  |  |  |  |
| --- | --- | --- | --- |
| Company | Themes | Categories | Codes |
| Company A | communication | communicate | communicate specifications |
| Company A | management | project | project participants and methods |
| Company A | communication | value | value, marketing more advanced |
| Company A | risk/uncertainty | risks | FMEA needs to be used more |
| Company A | lead time | earlier specs | to do specifications earlier |
| Company A | lifecycle | lifecycle | resource efficiency for lifecycle |
| Company A | communication | method problem description | method for problem description |
| Company A | management | easy method | easy and available methods |
| Company A | knowledge | patents | look up for patents |
| Company A | lead time | time | lack of time |
| Company A | actors | marketing | marketing involvement |
| Company A | actors | developers | few developers |
| Company A | strategy | strategy | business case |
| Company A | communication | communication | lack of communication |
| Company A | communication | documentation | documentation needed |
| Company A | risk/uncertainty | risk | risk analysis |
| Company A | strategy | strategy | product strategy |
| Company A | knowledge | training | product development training |
| Company A | lifecycle | lifecycle | long sight planning |
| Company A | actor | customer | customer/user |
| Company A | communication | specification | environmental specification |
| Company A | actor | marketing | marketing involvement |
| Company A | communication | specification | specifications |
| Company A | management | useful method | useful and useable methods and tools |
| Company A | actor | customer | customer/user |
| Company B | actors | suppliers | involve suppliers |
| Company B | lead time | shorten time | virtual testing  method shorten time |
| Company B | strategy | decision making | decide right project |
| Company B | decision | decision | what is needed |
| Company B | communication | information | update information |
| Company B | thinking | attitude | change of attitude |
| Company B | lifecycle | lifecycle | different lifecycles |
| Company B | management | easy understand | easy to use, understand |
| Company B | lifecycle | lifecycle | recycling, disassembly needed |
| Company B | communication | specifications | good database specifications |
| Company B | knowledge | method | designers need methods |
| Company B | role | skills | an actor/role to work with environmental parameters |
| Company B | decision | parameters | environmental parameters with points |
| Company B | communication | meetings | more meetings |
| Company B | lifecycle | environment | recycling needs |
| Company B | knowledge | environment | environmental aspects in each work |
| Company B | risk/uncertainty | risk | better understanding of uncertainties |
| Company B | actors | suppliers | support to select the right material |
| Company B | lifecycle | strategy | understand the whole |
| Company B | actors | experts | involve experts |
| Company B | risk/uncertainty | risk | risks are tiring for competent staff Support rather for creativity |
| Company B | skills | skills | personal skills rather than process |
| Company B | role/management | person project | specific person to be active in project |
| Company B | communication | documentation | excel file |
| Company B | decision making | decision | market analysis |
| Company B | risk/uncertainty | risk | risks to be taken earlier |
| Company C | lifecycle | lifecycle | more understanding of resource efficiency |
| Company C | communication | specification | match between need and factual specification |
| Company C | actors | marketing | marketing needs to be involved |
| Company C | communication | specification | understanding of specifications |
| Company C | skills | environment | translate environmental gains to money |
| Company C | lead time | time | timeline in advance |
| Company C | risk/uncertainty | decision making | environmental comparison among alternatives |
| Company C | lead time | timeline | timeline of project |
| Company C | knowledge/management | knowledge | energy efficiency materials |
| Company C | lifecycle | decision | lifecycle management as decision making tool |
| Company C | lead time | time | need to deliver quicker |
| Company C | lifecycle | decision making | method for understanding value, compare |
| Company C | strategy | strategic development | strategic development for environment |
| Company C | lead time | time | time aspects |
| Company C | role | skills | customer awareness of environmental aspects new role energy efficiency |
| Company C | communication | specification | why are certain specifications needed |
| Company C | communication | specification | easy to interpret specifications |
| Company C | lifecycle | decision making | energy efficiency decision making |
| Company C | lifecycle | lifecycle | lifecycle done by Chalmers |
| Company C | lifecycle | awareness | customer awareness of environmental aspects energy efficiency |
| Company C | lifecycle | decision making | disassembly needed in future customers do not ask for resource efficiency |
| Company C | actors | suppliers | support to prioritize specifications |
| Company C | communication | design | communication with design |
| Company C | communication | needs | benchmarking for characteristics with designers needs to be done |
| Company C | lifecycle | economic reason recycling | no economic reason to do design for recycling |
| Company C | knowledge | lack of knowledge | not know how to use LCA |
| Company C | communication | useful | easy to use  group work |
| Company C | lifecycle/strategy | strategy LCA | environmental impact long-term view LCA |
| Company C | lifecycle | remanufacturing priorities | remanufacturing needs to be higher prioritized |
| Company C | communication | documentation | structured way of working documentation |
| Company C | management | structure | organized way of working for renovated products |
| Company C | management | structure | organized structure not implemented today |
| Company C | knowledge/management | knowledge skills | development along with LCA and LCC |
| Company C | actors | economy quality | economy and quality should be involved |
| Company C | lifecycle | recycling | today’s calculations do not account for recycling |
| Company C | decision making | specifications | prioritization of specifications |
| Company D | communication | documentation | lack of documentation |
| Company D | communication | documentation | create better documentation |
| Company D | actors | marketing | marketing and sales should be more involved |
| Company D | actors | sales | sales involved earlier |
| Company D | lifecycle | recycling | recycling  materials |
| Company D | actors | customers | value for customers earlier |
| Company D | actors | marketing | marketing’s opinion |
| Company D | actors | customers | customers involvement |
| Company D | management | early process | environmental possibilities early in the process |
| Company D | lifecycle | materials | look more for materials to reduce for example weight |
| Company D | management | method | methods easy to use |
| Company D | lead time | time | time line  lack of time |
| Company D | management | process | follow the process clear when and where actors should be included |
| Company D | actors | multiple actors | more persons should be involved in specifications |
| Company D | communication | specifications | better specifications |
| Company D | communication | communication | bad communication between marketing and developers |
| Company D | communication | meetings | daily meetings |
| Company D | uncertainty | testing develop | testing needs to be developed, better data needed |
| Company D | uncertainty | lack measures | uncertainty measurement is lacking |
| Company D | management | follow up | better follow up |
| Company D | management | process | what to do early in the process actors involved |
| Company D | actors | marketing | marketing involvement |
| Company D | management | process | clearer work activities |
| Company D | knowledge | resource efficiency | everyone in resource efficiency |
| Company D | communication | communication | better communication with purchasing |
| Company D | risk/uncertainty | risk | aware of risks is important time is a risk |
| Company D | management | process | methods are not followed |
| Company D | management/roles | process | some work activities are not clear on how to follow |
| Company D | lead time | time | time is a challenge project leader and chief developer, CEO and board make decisions |
| Company D | actors | resource-efficiency suppliers | more focus on resource-efficiency work with suppliers |
| Company D | actors/communication | customers | include customer early |
| Company D | actors/communication | purchasing | communication to include all actors purchasing production |
| Company D | lifecycle | business case decision making | environmental needs as part of business case |
| Company D | actors | customers | customers involvement in product development |
| Company D | actors | customers | customer involvement early |
| Company D | communication | feedback | more feedback |
| Company D | lead time | time | lack of time |
| Company D | actors | customers | follow up with customers |
| Company D | communication | documentation | documentation direct communication with customers |
| Company D | risk/uncertainty | uncertainty results | rely on environmental results |
| Company D | knowledge | knowledge | after sales work with energy efficiency |
| Company D | skills | culture | company's culture does not allow change |
| Company D | knowledge | lack of knowledge | sales personnel don’t know how specifications are done |
| Company D | communication | marketing | marketing involvement |
| Company D | actors | sales | sales need to be in the process from the beginning |
| Company D | communication | documentation | documentation not done properly |
| Company D | communication | clarity | clarity of method |
| Company D | actors | service | service involved from beginning |
| Company D | lifecycle thinking | transport recycling | look at transport  recycling material |
| Company D | communication | clarity | clarity and easiness as well as objective of method |
| Company D | knowledge | skills | training in e-learning |
| Company D | actors | multiple actors | all actors that are needed involved |
| Company E | communication | specifications | living specifications |
| Company E | actors | customers | customer needs |
| Company E | actors | customers | customer involvement |
| Company E | lead time | time | timeline |
| Company E | actors | suppliers | more supplier involvement |
| Company E | management | process | agile process |
| Company E | lead time | time | lead time is an important aspect |
| Company E | strategy | vision | vision in future |
| Company E | actors | IT | IT involved earlier |
| Company E | management | structure | concrete ideas |
| Company E | risk/uncertainty | safety | environment and safety needs to be addressed minimize e-waste |
| Company E | lifecycle | waste | quantify waste analyze society's changes |
| Company E | management | structure strategy | structure way to analyze economic, strategic effects |
| Company E | management | process | agile process |
| Company E | management | project | simplify project development |
| Company F | communication | documentation | documentation |
| Company F | lifecycle | resources | prevention resource-efficiency |
| Company F | knowledge | role | in house designer |
| Company F | lifecycle/decision making | costs | environmental vs economic costs |
| Company F | knowledge | skills | creativity innovation |
| Company F | knowledge | thinking | sustainable thinking more dialogue with actors |
| Company F | strategy | strategic | more strategic specifications |
| Company F | knowledge | roles | someone with initiative  holistic thinking |
| Company F | communication | workshop | method in workshop |
| Company F | strategy | strategic | more strategic thinking |
| Company G | lead time | time | faster working |
| Company G | management | plan | better planning |
| Company G | communication | documentation | digitalization |
| Company H | communication | documentation | digitalization |
| Company H | knowledge | thinking | energy efficiency thinking |
| Company H | knowledge | lifecycle | customer thinking in lifecycle |
| Company H | knowledge | lifecycle | customer thinking in lifecycle |
| Company H | communication | meetings | better meetings |
| Company H | risk/uncertainty | risks | lack of guarantees |
| Company H | communication | clarity | quantitative methods |
| Company H | communication | documentation | certifications |

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