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ScienceDirect

Procedia CIRP 91 (2020) 61–70

www.elsevier.com/locate/procedia

30th CIRP Design 2020 (CIRP Design 2020)

Advancing empirical evidence of iteration stereotypes in the fuzzy front end of product development processes

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Abstract

In this paper we corroborate and advance insights about iteration characteristics in the fuzzy front end (FFE) of product development processes (PDPs). We captured the characteristics of 122 iterations embedded in design activities and found empirical evidence for several iteration stereotypes. We additionally identified the stereotypes of Ideation and Consolidation which were associated with divergence and convergence in design processes, leading to a proposed coding scheme for iterations on a working level. Moreover, we show that the approaches of describing iterations with either their elements or their appearance can be integrated and directly applied in the FFE of PDPs.

Keywords: iteration stereotype; ideation stereotype; consolidation stereotype; iteration characteristic; fuzzy front end; product development process.

1. Introduction

Iteration is naturally occurring in any project and it is an important research topic of design and product development processes (PDPs) [1]. The early phase of (new) product development processes is among the most important and difficult challenges to manage [2,3], so that the period between "when an opportunity is first considered and when an idea is judged ready for development" [2] is called fuzzy front end (FFE). The larger a project is and the more novel and interconnected it is, the more iterative it can be [4,5]. The authors of several empirical studies point out the ubiquity of iteration in development projects [6,7,8,9,10], which supports the belief of both academicians and practitioners that iteration is a very important characteristic of design processes [1,11].

Iterations are driven by several causes and may have negatively or positively connoted outcomes. Design problems are usually ill-structured in the beginning [12]. Problem-solving cycles – i.e. the iterative co-evolution of both problem and solution space [1,13] – occur on a broad scale, ranging from individuals via teams to whole departments [14]. Iterations might also be caused by the decomposition and dispersion of work packages [15] among teams and they might occur during the integration of working results when problems appear [16]. Some authors of product development models have described feedback loops [17] from late to early project stages [18], which are called "worst case iterations" when they emerge after the market launch [19]. However, iterations may also have positive effects such as concept exploration and flaw identification and correction; they may additionally enable development under uncertainty, complexity, and/or change [20].

Iterations in design and development processes are usually described by reference to either their elements or their appearance. Regarding their elements, Smith and Tjandra [21] framed iterations as "cycles of proposal, testing, and modification" for their lab experiments with students. In a case study, Daniel et al. [22] conceptualized the cyclical process of "information gathering, evaluation activities, and solution refinement." Andreasen [23] explained, "A loop is characterized by a stop, reflection, partly reformulation/reframing and new efforts, leading to (partly) changed direction and to concretization." In this study, we refer to iterative cycles that

10.1016/j.procir.2020.02.151

start with a working session (W) and end with a presentation, feedback, and discussion session (PFD) [24]. Regarding their appearance, Safoutin [25] differentiated repetition, progression, and feedback iterations; Cash and Štorga [26] integrated ideation, problem solving, and design development; while Costa [27] established an iteration framework of rework, design, and behavior. In this study, we refer to a set of "iteration stereotypes" (cf. section 2), organized by Wynn and Eckert [1] according to three main functions of iterations, i.e. to progress toward completion; to correct errors and/or implement change; or to coordinate people, decisions, and/or workflows. Recognizing these stereotypes is an important step in their effective handling [1], especially if they are to be characterized in-situ. Such characterization can be simply descriptive, without any judgement about how "good," "successful," or "important" a single iteration is for the design process.

Besides characteristics of single iterations, there might also be patterns of iteration sequences, similar to the "divergence-convergence" pattern in design and development processes [28] or the "breathe in, breathe out" pattern described by Mussgnug et al. [29]. For example, Austin et al. [30] studied workshop teams working on a building design problem and observed that the designers iterated rapidly among several successive design phases. Boudouh et al. [31] also observed engineering students working together in a conceptual design process, finding that most iterations were expected, short in duration, and added value – rather than being unexpected, long, and aimed at correcting errors. While Smith and Tjandra [21] stated that different perspectives on iteration might be viewed as "complementary rather than competing," they emphasized the importance of more research by direct observation of iterations in industrial projects which are carried out by real-world design teams, such as recent examples of real-time performance measurement in the design projects of Škec et al. [32].

The aim of this study was to reveal new insights related to the design and development process by providing empirical evidence of iteration stereotypes in the FFE of real-world PDPs. We focused on development activities of design teams from mainly small- and medium-sized enterprises (SMEs). We conducted and observed workshops with teams that were working on their company-specific, business-relevant design challenge with regard to their new product and service development. As design-related iteration literature has unfolded in the approaches of describing iteration elements or their appearance, we investigated whether both approaches could be integrated and directly applied in PDPs.

2. Theoretical Background

The "taxonomy of iterative stereotypes" described by Wynn and Eckert [1] is a comprehensive framework of iteration appearance, based on Wynn's [33] six non-orthogonal perspectives on iteration. As iteration stereotypes are simplified depictions of iteration that can concisely express key characteristics of iterative situations, the authors organized the stereotypes according to three main functions of iterations, which are (1) to progress toward completion; (2) to correct errors and/or to implement change; and (3) to coordinate people, decisions, and/or workflows.

2.1. Stereotypes of progressive iterations

Progressive iterations are characterized by uncertainty in problem and solution definitions as well as the bounded rationality of the problem solver. As problem solving creates information and knowledge [1,34] and both can be used to revisit and consider issues with more insight [35], progression stereotypes suggest that iteration is necessary [1]. They appear with the stereotypes of Exploration, Concretization, Convergence, Refinement, and Incremental Completion.

Exploration describes the concurrent and iterative exploration of problem and solution space during creative problem-solving [1], highlighting the ill-defined nature of activities and goals [12], evolving in a disordered process of discovering, structuring, and addressing emerging issues at a fixed design level [1].

Concretization describes the revisiting of design elements at increasing levels of definition [1] while ensuring their consistency [25,36]. Thus, ambiguity about the design is progressively reduced by creating more detailed information [37].

Convergence describes the iterative determination of suitable parameters and/or detail adjustments in a monotonic fashion, in order to meet well-defined (performance) objectives when the main form of design is already determined [1] so that the remaining problems can be reduced [35].

Refinement captures situations in which solutions are further adjusted and improved to meet secondary objectives while they meet all primary ones. This may happen as intended to improve design elegance or to reduce costs (e.g. in software development, modifying the system's internal structure to improve maintainability, without changing its external behavior [65]), or unintentionally if additional time is available and/or evaluation criteria are subjective [1].

Incremental Completion describes the planned repetition of an activity to gradually move toward a goal [1], e.g. by decomposing a system into its components and working on them (simultaneously) with different resources in a similar manner before integration [36]. While Incremental Completion captures repeating an activity on different aspects of the same design, Refinement comprises revisiting the same design aspect by applying different tasks and/or information [1].

2.2. Stereotypes of corrective iterations

Corrective iterations are characterized by responding to unplanned and unfavorable issues that emerge, such as new information that reveals design flaws [38]. It is often associated with activities such as system integration; testing and handling of engineering changes, e.g. re-designing of parts [39]; or re-generating design output after input updates [40]. While corrective iteration is undesirable in general and would not be necessary without the unfavorable issues that emerge, it can still have positive effects in the form of additionally generated knowledge or value-adding design changes [41] in the form of New Work, Rework, and Churn.

New Work describes corrections so that a solution meets its requirements in a different way [42,43], e.g. if different solution principles afford different working approaches, which in turn may initiate work that was initially not needed [1].

Rework describes a required task repetition as the original task was attempted with imperfect information and/or assumptions [44]. It may also be caused if wrong information is used at the wrong time [45] or if work is too complex for identifying an efficient order to make progress on the work packages [16]. In contrast to New Work, Rework applies the same/similar approach to conduct the task. Even though it is often described in the literature, its measurement techniques are still lacking in project management [46].

Churn covers situations in which problem parts are revisited without converging, as each solution attempt creates problems at other parts. Being often linked with design complexity or self-propagating Rework [1], it can be perceived as failed Convergence and might be influenced by work allocation across teams, externally induced change, and imperfect testing [35].

2.3. Stereotypes of coordinative iterations

Coordinative iterations are characterized by structures and approaches to increase process effectiveness and efficiency and/or predictability. They are expected to provide benefits by, for example, reducing the risk and amount of costly iteration somewhere else. They are also associated with set-based design and agile development approaches [1] and appear as Governance, Negotiation, Parallelization, Comparison, and Concentration.

Governance describes facilitation of oversight and management by allowing frequent information releases, e.g. as a process of risk management for "controlled, feedback-based redesign" [47] to regulate risk through the introduction of (repeating) design reviews [48], or more generally to provide frequent feedback releases from users and/or an evolving context [49]. In either case, governance describes feedback-enabling structures which shall ensure completion on time, within budget, and with the expected quality, "while iteration involving project management processes regulates design progress and schedule risks" [1].

Negotiation describes situations that are used for identifying solutions based on the emerging understanding among several participants and mutually accepted trade-offs between their respective goals and constraints [50]. As negotiation is characterized by multi-directional information flow among stakeholders, e.g. individuals, teams, or companies [1], its difficulty rises with the number of negotiated parameters [51] and the number of involved stakeholders, respectively. Moreover, it may appear at the beginning of design processes when participants do not know what to expect or what to achieve [52].

Parallelization describes the overlapping of successive tasks or phases within the PDP, which may involve either update communication during upstream task convergence in the overlapping period or revisiting downstream work due to successive change [53,54].

Comparison describes considering several alternatives in parallel before enough information is gathered to decide among them, which may require the repeating of activities to take the options further. These "narrowing iterations" [38] shape the funnel in the FFE of PDPs [55] as they appear during the generation, comparison, and recombination of several concepts [1,56].

Concentration describes the repetition of tasks or processes on different information/work packages [1], in order to benefit from economies of scale, e.g. when work packages are collected into batches to reduce set-up time, or in the period after outsourcing. Thus, the process performance may increase, as discussed in research on lean product development [1,57, 58].

3. Research Design

We corroborate and advance the understanding of iteration stereotypes in the FFE of PDPs, based on our observations of real design teams that were working in a workshop setting on a company-specific, business-relevant design challenge with regard to their new product and service development. The direct and industry-relevant outcomes of such workshops are new product ideas as well as trained and motivated teams [59].

3.1. Research sample

Data for our sample were garnered from observations of eight 2.5-days workshops, each of which was conducted with another company or business unit engaged in a specific design challenge. Participating companies applied for taking part in the workshops. The call for participation was announced publicly on the funding body's website. During the selection process, we considered the companies' challenges in product development and innovation, their expressed willingness to scrutinize and change the status quo, as well as their described ability to do so. Although the majority of companies dealt with new product developments in B2B- and B2C-markets, we also had service companies in our sample, allowing for the generalizability of our findings. Prior to the workshop, based on the company's challenges, the company's sponsor (usually the CEO or a board member) and the workshop moderator determined the workshop topic, cf. Table 1. Common to all participating organizations was the fact that they tackled a challenge within the workshop that they failed to resolve internally beforehand.

Table 1: Overview of participating companies with their industry sector and initially-defined design challenge.

Industry	Workshop Topic / Design Challenge
Machine & plant construction	How can we cool all machine formats with little footprint and minimal investments?
Insurance	How do we generate a social benefit with [service name]?
Machine manufacturer	How might we address the challenge of the [machine name]'s successor?
Tools, food, print	How can we support our customers in the kitchen of the future?
Machine manufacturer	What problems do we have to solve so that we can handle different shapes and materials at different speeds? How do we extend functions with one platform for capsule production and filling systems?
"Speed boat" in financial sector	How do we ensure that our [product name] offer is maximally utilized by our customers?
Data science	How can we enrich individual life events with social added value?
Service provider	How do we become an innovation hub for SMEs?

The observed teams were multi-disciplinary staffed with, on average, 14.2 participants from a broad range of corporate functions, as prerequisites for conducting the workshop. The company's workshop sponsor participated as well, to point out the workshop's importance for the company's future. Some companies used the chance to complement their teams and invited 1 to 2 external guests to broaden the experience and take their perspectives into account.

3.2. Research setting

We conducted the workshops (one at a time) in a company-external and semi-controlled research space which featured a distinct workshop concept of three phases [60]. Although the generalized workshop concept is described in three consecutive phases, the actual evolving workshop processes might have "jumped" between activities and phases. Participants might have explicitly referred and questioned earlier interim results, reflected on new insights, and acted upon those insights.

Following this non-linear approach [61], the co-evolution between problem and solution space was explicitly encouraged in two ways. First, as each individual iteration comprised a W and PFD session, each sub-team presented its working output to the other sub-teams and received feedback to reflect on its working direction and potentially deflect its working direction. Second, each workshop was guided by one out of three experienced moderators with an industry-related background to facilitate the workshop process and tailor the workshop to the companies' needs. They guided participants through three phases, as described below.

Phase 1: Identifying the 'right' questions. Participants started exploring their business context by drawing an environment map which showed their customers, competitors, and suppliers, as well as relevant technologies, the socio-economic environment, and politics. The analysis of this map comprised an identification of important signals, i.e. trends, chances, and risks that were suspected of possibly emerging in the coming years, as well as interpretations of how to operate in this environment.

Following a user-centered approach, the participants worked on an overview of stakeholders (stakeholder map), clustered their findings, and selected the most important stakeholders (stakeholder analysis) to head the forthcoming development process in promising directions. Up to this point, the participants had worked individually, but then they formed small (sub-) teams of 3 to 5 participants, each of which created a persona corresponding to the selected stakeholders. They collected and defined basic information such as name, demographics, character traits, hobbies, visions, and the assumed needs at the (potential) touchpoint with the company. To gain empathy with their persona, each team presented its persona from the persona's point of view, and receives feedback from the other teams to improve appearance, coherence, completeness, and depth of their persona. Aiming at identifying the persona's needs (need-finding), the teams simulated the persona's customer or user journey by applying current products and services, experiencing pros and cons, and identifying potential workarounds.

Eventually, the participants distilled their insights and formulated concise problem statements (user stories) for the needs of each persona. In some cases, they re-formulated these single-sentence user stories into questions in order to ease the ideation in the following phase.

Phase 2: Identifying promising solutions. This second phase began with a short warm-up challenge to learn more about ideation, e.g. the generation, re-combination, evaluation, and selection of ideas, and to reflect on divergent and convergent thinking. For the first relevant ideation sessions, the participants applied methods such as classical brainstorming, "brain walks" outside the workshop rooms, or the 6-3-5 method. They clustered their ideas and proceeded with visualizations such as collaborative sketching, and/or applying concepts such as powers of ten and/or thinking in analogies.

Based on their visualized ideas, the participants conducted several sessions on soft- and hard-prototyping to increase their understanding of problem and solution spaces, as well as to communicate their insights. Moreover, their prototypes supported their decision making and facilitated deducing of the next steps. When teams lacked information, they searched the web with iPads, interviewed local people, or called experts. In the case of service design challenges, they validated their hypotheses in role-playing scenarios (Wizard of Oz prototypes) and received feedback from their fellow participants.

As the participants gave and received feedback at the end of each iteration, this feedback was produced with the goal of being as valuable as possible for the presenting team. The moderator introduced feedback roles (symbols for the user's perspective, for highlighting positive aspects and encouraging constructive suggestions to build upon) to structure the giving of feedback; the same was done for the receiving of feedback. Participants learned how to prepare a pitch, i.e. how to embed their ideas in context, focus on the persona's needs, highlight the idea's key features, and present all of this in a consistent story. The last iteration in this phase closed with a final pitch.

Phase 3: Getting things done. The third workshop phase was aimed at preparing the company for implementing the generated results, i.e. developing the product ideas further in their respective PDPs, and setting up the organizational change that might be necessary to do so. To direct this development, the participants created a vision of what they wanted to achieve within one year and wrote an article in a mock newspaper using a title page template. Bridging the gap between the current state (workshop results) and the envisioned future state is considered as project management by defining milestones and deducing the next steps to get there. The workshop closed with a reflection and feedback session about what the participants learned and what they wanted to transfer to their company.

3.3. Data collection and analysis

We applied an observational research approach to collect qualitative data throughout the workshops. To capture the workshop process with its different activities, we observed the participants, wrote a detailed workshop diary, shot hundreds of photos, and videotaped the PFD sessions of each iteration. To distinguish among iterations, we used the definition of a recurring cycle in which an iteration started with a W session and ended with a PFD session [24].

After each observed iteration, we conducted and videotaped a short (2 to 5 minutes) in-situ interview with the workshop moderator according to a structured reflection guideline (cf. Table 2). This interview guideline covered the input, output, and actual activity with its stereotypical characteristics, as well as the next iteration's goal [62,66]. To capture the different emerging iteration stereotypes, we embedded in the activity-dimension of the guideline the framework of iteration characteristic by Wynn [33]. To prevent moderators' overconfidence in thinking that some activities were naturally linked with specific stereotypes, we let them first describe in detail what happened during the iteration, e.g. what the participants did, what information/material/space was used, how working results were created, whether something unusual happened, etc. In a second step, they compared their description with the different iteration stereotype definitions (they were trained and calibrated prior to the workshops by jointly discussing the framework of iteration characteristics described by Wynn [33]). Then, the moderators could either choose an iteration stereotype if they saw an appropriate fit or they could describe in their own words how they would characterize the iteration. Thus, new stereotype categories could emerge.

We observed 122 iterations, of which 107 were directly described and characterized by the moderators (while the participating teams were already working on their activities in the subsequent iteration). However, in a few cases the moderator might not have had enough time during the antecedent iteration to conduct the interview, so he/she had to describe and characterize up to three iterations later on in the workshop process [62,66].

For coding of the iterations, we extracted the iteration stereotypes directly from the videotaped interviews in case they were clearly stated by the workshop moderators, or we coded the characteristics if they only described what the participants actually did and how they would characterize their activities (we coded e.g. "divergent thinking" and "ideation" into the new stereotype category "ideation").

Table 2: Interview guideline for the iteration reflection with the workshop moderators after each observed iteration [62].

Dimension	Question to reflect on	Scale
Input	What was input and starting point of this iteration?	free speech
Activity	What did the participants actually do and how would you characterize it (e.g. as exploration, convergence, refinement, rework, negotiation, repetition, or as something else)?	free speech, selection, or free speech
Output	What is the concrete output of the iteration, and is there anything unexpected about it?	free speech
Performance	How do you evaluate the performance of the iteration? Effectiveness: off target to overmatch target. Efficiency: time wasted to very fast	–3 –2 –1 0 1 2 3 –3 –2 –1 0 1 2 3
Goal	What is the goal for the next iteration?	free speech

4. Results

In the first part of the results, we summarize iteration characteristics for each coded iteration category, including two newly identified iteration stereotypes. The descriptions cover what the participants actually did during the evolving workshop process, based on the data from the interviews with the moderators, the detailed workshop diary, the photos, and the videotaped PFD sessions. In the second part of the results, we show the distribution of the identified iteration stereotypes in terms of occurrence and duration. Where appropriate, we include the additional iteration stereotypes.

4.1. Identified iteration characteristics

The following sub-sections describe the dominant iteration characteristics that we identified in the evolving workshop processes, including the two new identified stereotypes of Ideation and Consolidation. The findings are based on our own observations as well as data extracted from in-situ moderator interviews conducted after each observed iteration.

Exploration: While 'identifying the right problem' (in workshop phase one), the participants primarily explored the problem space originating from the initially ill-defined design challenge (workshop topic). Using an environment map to collect insights about their customers and markets, legal and technology-related issues, etc. enhanced their general understanding of the organization's situation. An evaluation and interpretation of this map triggered an emerging structure of current and potential future business stakeholders, which could then be investigated in detail. Creating personas and discovering their pain-points in need-finding activities such as market research, role playing customer journeys, and conducting ad-hoc interviews allowed for an evolution of the design challenge that would be addressed in the second workshop phase.

In the next phase 'identifying promising solutions', the participants explored the solution space by prototyping their generated ideas with manifold materials. Learning more about the potential and perceived product properties (i.e. obstacles and advantages) in their applications was, at this level of design definition, a rather disordered process. However these led to the evolution of potential solution concepts and promising interim results. While participants in workshop phase one were mostly overwhelmed by the complexity of the problem space, they enjoyed learning about – and getting a grip on – their solutions in the second workshop phase. In particular, prototyping sessions provided participants the opportunity to get into the state of 'flow.' Moreover, in both cases the amount of insights, the gained knowledge, the number of design concepts and solution alternatives, and business opportunities increased.

Ideation: Once the initially ill-defined design challenge was reframed and clearly stated (i.e. in a problem statement or with user stories), the participants started generating ideas on how to tackle the issues and overcome the problems. Divergent thinking was encouraged by activities such as classical brain-storming and brain-walks as well as the scribbling of ideas and visualizations of additional potential solution concepts. In most cases, the participants could not wait to think "out-of-the-box," and to fill and expand the solution space with their ideas.

Refinement: If larger and longer activities such as need-finding or prototyping needed more than one iteration, the second iteration especially appeared as a refinement stereotype. While the most important requirements could already be satisfied with the outcome of a first iteration, several aspects of these interim results (such as secondary characteristics) were modified and improved in a second turn. This was observed during the first and second workshop phase while the participants elaborated on the problem and solutions space and while interim results were optimized (e.g. prototypes were built with soft materials in an initial iteration and got improved with more durable materials in a following iteration). In most cases, this iteration stereotype was initiated by the participants' ambitions, which led to (incrementally) improved interim results.

Rework: The rework stereotype occurred when the interim result of the preceding iteration did not satisfy the requirements, goals, or expectations, due to processed imperfect information or assumptions. This happened early in the workshop in situations in which user needs were not properly investigated and participants were subsequently unable to reframe their team's design challenge into a concise problem statement. Another example involved prototyped solution concepts that did not meet the main requirements (in the second phase, and in contrast to predecessors of refinement iterations which fulfilled the main requirements but secondary were to be elaborated). Even though it was cumbersome to start in a rework iteration, the outcome seemed to be very satisfying for the participants.

Negotiation: Intense negotiations emerged when content- and process-related uncertainties arose in working sessions. These were expressed during workshop phase one with questions such as, "What are we doing here?" and "What do we do next?" [66] They were also expressed when participants had to deal with their different priorities regarding the next steps or the project plan as a whole (merely in phase three). Those iterations were not intended to be of the negotiation stereotype, but the emerging (working) situation shaped/ transformed the iteration into a negotiation iteration. An honest discussion with a multi-directional information flow amongst all participants about the current situation and desired direction resulted in useful insights and mutual understandings. However, the integration of each participant's perspective became more difficult as the numbers of involved participants or their responsibilities increased.

Convergence: This stereotype was observed during all workshop phases, primarily indicating the end of a workshop phase. Typical forms of appearance were the formulation of the problem statement/user story at the end of the first workshop phase, the preparation of the final presentation at the end of phase two, and the planning of the next steps to transfer the workshop results into the company (at the end of phase three), cf. [66]. In each of these examples, the participants were concerned about the small details in their results, whether they related to the exact formulation of the persona's needs (in the user story), the progressive elimination of remaining design flaws in their most promising solutions, or the committed milestones in the action plan (on how to transfer the results and start the next development phases) which might be optimally aligned with industrial fair dates. As it was satisfying for the workshop participants to successfully complete a workshop phase, the workshop moderator aimed at having such convergence stereotype iterations at the end of a working day or in the evening, cf. [66].

Consolidation: The consolidation stereotype was observed in the third workshop phase, when participants reviewed their most relevant interim results, sorted out ideas and results, and determined what they wanted to "take home." Based on the created and mutually agreed-upon vision of what should be achieved in the following year and by formulating the newspaper article to fixate this vision, the teams then had a good starting position for defining the next steps in their organization, such as setting up new projects and advanced development processes. They reflected on their experiences and learning and determined how to communicate this to their colleagues who could not take part in the workshop. While it was satisfying to finish the workshop with a consolidation iteration, the participants were also exhausted after two-and-a-half days filled with new impressions, working approaches, practicing methods and tools, and hands-on experience in a highly iterative fuzzy front end product development, cf. [66].

4.2. Distribution of identified iteration characteristics

Table 3 displays the observed occurrence and mean duration of each observed iteration stereotype in each workshop phase. Regarding their occurrences, we found an uneven distribution, both over the total sample and along the three workshop phases. Over the total sample, Exploration and Refinement dominated in total occurrence (31.1% and 27.9%, respectively), while Rework occurred only rarely (2.5%). Along the workshop phases, roughly half the iterations (49.2%) occurred in phase 1, more than 40% (42.6%) occurred in phase 2, and less than 10% (8.2%) occurred in phase 3. More specifically, Negotiation and Convergence occurred in all three phases. Exploration, Refinement, and Rework were only observed early on (phases 1 and 2), while Consolidation occurred only later (phases 2 and 3). Ideation was only seen in phase 2. Exploration in phase 1 occurred most often (22.1%). Negotiation appeared mostly in phase 1 (6.6%) compared to phase 2 (0.8%) and phase 3 (0.8%), while Consolidation appeared mostly in the third phase (4.9%) compared to phase 1 (none) and phase 2 (0.8%). Finally, the occurrence of Exploration and Refinement in phases 1 and 2 was almost inverted. While Exploration decreased from 22.1% to 9.0%, Refinement increased from 9.8% to 18.0%.

Regarding the duration of iterations, Table 3 also shows an uneven distribution among the different stereotypes. While the mean duration of Refinement was the longest (1:15h), the mean duration of Rework and Negotiation was the shortest (each 0:40h). Along the workshop phases, the iterations in phase 1 were, on average, the shortest (0:45h). The iterations in phase 2 were the longest (1:23h), while the average duration of all iterations was about one hour (1:03h).

Table 3: Occurrence and duration of each observed iteration stereotype (n=122 iterations).

Iteration Stereotypes	Observed Occurrence of Iterations				Iteration Duration: Mean (SD) in [h:mm].			
	Sum	Phase 1	Phase 2	Phase 3	Mean (SD)	Phase 1	Phase 2	Phase 3
Exploration	31.1%	22.1%	9.0%	----	1:01 (0:35)	0:49 (0:25)	1:32 (0:37)	----
Ideation	7.4%	----	7.4%	----	1:03 (0:32)	----	1:03 (0:32)	----
Refinement	27.9%	9.8%	18.0%	----	1:15 (0:43)	0:48 (0:31)	1:30 (0:42)	----
Rework	2.5%	1.6%	0.8%	----	0:40 (0:28)	0:24 (0:10)	1:12 (0:00)	----
Negotiation	8.2%	6.6%	0.8%	0.8%	0:40 (0.24)	0:44 (0:25)	0:35 (0:00)	0:11 (0:00)
Convergence	17.2%	9.0%	5.7%	2.5%	0:57 (0:37)	0:40 (0:28)	1:25 (0:40)	0:55 (0:20)
Consolidation	5.7%	----	0.8%	4.9%	1:07 (0:39)	----	1:12 (0:00)	1:06 (0:43)
Total	100.0%	49.2%	42.6%	8.2%				
Means					1:03 (0:37)	0:45 (0:26)	1:23 (0:39)	0:57 (0:37)

5. Discussion

5.1. Fit between the identified iteration characteristics and the taxonomy of iterations

The following sections discuss the fit between the identified iteration characteristics and Wynn and Eckert's [1] taxonomy of iteration, presented according to the three functions of iterations (progressive, corrective, and coordinative).

Fit of progressive iteration stereotypes. While the definition of Exploration describes problem-solving as one entity, the workshop iterations first focused on the problem space and later on the solution space, even though there was often an overlap and participants learned more about the problem during solution development. In all other aspects, the observed iterations complied with the definition.

Concretization did not appear as a dominant iteration stereotype during the workshops. However, there might have been aspects of this stereotype in almost all of the observed iterations when the sub-teams prepared for each of their interim-presentations by defining details, ensuring consistency in their stories, and reducing ambiguity about their findings.

The Convergence stereotype was observed in all workshop phases, and in most cases it marked their end. In each case, the participants were concerned about the small details of their results, the progressive elimination of remaining design flaws in their solutions, and/or the optimal alignment of action plans. These observations complied with the definition.

Incremental Completion was not observed as a dominant stereotype but it might have been applicable to aspects of the workshop design. On the level of workshop phases, the participants worked in sub-teams simultaneously and in a similar manner on either their own problem or on a part of the whole problem by identifying promising solutions. If the evolving solution parts could be integrated into one solution it could be regarded as an Incremental Completion; if, however, a dominant solution emerges it would be considered a Comparison.

Fit of corrective iteration stereotypes. Rework occurred when the interim result of the preceding iteration did not satisfy the requirements/goals, due to processed imperfect information or assumptions. This might have happened if, for example, persona needs were not properly investigated or comprehended so that the participating teams were unable to re-frame the design challenge. It might also have happened when prototyped solutions did not fulfill the main requirements (in contrast to predecessors of Refinement which fulfilled the main requirements but secondary were elaborated). While it is frustrating to start a rework iteration, its results seem to be very satisfying. This complies with the definition.

Fit of coordinative iteration stereotypes. Besides the actual observed iteration stereotypes of progressive and corrective iterations (on a working level) for which we collected data, there were also coordinative iterations (on the management level), both in the taxonomy and the workshop setting, even though we did not directly collect iteration occurrence-specific data relating to them.

Negotiation: The observed iterations complied with the definition, as they emerged during working sessions and transformed the iterations' intended stereotype to a negotiation stereotype. Thus, process-related questions on a working level escalated to the management level where the moderator could handle them. Moreover, we observed workshops that started with a negotiation iteration, cf. [52].

5.2. New iteration characteristics beyond the taxonomy

Ideation (Progressive): There is no direct theoretical counterpart of the observed ideation iterations. While it is also addressing the solution space (by coming up with potential solutions), it differs from 'Exploration' in having a clearly formulated and well-defined problem statement as goal to be tackled. Furthermore, exploration deals with already-existing problems and solutions that are discovered, while ideation comprises iterations in which ideas and potential solutions are generated and developed.

Consolidation (Progressive): This does not have a direct theoretical counterpart of the observed consolidation iterations. Refinement refers to secondary improvements in spare time, while Consolidation is focused on relevant results and sorting out the rest. Thus, we placed it in with the progressive stereotypes, as it brings all relevant information and knowledge together (after several problem-solving iterations), encourages reflection on the process, and thus demonstrates that iterative situations may be necessary to achieve a common goal.

5.3. Not-observed iteration characteristics

The New Work (Corrective) stereotype did not appear during the workshops, which might be explained by the iterative workshop design. It was assumed that situations of New Work would be handled in a sequence of iterations, e.g. a "failed" (prototyping) Refinement, followed by an Exploration (of other solution principles) and another Refinement.

Churn (Corrective) was not applied in-situ to characterize iterations. However, it might be applicable for iterations that happened directly before – i.e. causing/calling for – Rework iterations, in case of failed (Convergence) iterations. As we split the characterization from the performance evaluation during the interviews, we could distinguish between failed Convergence (i.e. with low effectiveness) and Churn. Even though we did not observe Churn as a dominant stereotype during the workshop, it might be applicable for re-evaluating iterations after a workshop.

Governance (Coordinative) was not observed as a dominant stereotype but it might be applicable for aspects of the workshop management. The workshop concept comprised three phases, each of which consisted of a sequence of iterations. As the participants were not familiar with the workshop process, they were guided by a workshop moderator. This moderator facilitated the PFD session at each iteration's end and eased the change from one iteration to the next. As this was a recurring process, the moderator's feedback enabled timely completion of the workshop, within the budget, and of high quality. The data gathering (and moderator coaching by the authors) can be interpreted as governance.

Parallelization (Coordinative) was not observed as a dominant stereotype of single iterations but it might be applicable to aspects of the workshop progress on the whole. During the workshops, several (3 to 5) sub-teams worked in parallel on their specific sub-challenges. Although the frequent PFD sessions provided the opportunity to incorporate the information and insights of other sub-teams, there might have been a "phase-shift" of applied methods or tools over the course of iterations.

The Comparison (Coordinative) iteration was not observed as a dominant stereotype of single iterations but it might be applicable for aspects of the workshop progress on the whole. Especially after Ideation iterations, the participants had a huge amount of ideas on how to approach their problem statements. The subsequent iterations were dedicated to clustering, visualizations, prototyping etc. and individually characterized with Exploration, Refinement, or Convergence. However, considering the entire second workshop phase, they were working on – and singling out – most of their generated alternatives.

Finally, Concentration (Coordinative) was not observed as a dominant stereotype of single iterations but it might be applicable for aspects of the research setting on the whole. On the level of a single company participating in such a workshop, the workshop itself could be conceptualized as a concentrated iterative situation, as different ideas and capabilities were brought together in a spatiotemporal manner in this company-external ideation space. On the level of the research space, we conducted a series of nearly standardized workshops.

5.4. Occurrence and duration of iterations

Both the occurrence and duration of iterations varied and depended on their context. Exploration and Refinement were most dominant among all stereotypes, and while Exploration dominated phase 1, Refinement dominated phase 2. The additionally identified stereotypes of Ideation and Consolidation accounted for more than 13% of the whole sample (7.4% and 5.7%) and occurred in either phase 2 only (Ideation) or in both phase 2 and phase 3 (Consolidation). Also the mean duration of iteration stereotypes deviated from the overall average of 1:03h. While Refinement took, on average, a rather long time (1:15h), both Rework and Negotiation were clearly shorter (both 0:40h). In contrast to the work of Smith and Tjandra [21], our study design allowed for frequent iterations especially in the early workshop, showed that iterations got by trend longer during the workshop's progress (iterations in phase 1 compared to iterations in either phase 2 or 3), and enabled discussions among workshop participants throughout the process.

5.5. Expected and unexpected iterations

We observed both expected and unexpected iterations. Considering the elements of iteration, we identified more than 100 provoked iterations with a frequent switching between "working" and "presentation-feedback-discussion," which was indeed expected. Considering their appearance, we also noted unexpected iterations [63] such as Negotiation which emerged from other stereotype intentions.

Moreover, both approaches of describing iteration with either their elements or their appearance can be integrated and directly applied in the FFE of PDPs [64]. With respect to the iteration elements, the used definition of an iterative, recurring cycle consisting of working and presentation-feedback-discussion, deviates from that of Daniel et al. [22] and Andreasen [23] only in phase shifting. Regarding their appearance, we found empirical evidence of iteration stereotypes with progressive and corrective functions as described by Wynn and Eckert [1]; we additionally identified the stereotypes of Ideation and Consolidation. Moreover, we could observe how Negotiation iterations initially emerged from other iteration characteristics. However, we did not observe Repetition which might be traced back to the applied definition of iterations, as a series of iterations has a repetitive characteristic.

5.6. Extension of the iteration stereotype taxonomy

According to the concept of divergence and convergence in design processes [28] and in line with the "breathe in, breathe out" pattern posited by Mussgnug et al. [29], we can cluster the stereotypes into three "breathing-conditions":

- "Breathe in" refers to the concept of divergence, when the workshop participants were broadening the considered problem and solution space in iterations characterized as part of the Exploration or Ideation stereotypes.

- "Breathe out," in contrast, refers to the concept of convergence, when the participants were narrowing down their problem and solution space by conducting iterations characterized as belonging to the Convergence or Consolidation stereotypes.
- "Hold breath" comprises iterations that fit neither divergence nor convergence, such as the stereotypes of Refinement, Rework, and Negotiation.

Based on our findings and the taxonomy of Wynn and Eckert [1], we propose an extended coding scheme for iterations on a working level. Aside from the observed stereotypes that fit directly into the framework of progressive, corrective, and coordinative iteration functions, the stereotypes of New Work, Churn, Concretization, and Incremental Completion can also be related to the three breathing conditions, as described in Table 4. The coordination stereotypes of Governance, Parallelization, Comparison, and Concentration do not fit on a level of intra-workshop iterations, but can be related to aspects of the workshop moderation and organization, as discussed above. This coding scheme might support further research to investigate a potential link between iteration stereotypes and the concept of divergence and convergence in design and development processes.

Table 4: Extended coding scheme for iterations of progressive and corrective stereotypes (on working-level). Data could be gathered for *-highlighted stereotypes, #-highlighted stereotypes appeared outside the taxonomy by Wynn & Eckert [1].

Iteration function	Breathe in	Hold breath	Breathe out
Coordinative	--	Negotiation*	--
Corrective	New work	Rework*	--
		Churn	
Progressive	Ideation#	Refinement*	Convergence*
	Exploration*	Concretization	Consolidation#
		Incr. completion	

5.7. Limitations

As we investigated real design teams with company-specific challenges in real PDPs, our study was conducted in a semi-controlled research environment. Thus, potential background variables such as team composition and the complexity of workshop challenges were defined by the participating companies. Moreover, most of our data related to progressive and corrective iteration stereotypes, although coordinative stereotypes were also associated with the workshop setting.

6. Conclusion

In this paper we offer corroboration for and advancement of the concept of iteration stereotypes in the FFE of real PDPs. Contributions are first and foremost related to the empirical evidence of several already well-described iteration stereotypes, as well as the additionally identified progressive stereotypes of Ideation and Consolidation. Using the example of emerging Negotiations, we have shown how iterations can change their intended functions from progressive/corrective to coordinative, i.e. from a working to a management level. Moreover, we highlighted the uneven distribution in occurrence and duration of iteration stereotypes. Thus, we corroborate and empirically extend the taxonomy of iteration stereotypes of Wynn and Eckert [1] in cases in which observed iterations could be characterized in-situ.

Second, we associate the stereotypes to the concept of divergence and convergence in design processes [28], leading to a proposed coding scheme for iterations on the working level. This may help practitioners facilitate the design process within the FFE of PDPs.

Third, we show that both approaches of describing iterations (with either their elements or their appearance) can be integrated and directly applied in the FFE of PDPs. Applying this guideline is also a convenient and practical approach to keeping the workshop overview from the moderator's point of view.

Acknowledgements

We are grateful for the research funding of Swiss Mobiliar cooperative company, the insightful collaboration with the moderators, and the time invested by all workshop participants. Moreover, we acknowledge the valuable comments of our colleagues during the NordDesign2016 conference, where we presented an early version of this study [66].

References

[1] Wynn C.D., Eckert C.M., 2017. Perspectives on Iteration in Design and Development, Res Eng Design, 28: 153-184.
[2] Kim J., Wilemon, D., 2002. Focusing the Fuzzy Front-End in New Product Development, R&D Management, Vol. 32, No. 4, pp. 269-279.
[3] Borgianni, Y., Cascini, G., Rotini, F., 2018. Investigating the Future of the Fuzzy Front End: Towards a Change of Paradigm in the Very Early Design Phases?, Journal of Engineering Design, 29:11, 644-664.
[4] Mihm, J., Loch, C., Huchzermeier, A., 2003. Problem-solving Oscillations in Complex Engineering Projects, Manage Sci 46(6):733–750.
[5] Braha, D., Bar-Yam, Y., 2007. The Statistical Mechanics of Complex Product Development: Empirical and Analytical Results, Manage Sci 53(7):1127–1145.
[6] Adams, R.S., Atman, C.J., 2000. Characterizing Engineering Student Design Processes: An Illustration of Iteration, In "Proceedings of the ASEE annual conference," ASEE.
[7] Heck, J., Meboldt, M., 2016. Current Challenges in Product Development Processes of Swiss SMEs, International Journal of Innovation Management, Vol. 20, No. 5, 1640009.
[8] Karniel, A., Reich, Y., 2013. Multi-level Modelling and Simulation of New Product Development Processes, Journal of Engineering Design, 24:3, 185-210.
[9] Love, P.E.D., Edwards, D.J., 2004. Forensic Project Management: The Underlying Causes of Rework in Construction Projects, Civil Eng Environ Syst 21(3):207–228.
[10] Osborne, S.M., 1993. Product Development Cycle Time Characterization Through Modeling Of Process Iteration, Master's thesis, MIT, Boston, MA.
[11] Maier, A., Störrle, H., 2011. What are the Characteristics of Engineering Design Processes?, In "International Conference On Engineering Design," ICED 11, Design Society.
[12] Simon, H.A., 1973. The Structure of Ill-Structured Problems, Artif Intell 4(3–4):181–201.
[13] Dorst, K., Cross, N., 2001. Creativity in the Design Process: Coevolution of Problem-Solution, Design Stud 22(5):425–437.
[14] Clark, K.B., Chew, W.B., Fujimoto, T., 1987. Product Development in the World Auto Industry, Brookings Pap Econ Act 3:729–781.
[15] Eppinger, S.D., 1991. Model-based Approaches to Managing Concurrent Engineering, Journal of Engineering Design, 2:4, 283-290.

[16] Eppinger, S.D., Whitney, D.E., Smith, R.P., Gebala, D.A., 1994. A Model-Based Method for Organizing Tasks in Product Development, Res Eng Des 6:1–13.
[17] Shapiro, D., Curren, M.D., Clarkson, J.P., 2016. DPCM: A Method for Modelling and Analysing Design Process Changes Based on the Applied Signposting Model, Journal of Engineering Design, 27:11, 785-816.
[18] Pahl, G., Beitz, W., 1996. Engineering Design. Springer, London.
[19] Meboldt, M., Matthiesen, S., Lohmeyer, Q., 2012. The Dilemma of Managing Iterations in Time-to-market Development Processes, In "MMEP2012," P. Heisig, J.P. Clarkson, eds., 2014. Modeling and Management of Engineering Processes - Concepts, Tools and Case Studies. Technical report, Cambridge: University of Cambridge.
[20] Le, H.N., 2012. A Transformation-Based Model Integration Framework to Support Iteration Management in Engineering Design, PhD thesis, University of Cambridge.
[21] Smith, R.P., Tjandra, P., 1998. Experimental Observation of Iteration in Engineering Design, Research in Engineering Design, No. 10, pp. 107–117.
[22] Daniel, J., Medland, T., Newnes, L., 2007. Graphical Representation of Key Iterations during the Design Process, Proceedings of International Conference on Engineering Design 2007, Paris, France.
[23] Andreasen, M.M., 2015. Personal discussion, Luxembourg, August 2015.
[24] Heck, J., Steinert, M., Meboldt, M., 2015b. Provoking Iterations in Ideation Workshops – An Explorative Study, Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. 11: Human Behaviour in Design, Design Education; Milan, Italy, 27.–30.07.2015, pp. 133–142.
[25] Safoutin, M.J., 2003. A Methodology for Empirical Measurement of Iteration in Engineering Design Processes, Dissertation at University of Washington.
[26] Cash, P., Štorga, M., 2015. Multifaceted Assessment of Ideation: Using Networks To Link Ideation and Design Activity, Journal of Engineering Design, 26:10-12, 391-415.
[27] Costa, R., 2004. Productive Iteration in Student Engineering Design Projects, Master's thesis, Montana State University.
[28] Liu, Y.C., Bligh, T., Chakrabarti, A., 2003. Towards an 'Ideal' Approach for Concept Generation, Design Studies, Vol. 24, pp. 341–355.
[29] Mussgnug, M., Boes, S., Meboldt, M., 2015. Principles Guiding Teams in New Product Development Projects, Proceedings of EPDE 2015, Loughborough, UK.
[30] Austin, S., Lyneis, J., Bryant, B.J., 2001. Mapping the Conceptual Design Activity of Interdisciplinary Teams, Des Stud 22(3):211–232.
[31] Boudouh, T., Anghel, D.C., Garro, O., 2006. Design Iterations in a Geographically Distributed Design Process, In "Advances in Design Part VII," H.A, ElMaraghy, W.H. ElMaraghy, Editors. Springer, London, pp 377–385.
[32] Škec, S., Cash, P., Štorga, M., 2017. A Dynamic Approach to Realtime Performance Measurement in Design Projects, Journal of Engineering Design, 28:4, 255-286.
[33] Wynn, D.C., 2007. Model-Based Approaches to Support Process Improvement in Complex Product Development, PhD thesis, Cambridge University, Cambridge, UK.
[34] Hatchuel, A., Weil, B., 2009. CK Design Theory: An Advanced Formulation, Res Eng Des 19(4):181–192.
[35] Yassine, A., Joglekar, N., Braha, D., Eppinger, S.D., Whitney, D., 2003. Information Hiding in Product Development: The Design Churn Effect, Res Eng Des 14:145–161.
[36] Costa, R., Sobek II, D.K., 2003. Iteration in Engineering Design: Inherent and Unavoidable or Product of Choices Made?, Proceedings of DETC'03, ASME 2003 Design Engineering Technical Conferences and Computers and Information in Engineering Conference Chicago, Illinois USA, September 2-6, 2003.
[37] Braha, D., Maimon, O., 1998. The Measurement of a Design Structural and Functional Complexity, IEEE Trans Syst Man Cybern Part A Syst Hum 28(4):527–535.
[38] Sobek, D.K., Ward, A., Liker, J., 1999. Toyota's Principles of Set-Based Concurrent Engineering, Sloan Manag Rev 40(2):67–83.
[39] Ahmad, N., Wynn, D.C., Clarkson, P.J., 2013. Change Impact on a Product and Its Redesign Process: A Tool for Knowledge Capture and Reuse, Res Eng Des 24(3):219–244.
[40] Wynn, D.C., Caldwell, N.H.M., Clarkson, P.J., 2014. Predicting Change Propagation in Complex Design Workflows, J Mech Des 136(8):081,009–1–081,009–13.
[41] Haller, M., Lu, W., Stehn, L., Jansson, G., 2014. An Indicator for Superfluous Iteration in Offsite Building Design Processes, Archit Eng Des Manag 11:360–375.
[42] Taylor, T., Ford, D.N., 2006. Tipping Point Failure and Robustness in Single Development Projects, Syst Dyn Rev 22(1):51–71.
[43] Isaksson, O., Keski-Seppälä, S., Eppinger, S.D., 2000. Evaluation of Design Process Alternatives Using Signal Flow Graphs, J Eng Des 11(3):211–224.
[44] Smith, R.P., Eppinger, S.D., 1997a. Identifying Controlling Features of Engineering Design Iteration, Manage Sci 43(3):276–293.
[45] Browning, T.R., 1998. Modeling and Analyzing Cost, Schedule and Performance in Complex System Product Development, PhD thesis, MIT.
[46] Cooper, K.G., Steele, J., Macmillan, S., Kirby, P., Spence, R., 2002. Learning to Learn, from Past to Future, Int J Project Manage 20:213–219.
[47] Unger, D., Eppinger, S.D., 2011. Improving Product Development Process Design: A Method for Managing Information Flows, Risks, and Iterations, Journal of Engineering Design, Vol. 22, No. 10, pp. 689–699.
[48] Ahmadi, R., Wang, R., 1999. Managing Development Risk in Product Design Processes, Oper Res 47(2):235–246.
[49] Iansiti, M., MacCormack, A., 1997. Developing Products on Internet Time, Harvard Bus Rev 75(5):108–117.
[50] Bucciarelli, L.L., 1994. Designing Engineers, MIT Press, Cambridge, MA.
[51] Krishnan, V., Eppinger, S.D., Whitney, D.E., 1997b. Simplifying Iterations in Cross-Functional Decision Making, J Mech Des 119(12):485–493.
[52] Eckert, C.M., Isaksson, O., Earl, C.F., 2014. Design Margins as a Key to Understanding Design Iteration, in "Proceedings of the ASME 2014 Design Engineering Technical Conferences and Computers and Information in Engineering Conference," ASME.
[53] Krishnan, V., Eppinger, S.D., Whitney, D.E., 1995. Accelerating Product Development by the Exchange of Preliminary Product Design Information, J Mech Des 117(12):491–498.
[54] Terwiesch, C., Loch, C.H., Meyer, A.D., 2002. Exchanging Preliminary Information in Concurrent Engineering: Alternative Coordination Strategies, Organ Sci 13(4):402–419.
[55] Ulrich, K., Eppinger, S., 2011. Product Design and Development, 5th Edition, McGraw-Hill Education, New York.
[56] Chusilp, P., Jin, Y., 2006. Impact of Mental Iteration on Concept Generation, J Mech Des 128(1):14–25.
[57] Oppenheim, B., 2004. Lean Product Development Flow, Syst Eng 7(4):352–376.
[58] Beauregard, Y., Thomson, V., Bhuiyan, N., 2008. Lean Engineering Logistics: Load Leveling of Design Jobs with Capacity Considerations, Can Aeronaut Space J 54(2):19–30.
[59] Heck, J., Al-Falou, K., Steinert, M., Meboldt, M., 2014. Iterative Creation and Analysis of Generic Ideation Spaces for SMEs, Proceedings of Norddesign 2014, Espoo, Finland.
[60] Heck, J., Steinert, M., Meboldt, M., 2015a. Conceptualizing Ideation Workshops for SMEs, Procedia CIRP 36 (2015), pp. 248–253.
[61] Thurston, D.L., Nogal, A., 2001. Meta-Level Strategies for Reformulation of Evaluation Function during Iterative Design, Journal of Engineering Design, 12:2, 93-115.
[62] Heck, J., Rittiner, F., Steinert, M., Meboldt, M., 2016. Iteration-based Performance Measurement in the Fuzzy Front End of PDPs, Procedia CIRP 50 (2016), pp. 14–19.
[63] Smith, R.P., Eppinger, S.D., 1993. Characteristics and Models of Iteration in Engineering Design, International Motor Vehicle Program, Massachusetts Institute of Technology, 1993.
[64] Heck, J., 2017. Creating Momentum and a Positive Long-Term Impact on the Innovation Capability of Swiss SMEs, Dissertation at ETH Zurich.
[65] Mens, T., Tourwe´, T., 2004. A Survey of Software Refactoring, IEEE Trans Softw Eng 30(2):126–139.
[66] Heck, J., Rittiner, F., Steinert, M., Meboldt, M., 2016. Quantifying Characteristics of Iterations in the Fuzzy Front End of Product Development Processes, Proceedings of Norddesign 2016, Part 1, pp. 430–439.