AGILE DEVELOPMENT OF PHYSICAL PRODUCTS

An Empirical Study about Potentials, Transition and Applicability

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Executive Summary

Grundlegende Informationen zur aktuellen Stichprobe

Die Erhebung hat im Zeitraum September - Dezember 2018 für den deutschsprachigen Raum (DACH) eine Stichprobe mit 187 Antworten (cases) aus ca. 120 Unternehmen erzeugt. Der größte Anteil an Teilnehmern stammt aus maschinenbaulastigen Unternehmen, wobei nahezu alle sonstigen hardwarelastigen Branchen (Elektro-, Automobil- und Medizintechnik) vertreten sind. Mit Blick auf die Unternehmensgröße zeigt sich, dass die gesamte Bandbreite, von Kleinstunternehmen, über KMU bis hin zu Großkonzernen, vertreten ist. Die Kategorie der größeren Unternehmen (250 - 4.999 Mitarbeiter) ist besonders stark vertreten. Insgesamt hat die Studie den gewünschten Strukturquerschnitt erzeugt und liefert eine Differenzierung zu eher angloamerikanisch geprägten Studienergebnissen für die agile Entwicklung.
Für das Verständnis und die Nutzung der Ergebnisse ist es von großer Bedeutung, dass die Umfrage einen konkreten und detailreichen Einblick in die Welt der Praktiker erzeugt hat. Mehr als 75% der Unternehmen bringen eigene Erfahrungen aus realen Umsetzungs- und Anwendungsprogrammen mit. Der Großteil der Teilnehmer (mehr als 80%) hat ihren Arbeitsschwerpunkt entweder in der Forschung & Entwicklung (R&D) oder im Projektmanagement. Erneut ist es in 2018 gelungen die Möglichkeit zur Spiegelung der Meinungen und Projektionen von „Entwicklungsprojekt-erfahrenen“ Akteuren zu realisieren.

Perspektive 1: Trendlinien 2017 - 2018

Mit der Durchführung der 2. Erhebung liegen zwei vergleichbare Datensätze vor. Mit der Gegenüberstellung gleichartiger Fragestellungen und deren Antworten können erste vorsichtige Trendlinien für Potenziale und Herausforderungen gezogen werden:

- Das Konzept der Agilität ist übertragbar und wird für die physische Produktentwicklung breiter und universeller als nur für die Software angewendet - die positive Einstellung ist im Trend konstant.
- Agile Entwicklung wird über Branchen und Unternehmensgrößen hinweg angewendet – die Attraktivität ist übergreifend und etabliert sich konstant.
- In der Anwendungsreife sind Unternehmen mit Produkten, die hohe Embedded Software-Produktbestandteilen aufweisen, fortgeschrittener als Unternehmen mit ausgeprägten mechanischen oder maschinenbaulichen Produktfunktionalitäten (konstruktionslastig). Erfahrungen aus der Software sind häufig Ausgangspunkt für die Anwendung in der Hardware.
- Zu Beginn einer Umsetzung wird die agile Methodik mit *schnell, wendig, lean* in der Hauptsache assoziiert. Im weiteren Verlauf und mit zunehmender Anwendungsreife werden jedoch eher die Adjektive *kommunikativ, reaktionsschnell* und *nützlich* dem Konzept zugeschrieben. Im Trend bleibt dieser „Motivationsdrift“ ebenfalls konstant.
- In der Umsetzung sind fortgeschrittene Anwendungsreifen (Levels) nach 3 - 5 Jahren erreichbar. Dieser Erwartungshorizont ist über die Zeitspanne bestätigt worden.
- Die Umsetzung von agiler Entwicklung stützt sich weiter auf die 3 Vorgehensmodelle: Scrum, Kanban und Design Thinking. Hier ist keine Verschiebung zu beobachten. Die arbeitskoordinierenden Methoden bleiben dominant.

- Anwendungshürden (*Challenges*) und Konfliktprojektionen (*Conflicts*) sind nahezu alle überschätzt (größer als vermutet). Diese Praktikererfahrung wird erneut bestätigt.
- Die Problematik einer übersteigerten Erfolgserwartung (Hype-Falle) bezogen auf Projekterfolgskenngrößen wird erneut erfasst und bestätigt. Die „Überhöhung" scheint das Problem zu sein – nicht die positiven Wirkungen.
- Im Feld der Verbesserungen dominieren wiederum die teamorientierten „weichen" Faktoren *(Transparenz, Kommunikation, Commitment)* gegenüber „harten" Faktoren *(Qualität, Kosten, Zeit)*. Agilität ist augenscheinlich keine „Wunderlösung". Es benötigt ein realistisches Erwartungsmanagement und Zeit.

Perspektive 2: Ergebnisse neu gesetzter Schwerpunkte 2018

Im Unterschied zum Fragenkatalog 2017 wurden 2018 neue Detailfragen bzw. neue Fragerichtungen aufgenommen. Die Auswertungen der diesbezüglichen Antworten zeigen:

- Von 36 abgefragten organisatorischen und technischen Herausforderungen für die Anwendung stellte sich als einzige (1 aus 36) der Umgang mit der gewohnten Arbeitsspezialisierung mit größerem Problempotenzial heraus.
- Die Erwartungshaltung zwischen R&D-Mitarbeitern und Projektmanagement gehen in vielen Aspekten deutlich auseinander. Vor allem Projektmanager überschätzen die erwarteten Vorteile agiler Entwicklung stark.
- Die Anwendungshürden der agilen Entwicklung sind mannigfaltig: Prototypenerstellung und externe Abhängigkeiten auf der technischen Ebene, ungeeignete Unternehmenskultur in der Verhaltensebene, unpassende Unternehmensstruktur in der organisatorischen Ebene.
- Als tatsächliche unterschätzte Umsetzungshürde konnten Befürchtungen (social conflicts) des Macht- und Verantworungsverlusts der Führungspositionen erkannt werden.
- Arbeiten in Iterationen gemäß Scrum ist grundsätzlich keine Hürde - Iterationslängen von 2 Wochen werden häufig verwendet. Im Gegensatz dazu stellt die Erzeugung von MVPs (Minimum Viable Products bzw. vorzeigbare Inkrement-Ergebnisse) eine große Hürde dar.
- Mit fortschreitendem Transformationsgrad der Agilität in die Organisation hinein (Skalierung) treten zusätzliche (teilweise auch eigenentwickelte) Entwicklungsmethoden in Erscheinung. Die Veränderung mündet in methodische Anpassungen – denkbar als Potenzial für einen R&D-Wettbewerbsvorteil.
- Die Umsetzung agiler Entwicklung entwickelt sich bereits weg von isolierten Pilotanwendungen (Stadium des isolierten Experiments) hin zu Multiprojekt- und organisationsübergreifenden Wandlungsprogrammen (Transformation Levels 1 - 5) – für Pionier-Unternehmen offensichtlich realistisch vorteilhaft.
- Für die kommenden 3 - 5 Jahre wird in den Entwicklungsportfolien eine Zunahme der agil durchgeführten Projekte von heute ca. 20% auf zukünftig ca. 50% erwartet.
- Es ist eine zunehmende Fortentwicklung der Entwicklungssysteme hin zu Mischungen mit „klassischen" Vorgehensmodellen (Hybride-Modelle) erkennbar - Als „evolutionäre" Entwicklung verständlich, jedoch wahrscheinlich konfliktträchtig, da implizite Gegensätzlichkeiten so nicht aufgelöst werden.

⇒ Insgesamt ist festzuhalten, dass agile Entwicklung heute noch kein Standard für die physikalische Produktentwicklung ist. Die Vorteilhaftigkeit ist durch die Rückmeldungen der Teilnehmer zu den andauernden und prognostizierten Umsetzungsaktivitäten der Unternehmen bis in ganze Organisationsveränderungen hinein mit dieser Studie untermauert. Die Anstrengungen lohnen sich und können vor dem Hintergrund der vorliegenden Ergebnisse zielgerichteter in Angriff genommen werden. Es wird kein Selbstläufer sein, aber das Risiko des Scheiterns lässt sich deutlich minimieren.

Executive Summary

Basic facts of the current sample

In the period September - December 2018, the survey generated a sample of 187 answers (cases) from approx. 120 companies for the German-speaking (DACH) regions. The largest share of participants comes from mechanical engineering companies, whereby almost all other hardware-related industries (electrical, automotive and medical technology) are represented. In terms of company size, it can be seen that all company sizes are represented, from micro-enterprises to SMEs and large corporations. The category of larger companies (250 - 4,999 employees) is particularly well represented. Overall, the study has produced the desired structural cross-section and on the basis of this provides a differentiation to rather Anglo-American study results for agile development.

For the understanding and use of the results it is of great importance that the survey has produced a concrete and detailed insight into the world of practitioners. More than 75% of the companies have shared their own experiences from real implementation and application programs. The majority of the participants (more than 80%) work either in research & development (R&D) or in project management. In 2018 it was once again possible to reflect the opinions and projections of actors experienced in development projects.

Perspective 1: Trend lines 2017 - 2018

By conducting the second survey, two comparable data sets are available for the agile development of physical products. By comparing similar questions and their answers (core questions), first tentative trend lines regarding potentials and challenges can be drawn:

- The concept of agility is transferable and applied to physical product development more broadly and universally than just for software - the positive attitude is constant in the trend.
- Agile development is applied across all industries and company sizes - the attractiveness is comprehensive and constantly rising.
- Regarding the application maturity, companies which produce products with high embedded software - components are more advanced than companies with pronounced mechanical (engineering) product functionalities (design intensive). Experiences in the software industry are often the starting point for the application of agile hardware development.
- At the beginning of an implementation, the agile methodology is mainly associated with *fast, versatile, lean*. In the further course and with increasing maturity, however, the adjectives *communicative, responsive* and *beneficial* are attributed to agile development. In line with the trend, this “motivation drift“ also remains constant.
- In terms of implementation, advanced levels of application maturity are achievable after 3 - 5 years. This expectation horizon has been confirmed over time.
- The implementation of agile development continues to be based on 3 process models: Scrum, Kanban and Design Thinking. No shift can be observed here. The work-coordinating methods remain dominant.

- Almost all application challenges and conflict projections are overestimated (larger than expected). This practical experience is confirmed once again.
- The problem of exaggerated success expectations (hype pitfall) in relation to project success parameters is again recorded and confirmed. The “exaggeration“ seems to be the problem - not the positive effects.
- Regarding the benefits associated with agile hardware development, team-oriented “soft“ factors *(transparency, communication, commitment)* dominate in contrast to “hard“ factors *(quality, cost, time)*. Agility is no a “silver bullet“. It requires a realistic expectation management and time.

Perspective 2: Results of new focal points in 2018

In contrast to the 2017 survey, new detailed questions and new question directions were added in 2018. The evaluations of the relevant answers reveal the following:

- Of the 36 organizational and technical challenges for the application asked in survey, the only one (1 out of 36) that turned out to be a very big challenge was the issue of the assignment of employees with a high degrees of work specialization.
- The expectations between R&D employees and project management differ significantly in many aspects. In particular, project managers strongly overestimate the expected benefits of agile development.
- Major application challenges of agile development are on different levels: Prototyping and external dependencies on a more technical level, unsuitable corporate culture on the behavioral level, inappropriate corporate structure on the organizational level.
- Regarding the social conflicts, the fear of power and responsibility loss of the leading positions could be recognized as a real underestimated source of conflict.
- Working in iterations according to Scrum is basically no hurdle - iteration lengths of 2 weeks are commonly used. In contrast, the generation of MVPs (Minimum Viable Products or deliverable increments) represents a major issue.
- As the degree of agility transformation into the organization progresses (scaling), additional (to some extent self-developed) development methods become apparent. The change leads to methodical adjustments - conceivable as potential for a R&D competitive advantage.
- The implementation of agile development is already moving away from isolated pilot applications (stage of the isolated experiment) to multi-project and cross-organizational transformation programs (Transformation levels 1 - 5) - obviously realistically advantageous for pioneer companies.
- For the next 3 - 5 years the development portfolios are expected to increase in the number of agile projects from approx. 20% as of today to approx. 50% in the future.
- There is an increasing advancement of the development systems towards mixtures with “classic“ procedural models (hybrid models) - understandable as “evolutionary“ development, but probably prone to conflict, since implicit opposites are not resolved in this way.

⇒ Overall, it can be said that agile development is not yet a standard for physical product development. The advantages are underpinned by the feedback of the participants on the ongoing and predicted implementation activities of the companies up to and including entire organizational changes with this study. The efforts are worthwhile and can be targeted even more in the light of the available results. It will not be a fast-selling item, but the risk of failure can be minimized.

Foreword by René Martin-Martin

Agile Coach, SENNHEISER electronic GmbH & Co. KG

Product development using agile process models is gaining ever more momentum. As offers and services enabling agile ways of thinking and behaving increase, so has the demand to deploy such processes in areas adjacent to the creation of products. Agile principles and methods are therefore also increasingly used in areas such as purchasing, marketing, sales, and distribution. This broader adoption is crucial to fulfill the vision of an agile organization.

The core competencies of Sennheiser electronic GmbH & Co. KG are the development, manufacture, and sale of electro-acoustic devices and systems. Looking back on our 74-year company history, we have created iconic products, such as HD414, which became the world's best-selling headphones when launched in 1968. Similarly, the company's dynamic microphones have secured an enduring, decades-long preeminence and are still used virtually in every area of professional sound technology. Back then, the product development approach was different: an idea resulted in a plan which was subsequently implemented in stages. In most cases, the demand from the market was greater than the supply. If products came close to aligning with a current trend, it was certain that customers would buy them. This procedure, with a lot of time for development and optimization, was successful until about the end of the 20th century.

Today, we are facing a changed market situation with more dynamic competition and ever-changing market rules. The demands have changed: exclusivity and need-oriented solutions to problems have priority. Today's customers learn quickly and change their ideas even faster. This requires a high degree of flexibility and dynamism in order to be able to react promptly to these volatile market changes.

The foundation for agile development at Sennheiser was laid in 2013. The new Innovation Campus offers a permanent home for projects and their teams. This involved developing a common understanding of future project-related thinking and leadership. That, in turn, led to a change in the work organization and forged a new ethos of cooperation – all driven by the aim to work more transparently and effectively to create innovations in the world of audio.

When the first agile projects were launched in October 2014, it was initially unclear whether Scrum would be successful for us at all in hardware development. The complexity and dependencies (e.g. on external development partners) are significantly higher compared to pure software development. For an early foray in agile development for physical products, we selected the project Digital 6000 (dual-channel receiver for sophisticated live productions) as a representative hardware project for Sennheiser, being that it demanded every specialist area (mechanics, electronics, high-frequency technology, digital signal processing and embedded software). The project teams worked iteratively and incrementally in three-week cycles. The project activity was characterized by a high degree of self-organization and personal responsibility. Early user involvement provided valuable feedback and contributed significantly to product acceptance by the customer. With an excellent focus on customer needs, the Digital 6000 product family is a huge success today that has exceeded all forecasts and expectations.

Today at Sennheiser, we apply agile principles in many projects, and have already gained positive experience in transferring the agile approach to other processes in the areas of supply chain management and customer relationship management. In projects with globally distributed teams, we achieved great results through the application of agile routines, short-cycle coordination and high transparency. Initial hurdles were overcome by the use of suitable collaboration tools. In the meantime, standard software facilitates the coordination of relevant topics and the associated task management across site boundaries. In addition, distributed estimates and, by extension, decision-making processes are supported far more effectively. Today, online meetings of global teams can be conducted efficiently with the best speech intelligibility and excellent sound quality through the in-house development of the Team Connect Wireless system.

Self-organized projects and empowered, autonomous teams need simple rules in the development processes, a clear framework for action, adequate infrastructures, tools and practices paired with good competence transfer and discipline. Software development has already gained a time advantage in recent years. Demand-oriented infrastructures, tools and practices have been developed that are tailored to the specific needs and challenges of software development. Examples of this are the development of continuous integration and automated testing towards continuous delivery. These practices were not available from the outset, instead being developed to meet a specific need due to past constraints.

As positive as these experiences and functioning solutions may be, there is still further need for action in the agile development of physical products. Applied here, Scrum has also proved to be a very popular method. However, the realization of prototypes within one single iteration remains challenging. The higher the proportion of hardware, the more likely it is that it will need to be adapted to our own needs in order to be successful. The potential here lies primarily in soft skills, such as improved communication, which in turn leads to an increase in reaction speed, thereby considerably increasing the effectiveness of project work. Furthermore, this can also lead to a positive effect on key business metrics such as time-to-market and product development costs. To achieve this, however, agile thinking and behavior must also continue to evolve in middle and upper management in order to best support interaction with agile projects/teams.

This study deals with these challenges inherent in hardware development. It makes a valuable contribution and enables companies to review their decision-making orientation with the help of applied statistics. Furthermore, it enables comparison of one company's transition with others' and reflection on individual views on agile development. Also, important to emphasize is the academic context of this study, which provides a scientific presentation of the results and a much-needed neutral point of view that makes this work a truly invaluable source of insight.

R. Martin-Martin

René Martin-Martin
Agile Coach
SENNHEISER electronic GmbH & Co. KG

Contents

Part I.

Introduction: Why and How We Conducted The Study

1. Goals and Motivation of the Study

Companies in all industries are increasingly facing the challenge of having to implement development projects under uncertain, volatile, complex and ambiguous conditions (VUCA) in order to remain competitive. Companies can rely on efficiency-oriented development processes and organizations that reflect the knowledge and competencies of their employees (Albers, Bursac, and Wintergerst 2015). In the concrete project organization, however, companies often fall back on classic plan-driven approaches such as the V-Modell XT or the Stage-Gate approach, which are often too cumbersome and inflexible in dealing with volatile and uncertain development conditions. Agile methods promise to enable development teams not only to react constantly and quickly to expected and unexpected changes in dynamic environments, but also to accept them and use them to their advantage (Böhmer, Beckmann, and Lindemann 2015).

In the industrial environment, the phenomenon of the "Guru problem" can be observed in this context: Despite various and diverse challenges, a considerable number of companies apply agile methods very efficiently for mechatronics development as well. These "success stories" are taken up by other companies and they try to transfer them to their own product development, whereby it is often not clear what the actual key factors for success are. This leads to frustration for the adapting companies, expectations are not fulfilled, and promising methodical approaches are ultimately burned. This is where the concept for the present study comes in. The aim is to identify influencing and success factors for the application and to derive recommendations for the application of agile methods that support a successful introduction under the respective specific boundary conditions.

Last year, the focus of the study was on identifying motivations (*Why do companies want to implement agile hardware development?*), potentials (*What is really achievable with agile hardware development?*), and applicability (*Is the concept of agile development limited to the software industry?*). The survey was repeated and adapted based on the insights gained in the study of 2017 (Schmidt, Weiss, and Paetzold 2018a), so the focus shifted to the following aspects:

Potentials: *What are the (positive and negative) effects of agile hardware development?* An essential result of last year's study was that the application of agile methods does not necessarily improve those aspects that are hard to assess using KPI's, such as the reduction of development costs and times, but rather soft factors such as communication or the overall commitment within the team. These aspects were selected in order to better differentiate the results of the past year. The aim is to achieve a better consideration of the means-end relationship (Schmidt, Weiss, and Paetzold 2018b) when introducing agile methods and at the same time to objectify the evaluation of the success of the introduction.

Transition: *How does the perception of agile hardware development change over the course of implementation?* In addition to the expectations for the use of agile methods, experience gained during the application also has an effect on the evaluation of the potential of agile methods. In the same way, experience gained in dealing with agile methods leads to adaptations of the methods themselves as well as in the organization and process structure, which in turn influences the efficiency of the use of the methods. Knowledge about transition mechanisms helps newcomers to create suitable framework conditions for the application of agile methods or to adapt the methods in a target-oriented way.

Applicability: *How well is agile development applicable in the development of physical products?* From the viewpoint of transition, it is repeatedly discussed to what extent the agile methods developed from software development can actually be adapted for the development of mechatronic systems. While last year the focus of the study was on questioning the effects of the physicality of the products on the application of methods, this year's focus was also on challenges arising from the handling of large and complex systems. Development in distributed teams that work in remote areas and where team sizes of 50 employees and more have to be taken into account is not unusual. These are all factors which agile methods were not originally designed for, but which are essential criteria for transferability.

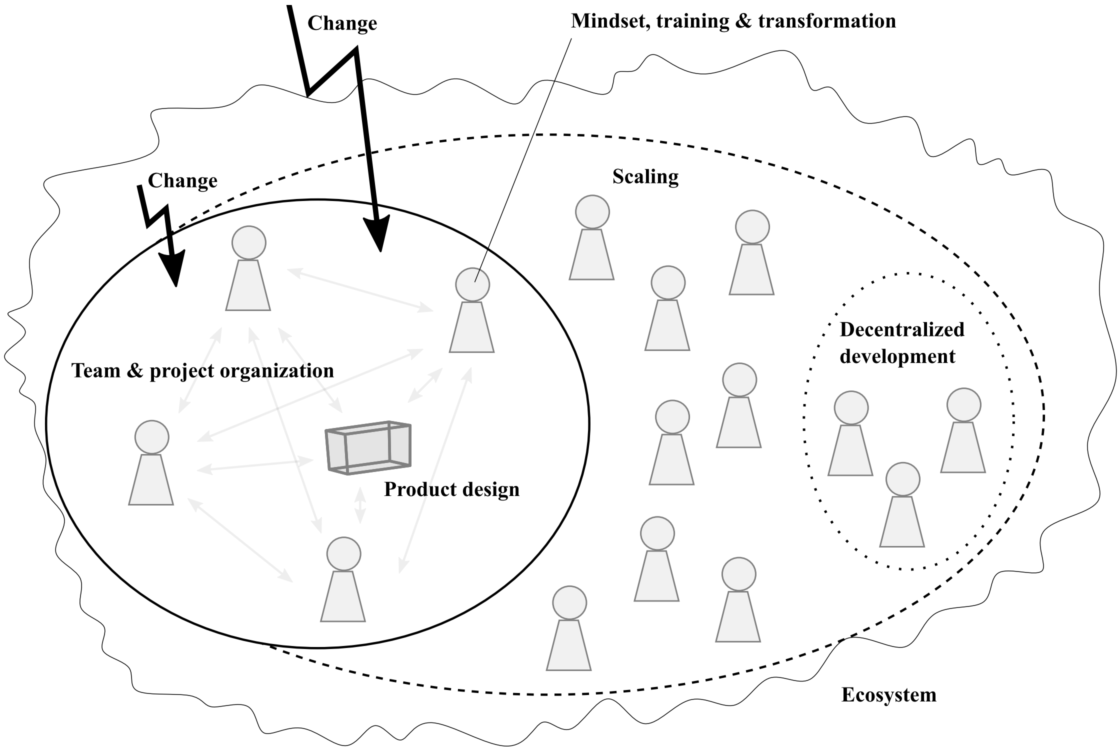

Figure 1.1.: Foci of this year's survey.

In sum, the focus has somewhat shifted with the conduct of the study in the second year. The aim was to gain insights into transition processes for the specific application of agile methods in mechatronics development in order to be able to understand how these influence the effectiveness and efficiency of agile methods and which framework conditions have to be taken into account. The study focuses exclusively on the development of physical products that were defined as products that consist of mechanics, electronics or embedded hardware at least to some extent. Thus, such products have a physical, tangible component and are not purely made of (virtual) software. In the context of this study, the term *hardware* is used interchangeably with *physical product*.

Without anticipating the results in detail, the data analysis shows partially surprising, partially alarming results. The potentials of the agile development concept are clearly present for physical product development, but the intensity and ranking are remarkable.

Finally, the author team once again likes to thank all participants, who spent their time in answering the extensive survey. Without their engagement these interesting results would not have been possible.

2. Features of the Study

I Actual versus real effects of agile hardware development

Selecting and designing the questions was based on experiences gathered from the insights obtained in last year's study as well as industrial projects and research. As last year, the study was conceptualized recording the "before - after" experience, which was transposed in the sequence of the question sections: The participants who signaled at the beginning of the survey that they are beginners in agile product development implementation were asked for their expectations but not for their experiences. Thus, the online process skipped the section "experiences made" when the participant was a beginner and vice versa, if the participant was experienced. Consequently, two samples of participants were generated, one of rather inexperienced, yet interested "beginners" and another sample of "advanced users", having clearly gained experience during the implementation. The differentiation was conducted based on the question regarding the participants' experience in both agile software and hardware development.[1]

II Contrasting project management and R&D perspective

Having analyzed last year's results, a broad variance in the perceptions became evident. In order to gain a thorough understanding of the differences between the two largest groups participating in this survey, personnel from project management and research and development (R&D) have been analyzed regarding their given answers.

III Implementation progress

Since the adoption and implementation of agility into a company is a long-running process, Figure 2.1 aims at visualizing the stages throughout this process. It can be explained in both an organizational and operational diffusion. In the scheme at hand, the work is based on **transitional levels**, being an index for how advanced the participating company is in terms of implementing agile hardware development.

The transitional level index reaches from Level 1 to 5 with increasing implementation progress:

- Level 1 companies have tried agile hardware development in a first pilot project (within a product development).
- Level 2 companies have applied it to several projects already (within a product development).
- Level 3 companies have rolled it out to a single product development.
- Level 4 companies have rolled it out across multiple product developments.
- Level 5 companies have not limited the concept of agility to R&D but have rolled it out to other departments, such as production, sales, or administration.

[1] The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

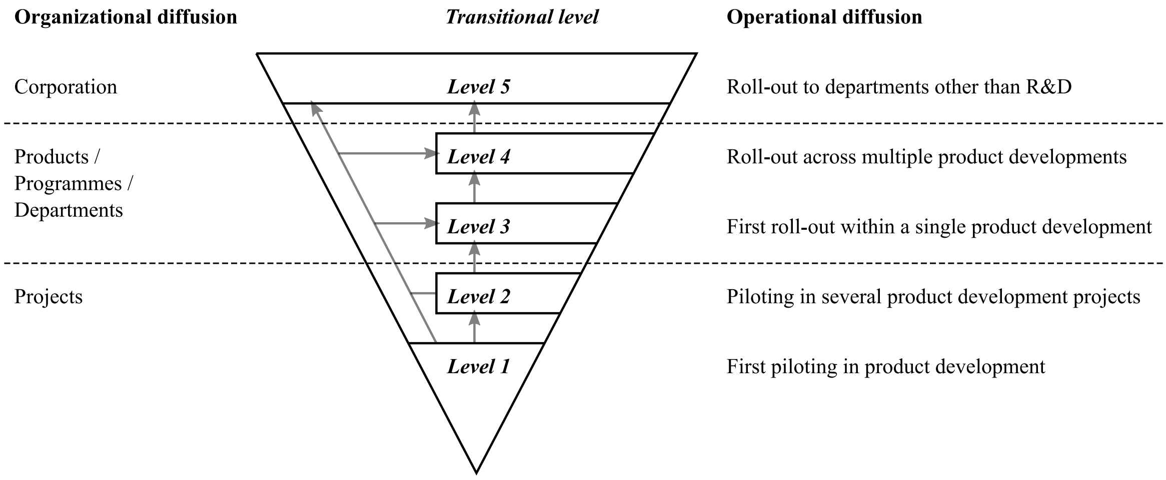

Figure 2.1.: Transitional levels towards implementation of agile hardware development.

The **operational diffusion** characterizes the advancement in terms of the introduction of agility inside a company. It starts with the first piloting in a product development project (Level 1), striving into the piloting into two or more development projects in Level 2. Following that, the shift is taken to other departments inside the R&D, with the roll-out of agile development in a first (single) product development (Level 3). The next step is the roll-out across multiple product developments, thus implementing agility throughout the entire R&D department (Level 4). The last and most time-consuming step of an agile transition is the roll-out of agility in other departments besides R&D.

In terms of **organizational diffusion**, the concept of an agile transition is characterized in three steps. Level 1 and 2 deal with agile hardware development on the project level, whereas Level 3 and 4 is about the roll-out across different departments or products. The shifts towards an agile corporation is the final step of an agile transition, which is characterized by Level 5. Yet, it is important to mention that a company does not necessarily have to start at Level 1 and follow the scheme step-wise but can start at higher levels or skip certain steps.

IV Trend analysis

Moreover, with this study being the second edition of the series on the agile development of physical products, comparisons to last year's results are drawn. By doing so, **(⇒) trends** are identified and general tendencies can be derived. Consequently, advancements regarding the applicability as well as the transferability from software to hardware can be characterized and are explained in more detail.

Part II.

Demographics: Who Participated

3. About the Respondents

To classify and interpret the answers, data on the participants and their company context are necessary. The first question cluster regarding company-related questions is standard for any type of survey to get an idea which contexts and perspectives the answers are referring to. The latter (product structure and interviewee-related) are unique in the realm of agile development. To the author team, these topics appeared to be crucial in order to investigate the development of physical products and its associated perception from different perspectives. Moreover, the identification of unexpected "constraints" or "special experiences" are interesting, since those could make the difference to software development apparent. Demographic aspects for all participants, regardless of which implementation progress they have, were evaluated in total.
Of course, the data gathered complies with the General Data Protection Regulation, in short GDPR (*German:* Datenschutz-Grundverordnung, DSGVO).

Structure of current chapter

3.1. Company-related Questions

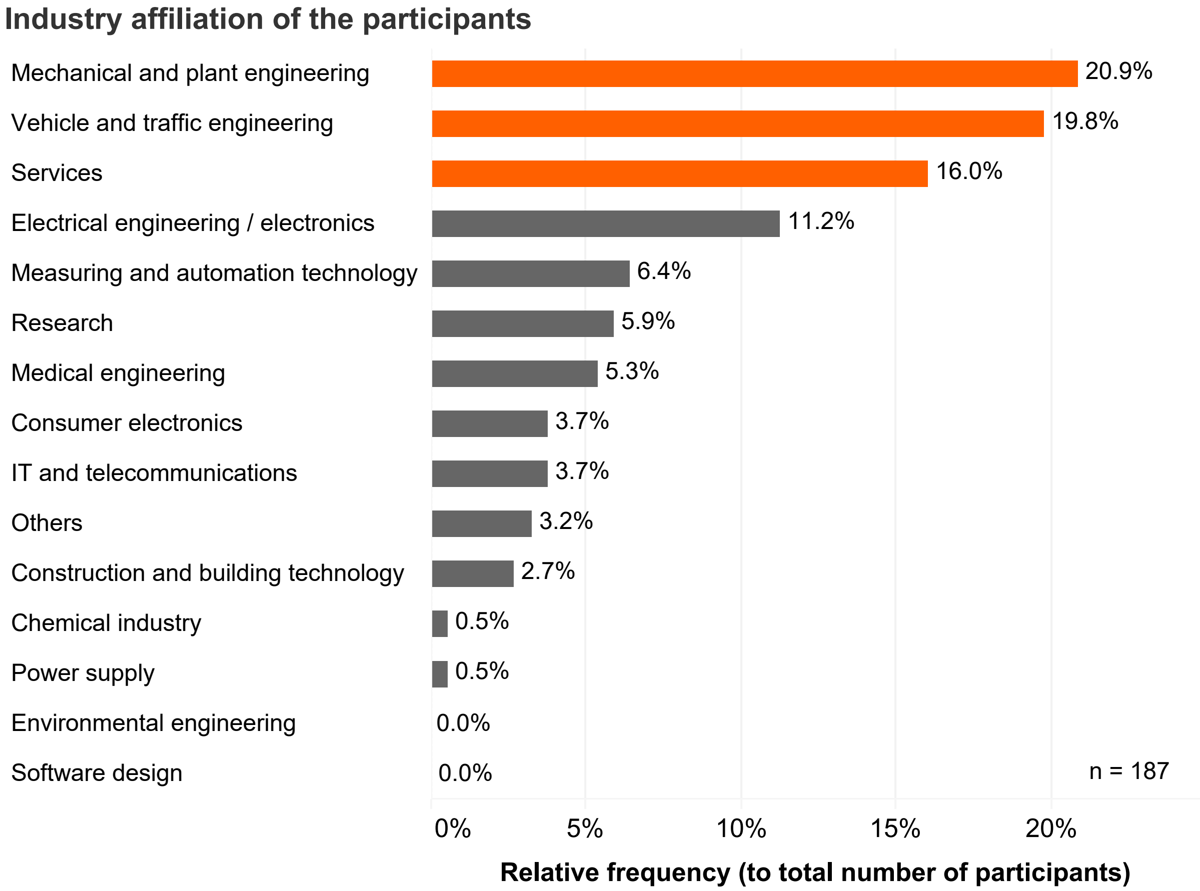

Figure 3.1.: Industry affiliation of participants' companies.

Description
Figure 3.1 displays the affiliation of the participants. Similar to last year's study, most participants work in mechanical and plant engineering as well as vehicle and traffic engineering. Product development-related services, such as consulting, form the third largest group among the participants.

Key learnings

- Most participants come from industries dominated by mechatronic product development, which meets the study's goal.
- Companies developing pure software are not included in the data, which was also part of the study's goal.

Interpretation

- Companies affiliated to the field of mechanical engineering have an even stronger interest than those from electrical engineering, as of today.
- The study's findings are a representative cross-section of the German industry.

⇒ Compared to last year's study, agile hardware development seems to diffuse to an even broader range of industries.

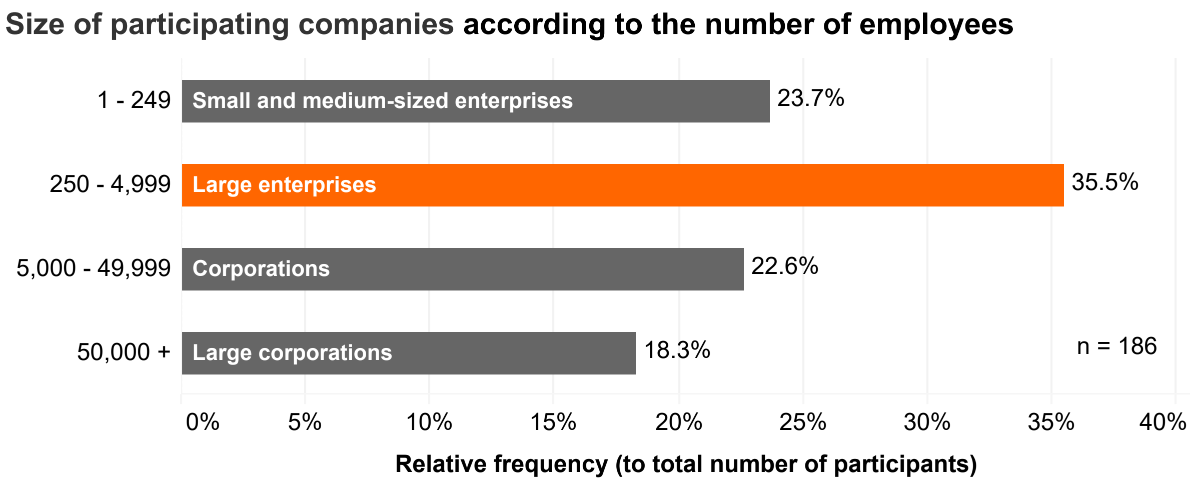

Figure 3.2.: Company sizes of the participants.

Description

Figure 3.2 visualizes the size of the participants' companies in terms of their total number of employees. The bin sizes chosen divide the companies in appropriate and thus comparable groups, with small and medium-sized enterprises (SMEs) being in line with the company size classification according to the European Commission (2003/361/EG). Most participating companies are in the group of large enterprises, ranging from 250 to 4,999 employees in total.

Key learnings

- More than one third of the participants work in large enterprises.
- About 60% of the participants stem from SME's and large enterprises, that are typical for the German industry. The remaining 40% are from (large) corporations.

Interpretation

- Companies of any size are interested in agile hardware development, whereas there is a tendency that large corporations are less interested than smaller ones.
- The company size is not a limiting criterion for the application or the attractiveness of agile hardware development.
- The study's findings are a representative cross-section of the German industry. There is no centering on global leaders or publicly listed companies.

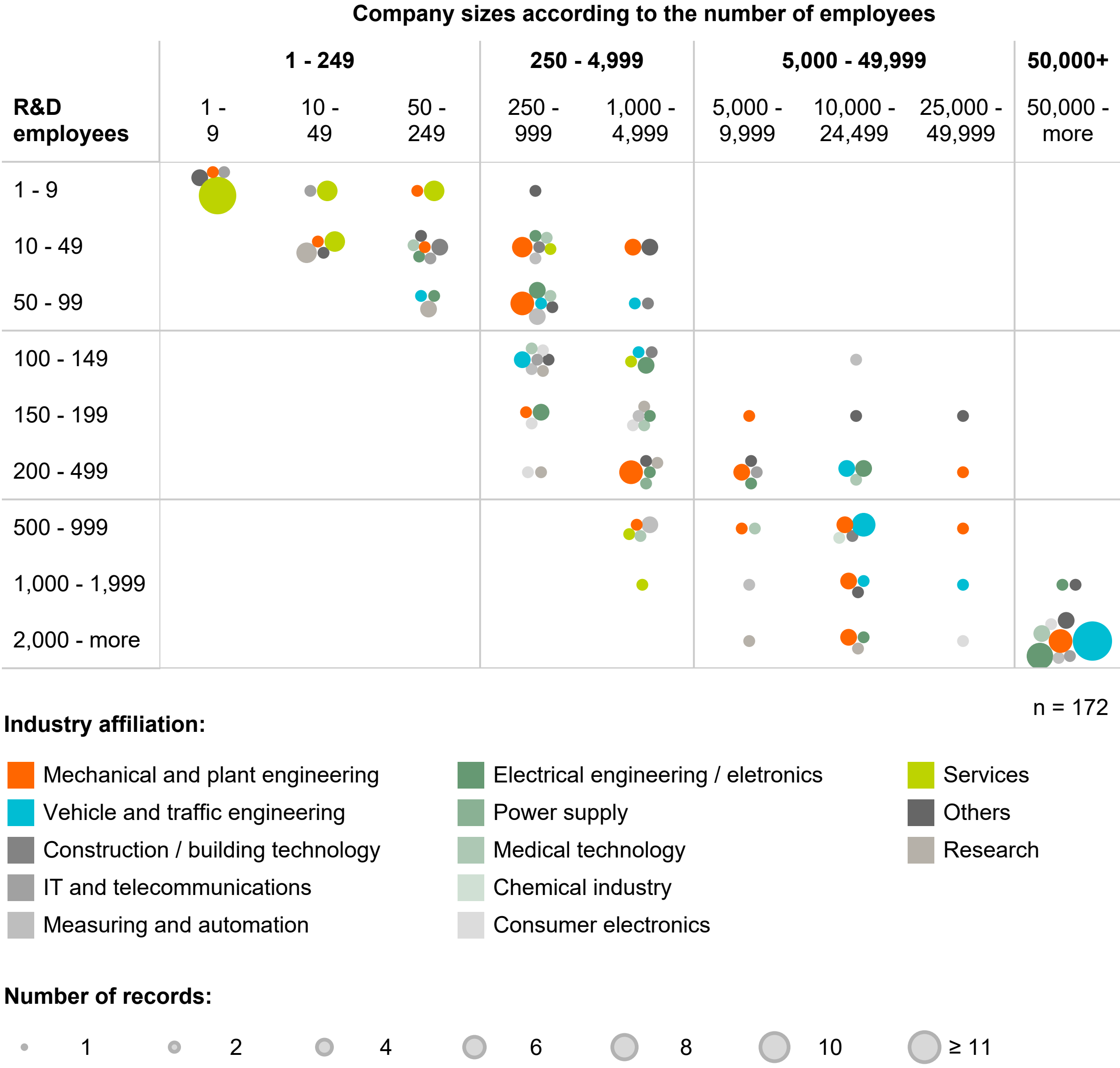

Figure 3.3.: R&D size of participating companies.

Description

Figure 3.3 shows the combination of R&D employees (y-axis) and total number of employees of participating companies (x-axis). The overlying categories represent the bin sizes chosen in Figure 3.2. The figure specifies the R&D share on the total workforce. The higher the share, the more the participating company is a development company. The lower, the more employees work in other areas of operations such as manufacturing, sales, or administration.

Key learnings

- Large companies (250 to 4,999 employees) have the highest deviation in terms of the R&D share.
- In the bin of SME's (1 to 249 employees), services are predominant.
- Shifting to very large corporations, vehicle and traffic engineering has a large portion.
- Companies in the field of mechanical and electrical engineering are represented throughout all company sizes to a greater extent.

Interpretation

- Since both the company sizes and their adjacent R&D sizes vary throughout the different branches, the findings are a representative cross-section of the German industry, which was the goal of the study.
- The findings show that especially the middle class is engaged in agility.

3.2. Product-related Questions

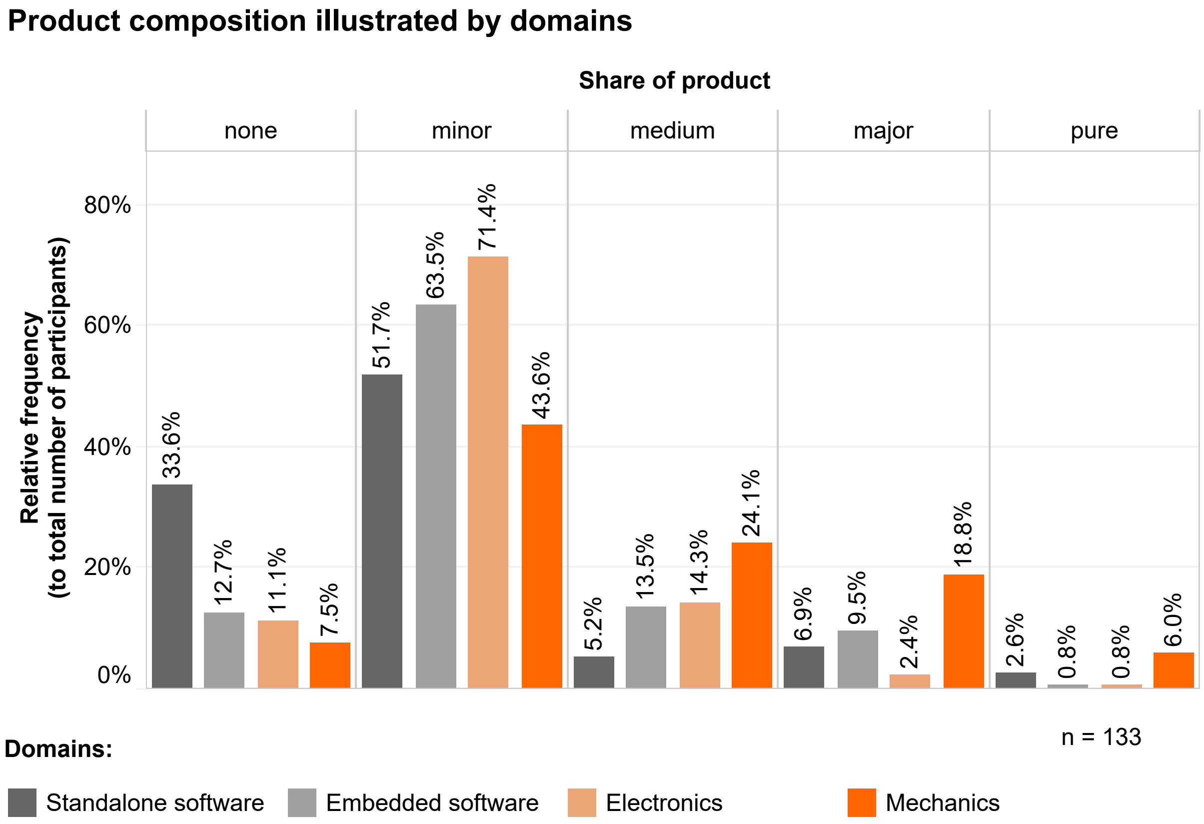

Figure 3.4.: Histograms of product composition regarding the domains involved by participating companies.

Description
Single domains were used to characterize the composition of the product to be developed in an agile manner. The estimation of the proportion (none = 0% to pure = 100%) was left to the subjective impression of the participants. The values are not equated with the added value or expense proportion but only the share of the respective domain on the resulting product.

Key learnings
- Most products are mechatronic in nature.
- Classical single domain products (“pure“ bin) are barely recognizable.
- Standalone software is significantly less represented than the remaining domains.
- Most products have a higher mechanics share compared to the other domains (higher share in the “medium“ and “major“ bin)

⇒ Compared to last year, a rise in the mechanics share is apparent, with a slight decrease in the share of electronics.

Interpretation
- Given the high frequency in the “minor“ bin of each domain, domain-overarching and thus inter- and/or transdisciplinary development is common.
- Due to this distribution, challenges related to the physicality of products are relevant for the participants of this study.

⇒ The rising share in the domain of mechanics is probably the driver of problem- and solution-complexity and the cause of several technical-related challenges (see Fig 4.14).

3.3. Interviewee-related Questions

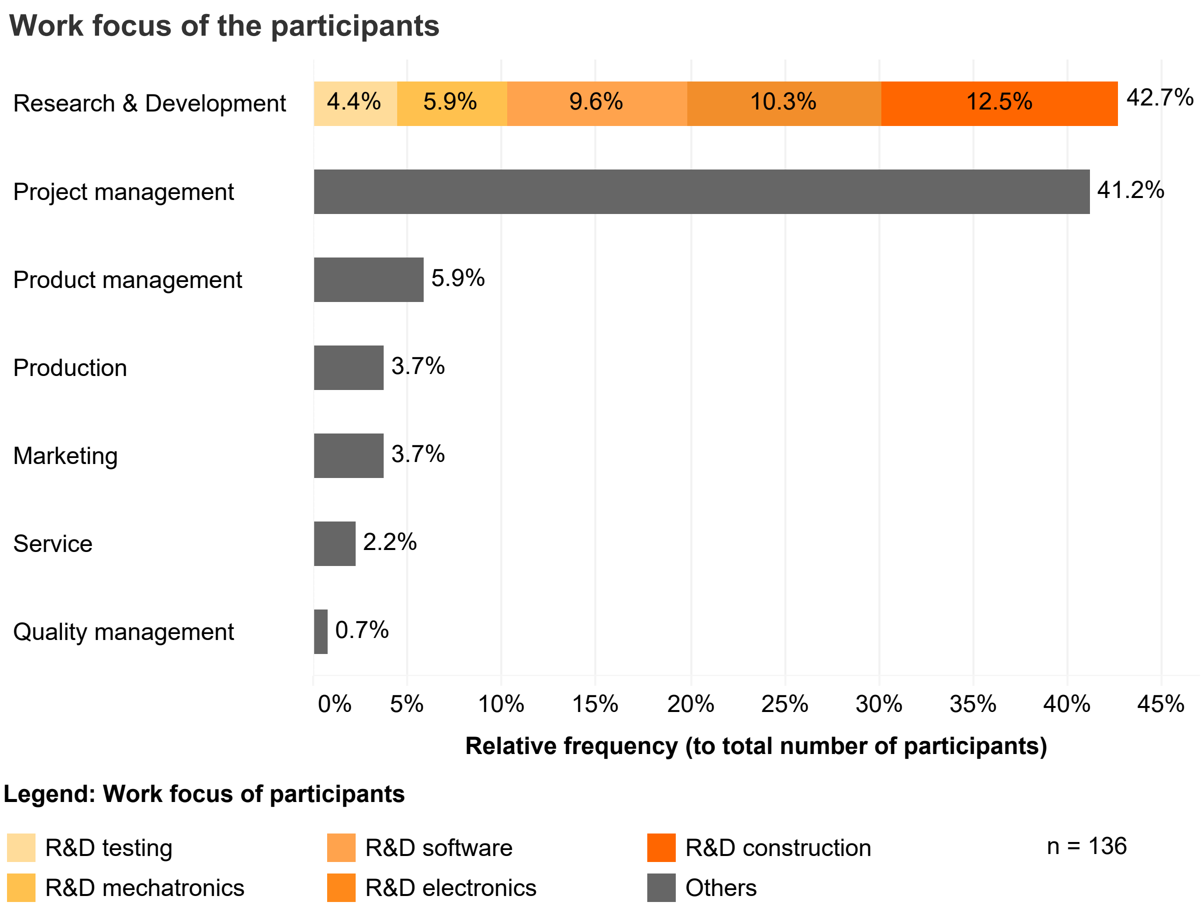

Figure 3.5.: Participants' focus of work.

Description

Figure 3.5 displays the focus of work of the survey participants. The data is dominated by participants from R&D and project management.

Key learnings

- More than 40% of the participants work primarily in R&D.
- Similarly, more than 40% of the participants primarily deal with project management.
- Less than 20% of the participants have their focus of work in product management, production, marketing, service, and quality management.
- Most participants with a R&D focus are obviously constrained by physicality, i.e., they stem from construction, electronics, and mechatronics.

Interpretation

- Agile hardware development seems to integrate operative (R&D) and administrative (project management) departments.

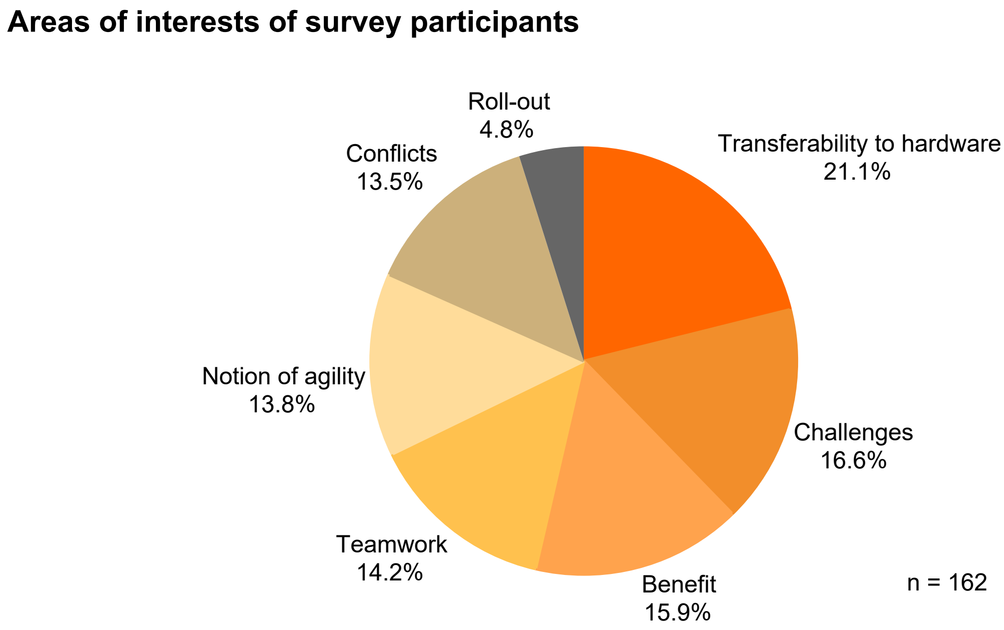

Figure 3.6.: Participants' primary areas of interest.

Description

The participants were able to choose from different topics depending on which they are most interested in or have most knowledge to contribute to the study.[1] Besides the options shown in Figure 3.6, the participants could tick *I want to answer all questions* or *Surprise me* (neglected here). The answers of the options concerning the participants' areas of interest are displayed in Figure 3.6.

Key learnings

- Among the topics provided, most participants are interested in the transferability of agile software development to agile hardware development.
- Least participants are interested in roll-out aspects.
- The remaining topics were chosen quite equally.

Interpretation

- As visualized in the right column "Grand total" of Figure 5.2, close to 50% of participating companies belong to transitional level 1 and 2 (piloting agile hardware development). This explains the high interest in transferability.
- The small share regarding *Roll-out* is striking. This might be due to an incomprehensible naming of the topic, or the fact that other topics such as dealing with pilot projects is of more importance as of now for the majority of the participants. This has to be evaluated in the future more thoroughly.

⇒ Having also been a major field of interest last year, Chapter 6 deals with the topic of transferability.

[1] The detailed survey design is explained in Chapter 9 elaborately.

Part III.

Findings: What We Found Out

4. Potentials of Agile Hardware Development

The survey differentiated between expected and actual effects regarding the benefits, challenges, and conflicts associated with agile hardware development. To avoid biases as best as possible, those participants who are about to start or are still beginners in agile hardware development were asked for their expectations. In contrast, experienced participants assessed the actual effects. To separate beginners from experienced participants, the survey utilized the question concerning the participants' implementation progress.[1]

Structure of current chapter

[1] The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

4.1. Understanding of Agile Development

4.1.1. Associations

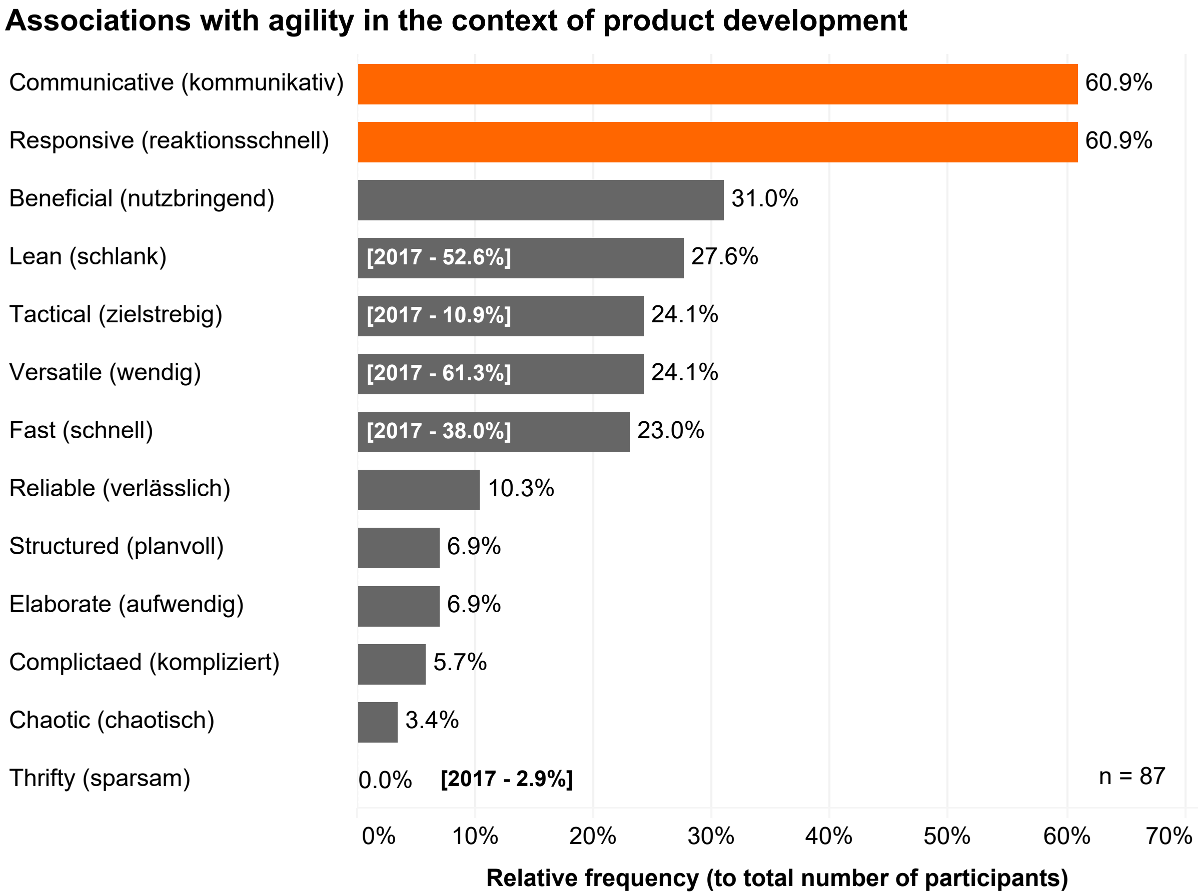

Figure 4.1.: Participants' association with agility in the context of product development.

Description
The participants were asked which adjectives they associate with agility in the context of product development. Compared to last year, the authors excluded some of the terms (lively, nimble) and added new ones to the survey. Figure 4.1 summarizes the distribution over two years. Multiple answers (max. 3) were allowed in both years. To avoid translation fuzziness, the German terms, that were presented in the survey, are added in parentheses.

Key learnings

- Most participants associate agile hardware development with *responsive* and *communicative* among the terms listed.

⇒ As in last year's survey, agile hardware development is still associated with the term *lean* and even rated higher than *versatile* and *lively*, in contrast to last year.

Interpretation

- The concept of agility in product development is subject to change, which might be due to the fact that agile hardware development is still an immature body of knowledge.
- Based on the adjectives chosen, the results may change largely. This shows that even the author team did progress by choosing more approriate terms than last year.

Associations with agility in product development

Agile transition	Lean n = 20	Versatile n = 20	Fast n = 48	Tactical n = 19	Responsive n = 51	Communicative n = 23	Beneficial n = 19
Level 1	30.0%	21.1%	15.0%	5.3%	12.5%	7.8%	13.0%
Level 2	20.0%	42.1%	40.0%	42.1%	33.3%	35.3%	26.1%
Level 3	25.0%	21.1%	15.0%	36.8%	31.3%	37.3%	39.1%
Level 4	15.0%	15.8%	25.0%	15.8%	20.8%	19.6%	17.4%
Level 5	10.0%		5.0%		2.1%		4.3%

N = 87

Figure 4.2.: Participants' association with agility in the context of product development depending on the transitional level.

Description

The perception of the top 7 rated terms of Figure 4.1 are displayed over the transition levels (as explained in Chapter 2). The results are normalized column-wise and sorted by the rising mean value throughout the transitional levels. The results show that agility in product development is associated with *lean* or *versatile* preferably in the beginning, with a decrease throughout the levels. *Fast* is referred to both at the beginning and in an advanced stage. *Tactical, responsive, communicative*, and *beneficial* are rather associated with agile hardware development in advanced transitional levels.
N symbolizes the total number of participants who voted for the terms listed here. n symbolizes the clicks per adjective (thus Σ n $\neq$ N). The number of participants per column varies because multiple choices per participant (max. 3) were allowed among the adjectives displayed in Figure 4.1.

Key learnings

- Lean, versatile, and fast are common associations for beginners, yet still referred to in more advanced stages.
- Tactical and communicative are rarely referred to at the beginning, yet are gaining momentum very fast.
- Associations with responsive and beneficial grow as the participants' implementation matures over the transitional levels.

Interpretation

- The perception of the effects and its associated benefits become aware over time.
- This can also be seen in the assessment of the actual effects of agile development (compare Figure 4.8).

4.1.2. Hypotheses

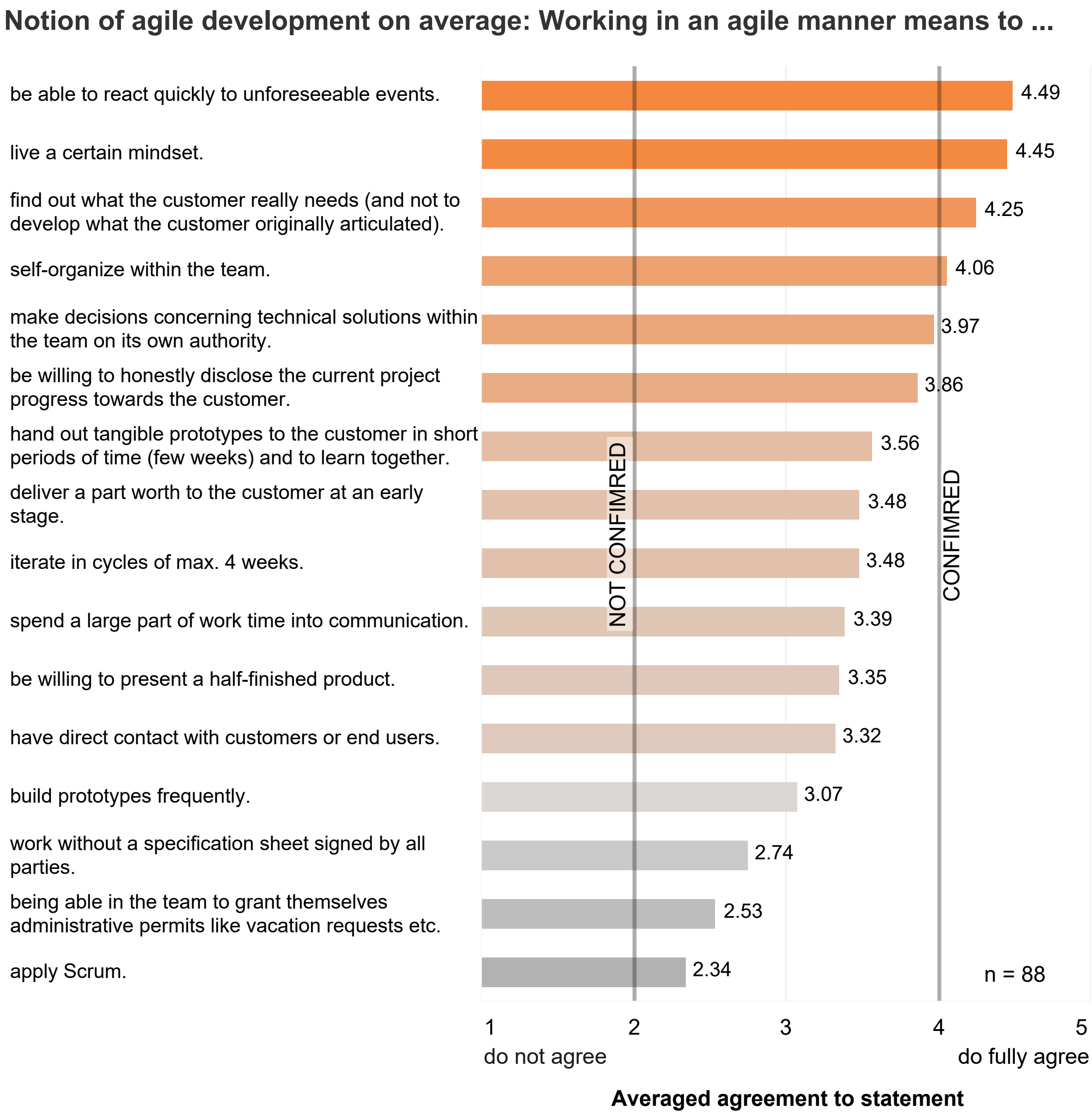

Figure 4.3.: Participants' notion of agile hardware development.

Description

In the survey, the participants rated their agreement to listed hypotheses. Compared to last year, some hypotheses were replaced by new ones. Overall, four hypotheses are certainly confirmed as their average ratings are larger or equal to 4, none are certainly neglected (≤ 2).

Key learnings

- Participants confirm: Agility is the ability to react quickly to the unforeseen.
- Participants confirm: Agile development deals with living a certain mindset.
- Participants confirm: Agile development aims at delivering real customer value.
- Participants confirm: Agile development teams are self-organized.

⇒ Compared to last year's study, covered hypotheses are rated very similarly. No change in conception here.

Interpretation

- It turns out, that the high notions which are confirmed by the participants focus on *what* agile development is about. When it comes to *how* to execute agile development (iterative and incremental development, direct customer interaction), these notions are rated rather medium, which shows that the realization of agile development is still not fully understood.
- Participants understand the necessity of finding out what the customers wants, and that they should hand out tangible prototypes to the customer in order to learn together. Yet the frequent prototype generation, which is the measure of progress in the context of physical product development and thus the actual source of learning and knowledge generation, was only rated medium. This shows, that the concept of agility is understood, yet not its subsequent execution.

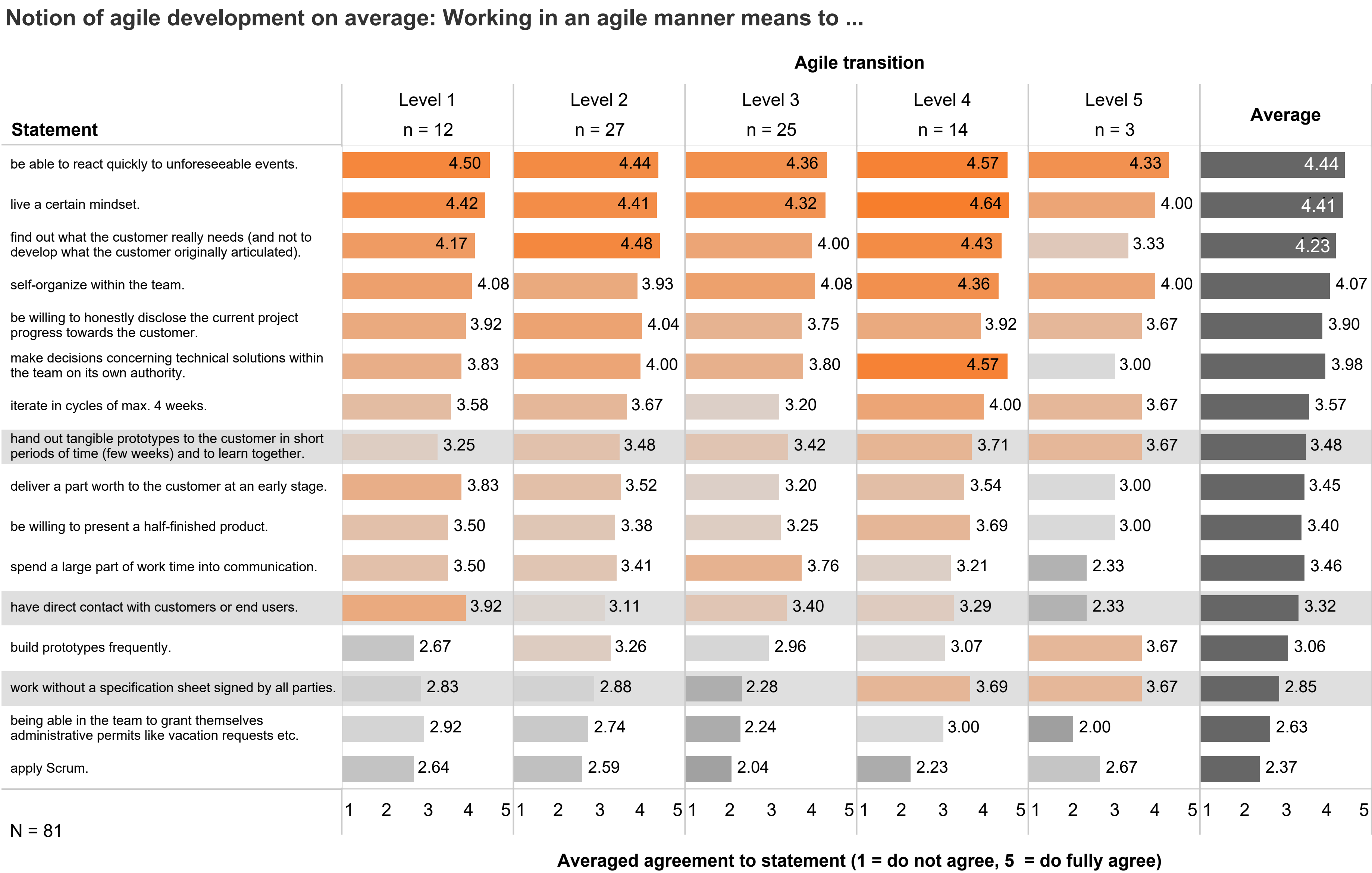

Figure 4.4.: Participants' notion of agile hardware development depending on the transitional level.

Description

The perception of the statements of Figure 4.3 are displayed over the agile transition levels, with the mean value as a reference on the far right for the sake of comparison. With only 3 participants of level 5 having rated the statements, this column is statistically invalid, yet it is displayed for the sake of completeness.

Key learnings

- Handing out tangible prototypes for knowledge generation is increasing throughout the levels.
- The need for direct customer / user contact on the other hand is decreasing.
- Working without a specification sheet signed by all parties is increasing a lot when reaching high levels.

Interpretation

- Statements which are rather either very high or low do not show a large difference between the levels.
- Being a problem of rather larger companies, circumventing bureaucracy by not having the specification sheet signed by all parties, is seen as an advantage.
- The need for prototyping is visible in the course of maturing, which shows that the concept of how to realize agile development inside the company is understood better over time. However, a decrease in the direct user-interaction is also recognizable, which seems contradicting to both an increased learning and also the principles of the Agile Manifesto.

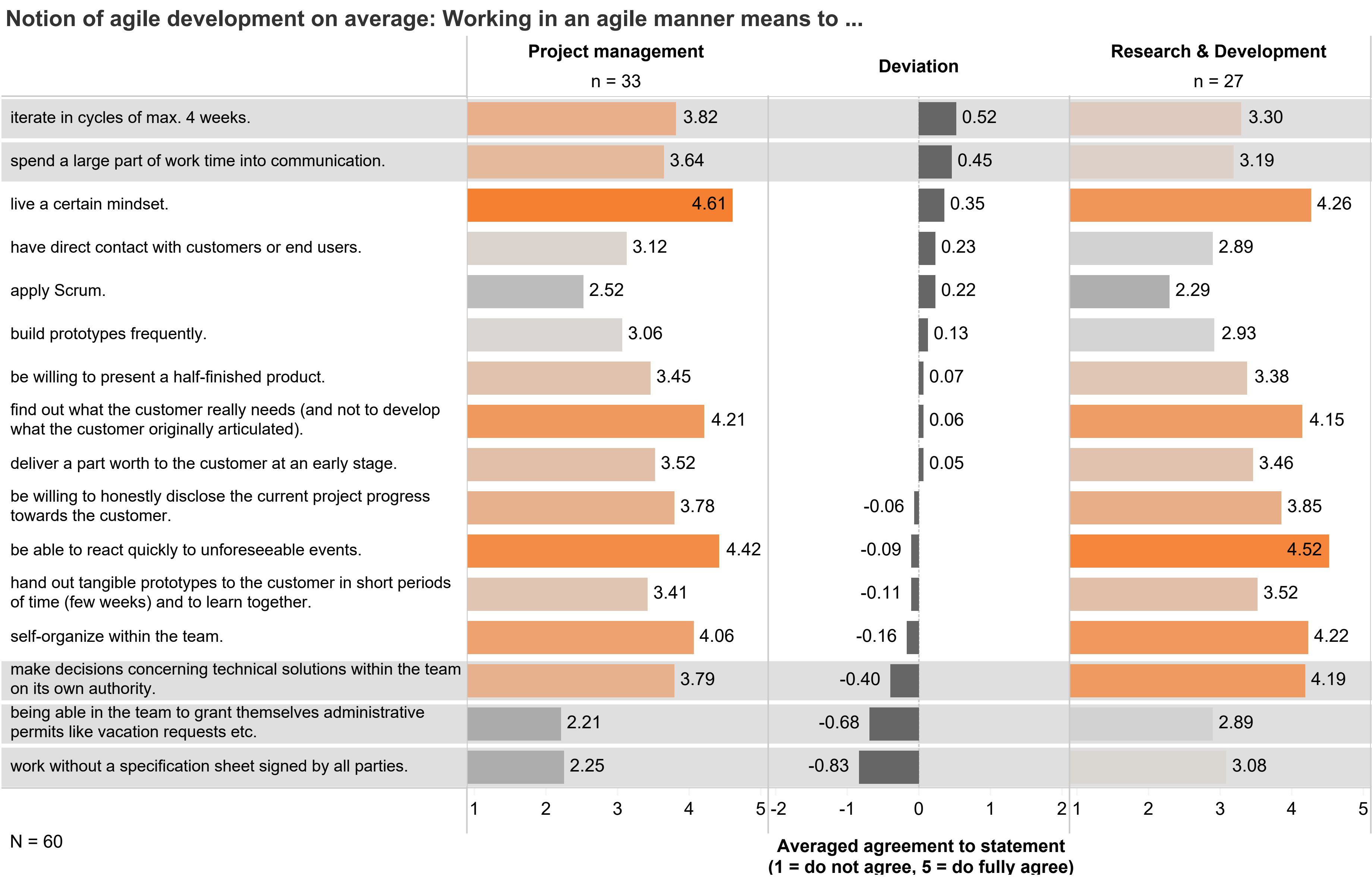

Figure 4.5.: Participants' notion of agile hardware development depending on their focus of work.

Description
The perception of the statements of Figure 4.3 of project management is compared against the developer's viewpoint in the figure above. The differences in perception are displayed in the intermediate column. The largest differences are highlighted by grey boxes.

Key learnings

- Iterating in short cycle times is seen as a lot more important to project management compared to R&D.
- Spending a large amount of work time into communication is also seen as a lot more important to project management compared to R&D.
- However, the ability of decision-making regarding technical issues within the team is seen a lot more important to R&D than to project managers.
- Having been rated worst by project managers, the specification sheet-topic as well as the vacation permits are more important for the R&D employees.

Interpretation

- In terms of responsibility, fixed goals are seen as a lot more important by project management than R&D.
- Freedom in decision-making with respect to technical issues with a decline in the associated bureaucracy is seen as a lot more important to R&D.

4.1.3. Methods Used

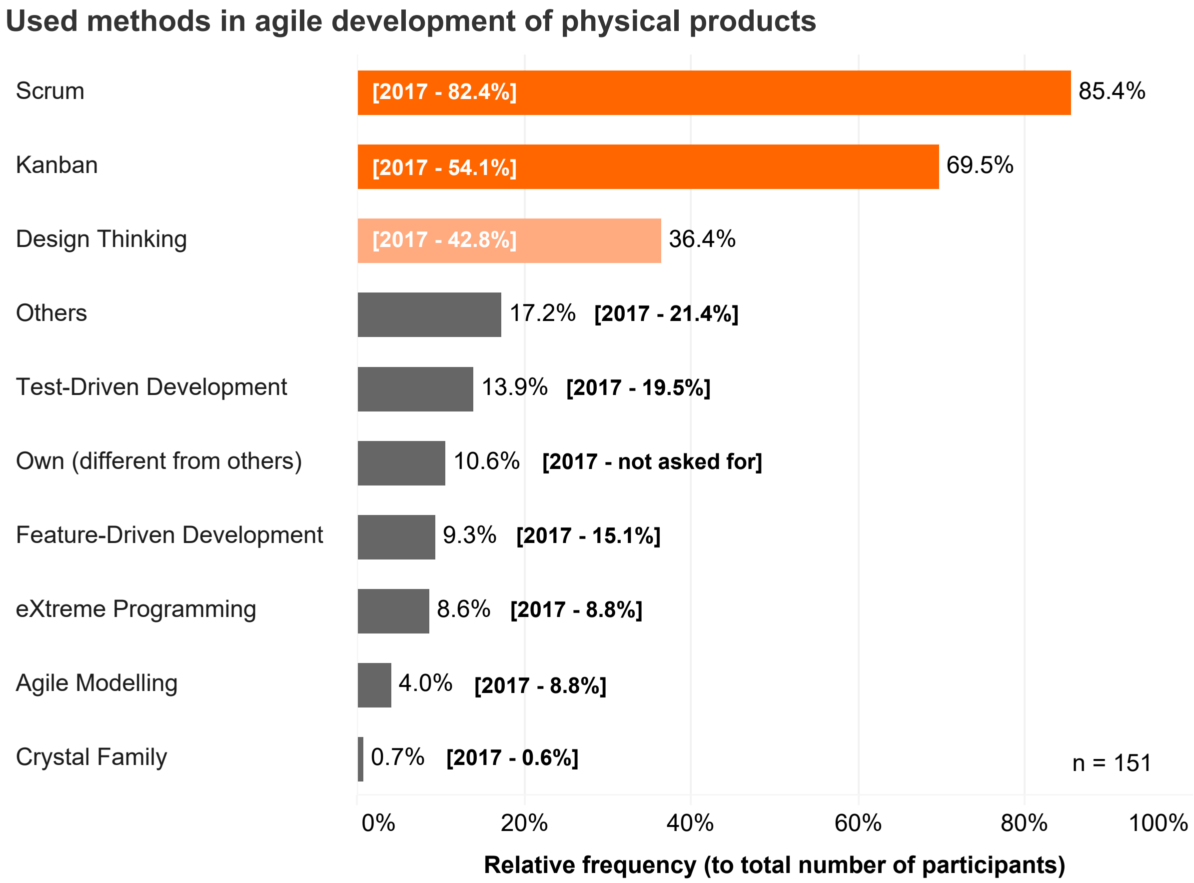

Figure 4.6.: Agile methods used by participants.

Description
The participants were asked to tick the agile methods their companies use in agile hardware development. Multiple choices were allowed. The results of last year's survey are displayed in parentheses for the sake of comparison.

Key learnings
- Scrum, Kanban, and Design Thinking are the most used methods in agile hardware development.

⇒ Compared to last year's findings, Kanban gained importance; the remaining methods were chosen very similar last year.

Interpretation
- Scrum and Kanban are by far the most used methods in agile hardware development.
- A small share of companies align agile methods to their context - approx. 11% use their own (aligned) methods.

⇒ Scrum, Kanban, and Design Thinking are still the most used methods (compared to last year).

Agile transition

Method	Level 1 n = 33	Level 2 n = 36	Level 3 n = 44	Level 4 n = 30	Level 5 n = 8
Scrum	48.5%	88.9%	84.1%	93.3%	87.5%
Kanban	45.5%	63.9%	72.7%	73.3%	75.0%
Design Thinking	9.1%	27.8%	43.2%	33.3%	87.5%
Others	9.1%	2.8%	11.4%	10.0%	25.0%
Test-Driven Development	3.0%	16.7%	11.4%	10.0%	25.0%
Own (different to others)	9.1%	16.7%	9.1%	16.7%	50.0%
Feature-Driven Development	0.0%	8.3%	11.4%	6.7%	12.5%
eXtreme Programming	6.1%	0.0%	4.5%	13.3%	12.5%
Agile Modelling	3.0%	0.0%	4.5%	3.3%	0.0%
Crystal Family	0.0%	0.0%	0.0%	0.0%	0.0%
N = 151	0% 100%	0% 100%	0% 100%	0% 100%	0% 100%

Relative frequency (to total number of participants per level)

Figure 4.7.: Agile methods used by participating companies depending on the company's transitional level.

Description

Figure 4.6 is extended by adding the transitional levels of each participant. The distribution throughout the transitional levels of the mean value is displayed. Please note that only eight participants belong to Level 5, which is statistically invalid.

Key learnings

- Almost 88% of the participants belonging to Level 2 to 5 apply Scrum, whereas only 49% participants from Level 1 do so.
- The share of both Scrum and Kanban rises when shifting to the further levels.
- Participants from Level 1 favor Scrum and Kanban equally, whereas Design Thinking does not play an important role.
- Participants from Level 5 apply Scrum, Kanban, and Design Thinking almost equally.

Interpretation

- In contrast to Design Thinking, Scrum and Kanban seem to be the starter methods in agile hardware development.
- When advancing, Design Thinking as well as own methods are gaining momentum.
- The more mature in agile development, the more diverse agile methods are selected (broader range of methods).

4.2. Benefits of Agile Development

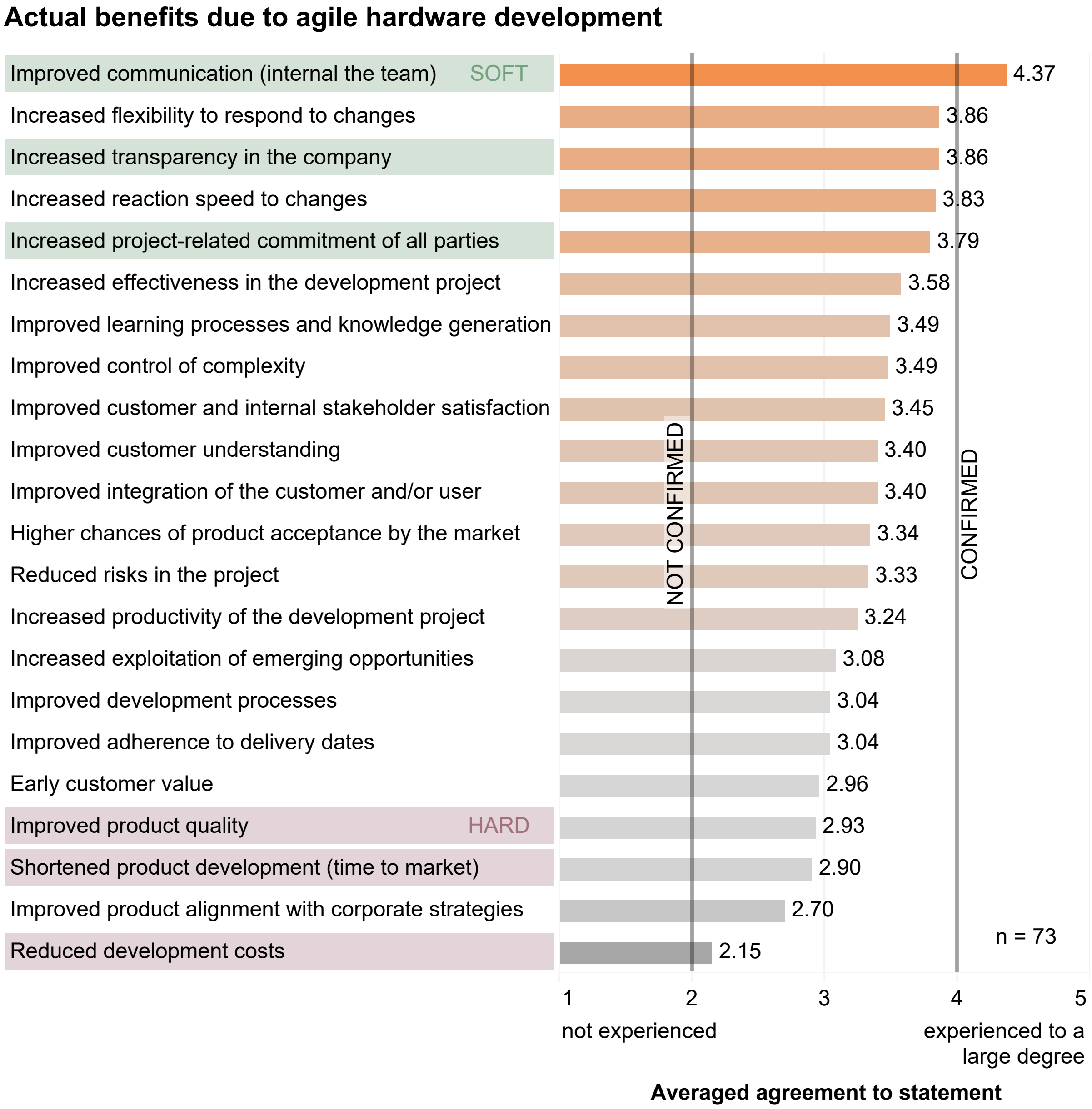

Figure 4.8.: Actual benefits of agile hardware development.

Description

Experienced participants[2] were asked to state their opinion about the benefits of agile hardware development they have experienced in practice. Each of the listed effects in Figure 4.8 was rated on a scale from 1 (not experienced) to 5 (experienced to a large degree). To increase readability, guiding lines regarding the distinct approval or denial of statements naming *not confirmed* and *confirmed* have been added.

[2]The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

Key learnings

- Agile hardware development comes with various benefits.
- Particularly, *very soft factors* such as improved communication, flexibility, transparency, reaction speed, and commitment are the most significant benefits of agile hardware development.
- Improvements in *very hard factors*, such as quality, cost, and time-to-market are present but much less distinct.

Interpretation

- Soft factors propagate on several means-to-an-end instances towards hard factors (Schmidt, Weiss, and Paetzold 2018b). This process requires patience. Improvements in hard factors are only indirectly ascribable to agile hardware development.

⇒ Compared to last year's results, the extreme values did increase in both directions, communication being rated higher and the development costs being rated lower this year.

⇒ Thus, agility does indeed have a positive effect in terms of communication, yet it does not reduce the development costs.

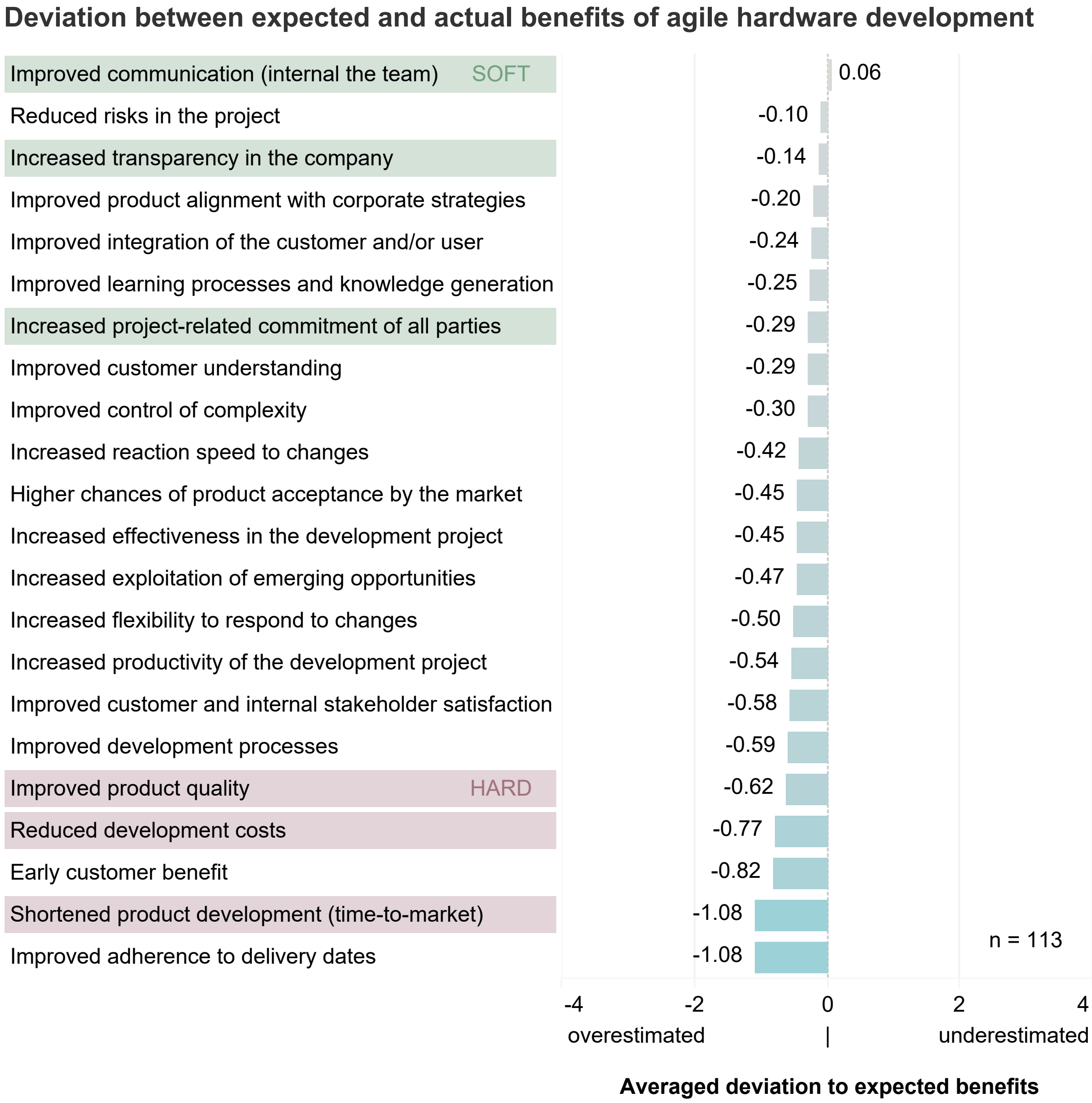

Figure 4.9.: Difference between expected minus actual benefits of agile hardware development.

Description

This figure visualizes the difference between the expectations and actual effects concerning benefits of agile hardware development. Beginners[3] rated the expectations while experienced participants assessed the actual benefits. In this figure, the deviations between expected minus actual values are displayed, no absolute values. Overall, the expectations and actual benefits diverge in many respects.

Key learnings

- Especially improved adherence to delivery dates and shortened time-to-market are overestimated (expectations are higher than real effects).
- Only improvements in communication turn out to be larger than expected, though very small.

[3]The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

Interpretation

- The hype around agile hardware development is not over yet. Still, the expectations are higher than the actual benefits. Especially beginners risk to be disappointed in the next years to come. An appropriate expectation management is recommended that includes all stakeholders involved in implementing agile hardware development.
- However, please note that Figure 4.9 depicts the difference between actual and expected benefit assessments. Thus, it is very important to understand that an effect can be intensive, although it is overestimated. See Figure 4.8 for the actual benefits of agile hardware development.

⇒ Compared to last year, the results are even more overestimated. This leads to the assumption that agile hardware development is in close vicinity of the peak of inflated expectations, moving towards the through of disillusionment (Schmidt, Weiss, and Paetzold 2018b).

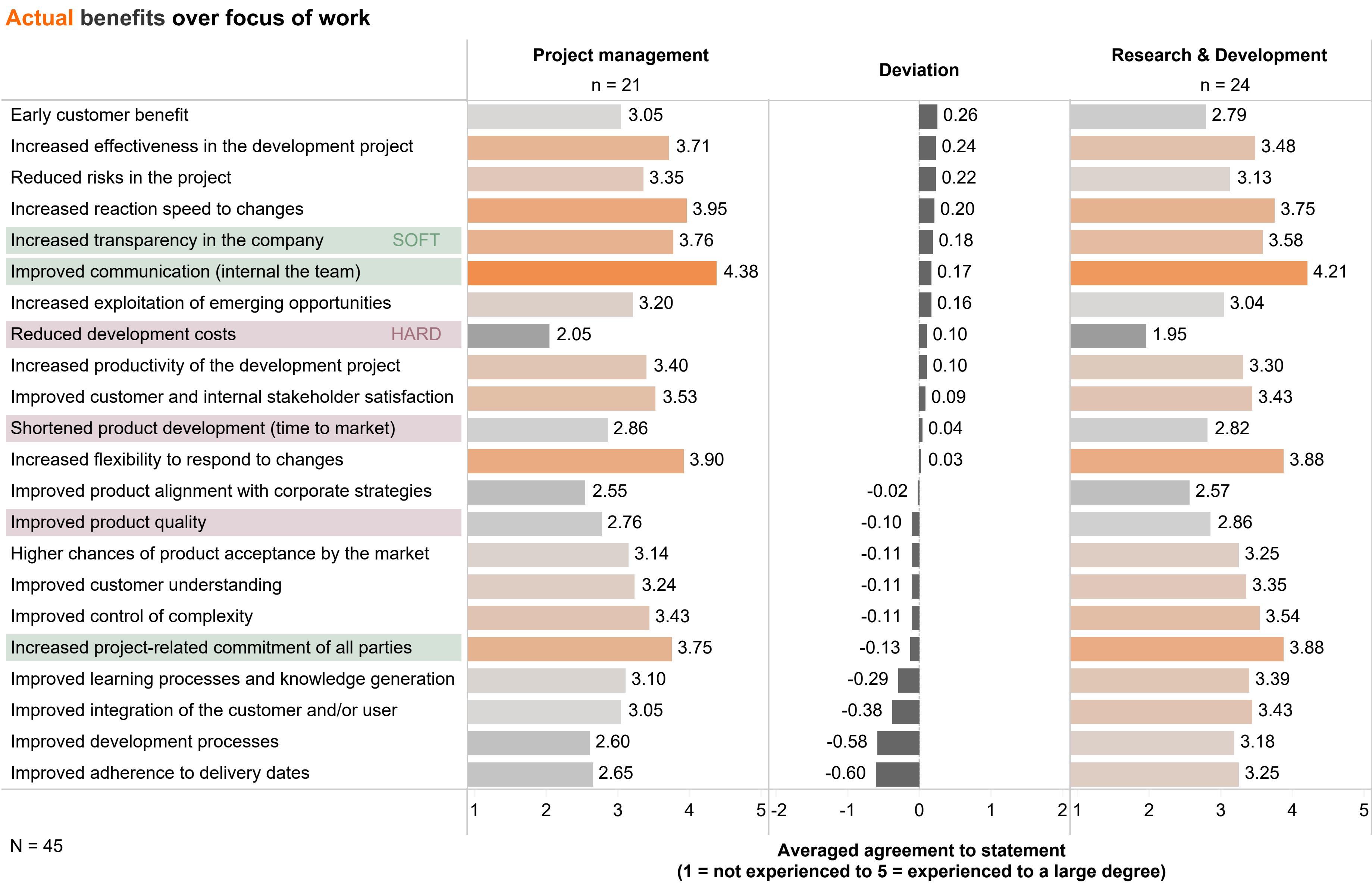

Figure 4.10.: Actual benefits (rated by experienced participants) in agile hardware development depending on their focus of work.

Description
In this figure, the results of the actual benefits (compare Fig. 4.8) rated by experienced practitioners are displayed from the viewpoint of project management in contrast to R&D. The deviations on the respective benefits between both project management and R&D are visualized in the intermediate column (grey bars). Positive deviations refer to a higher value from project management, negative deviations to smaller values than people from R&D.

Key learnings

- The highest deviation can be seen regarding "Improved development processes" and "Improved adherence to delivery dates" with project management rating it rather poorly, R&D rather neutral.
- Moreover, "Improved learning processes and knowledge generation" and "Improved customer/user integration" is also rated higher by R&D compared to project management.
- In terms of "Early customer benefit, Increased effectiveness in the development project" and "Reduced risks in the project" project management tends to rate it higher than R&D.

Interpretation

- Overall, both groups tend to rate the actual benefits rather similarly, with a few exceptions.
- Taking a look at the larger deviations, people from R&D tend to rate aspects better regarding the team-internal collaboration (Knowledge generation, User integration, Improved development processes), whereas people from project management rather favor "measurable" aspects (Customer benefit, Effectiveness, Reduced risks) they are held accountable for.
- In terms of the *very hard factors* (Quality, Cost, Time) project management and R&D do not show a great deviation in their viewpoints. The same is valid for the rating of the *very soft factors* (Transparency, Communication, Commitment).

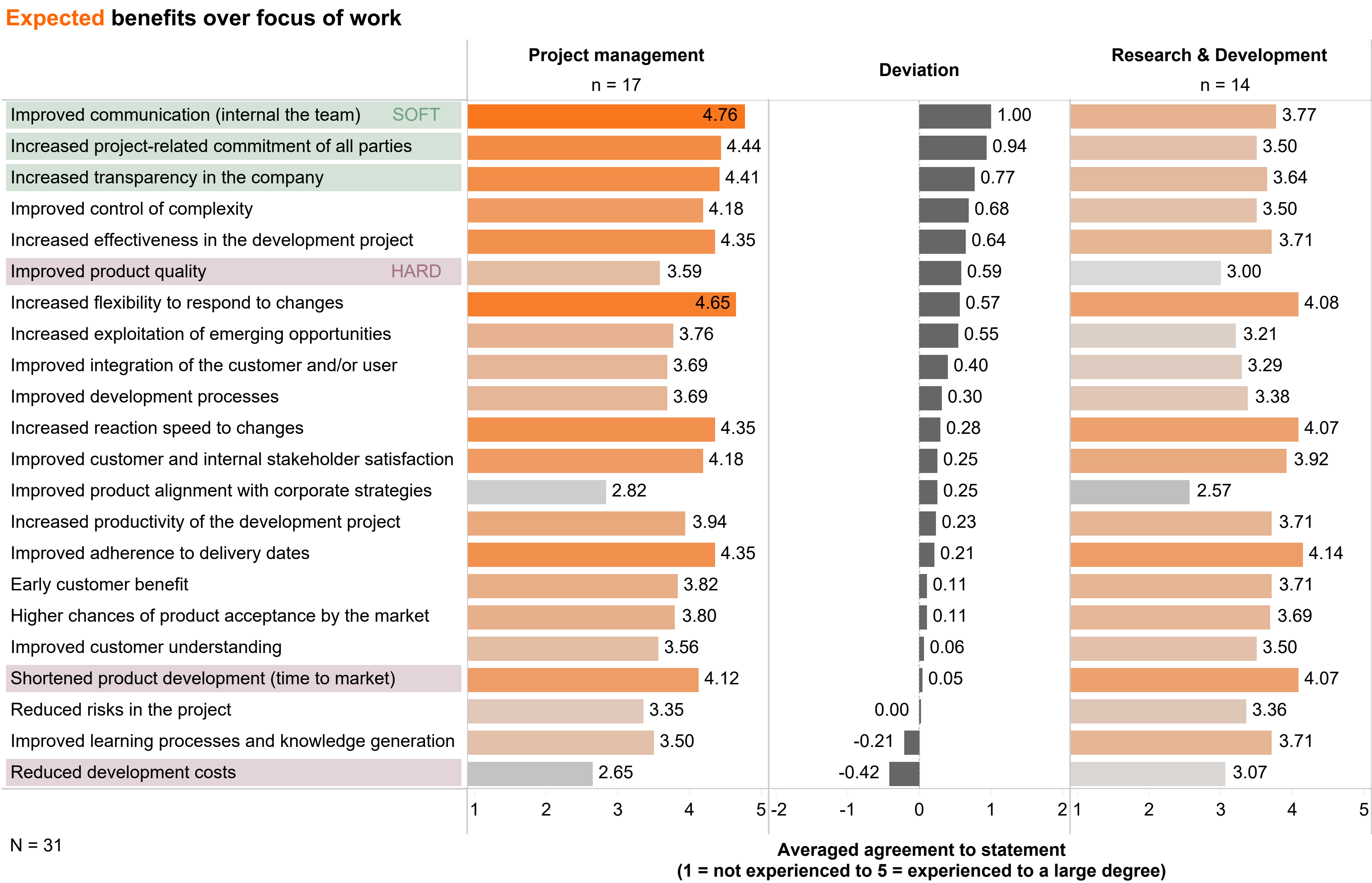

Figure 4.11.: Expected benefits (rated by beginners) in agile hardware development depending on their focus of work.

Description
In this figure, the results of expected benefits from beginners and less experienced people in the field of agile hardware development[4] are displayed from the viewpoint of project management in contrast to R&D. The deviations on the respective benefits between both project management and R&D are visualized in the intermediate column (grey bars). Positive deviations refer to a higher value from employees from project management, negative deviations to smaller values than employees from R&D.

Key learnings
- Overall, project management has much higher expectations in terms of the benefits compared to R&D.
- Surprisingly, the deviations regarding the *very soft factors* (Transparency, Communication, Commitment) vary greatly, with project management having much higher expectations than participants from R&D. This might be due to the fact, that R&D employees being mostly engineers tend to be question the benefits of new things rather than simply rubber-stamping it. The same can be seen when it comes to completely new working styles - they do not deny it, yet they have to be convinced.
- Only in terms of "Improved knowledge generation" and "Reduced development costs" people from R&D have higher expectations than their colleagues from project management.
- The *very hard factors* are seen differently; Quality is expected to increase in the eyes of project management, Time-to-market is rated almost equally (better) among both groups and in terms of the Costs project management sees less potential compared to R&D.

Interpretation
- Especially people from project management have high expectations when being unexperienced in this field.
- The large deviation regarding the very soft factors with project management favoring them more than R&D might be due to the rather critical posture by R&D employees.
- The expected product quality being rated better by project management than the actual developers from R&D, might add to the presumption of the developer's critical posture.
- The hype around agile hardware development seems to be driven mostly by project management. Further analysis on this topic is needed though.
- Cost reduction is traditionally a project management concern. Interestingly, project managers do not expect great improvements on this very hard factor.

[4]The differentiation between "beginners" and "experienced" participants is explained in chapter 9 elaborately.

4.3. Challenges

4.3.1. Organizational Challenges

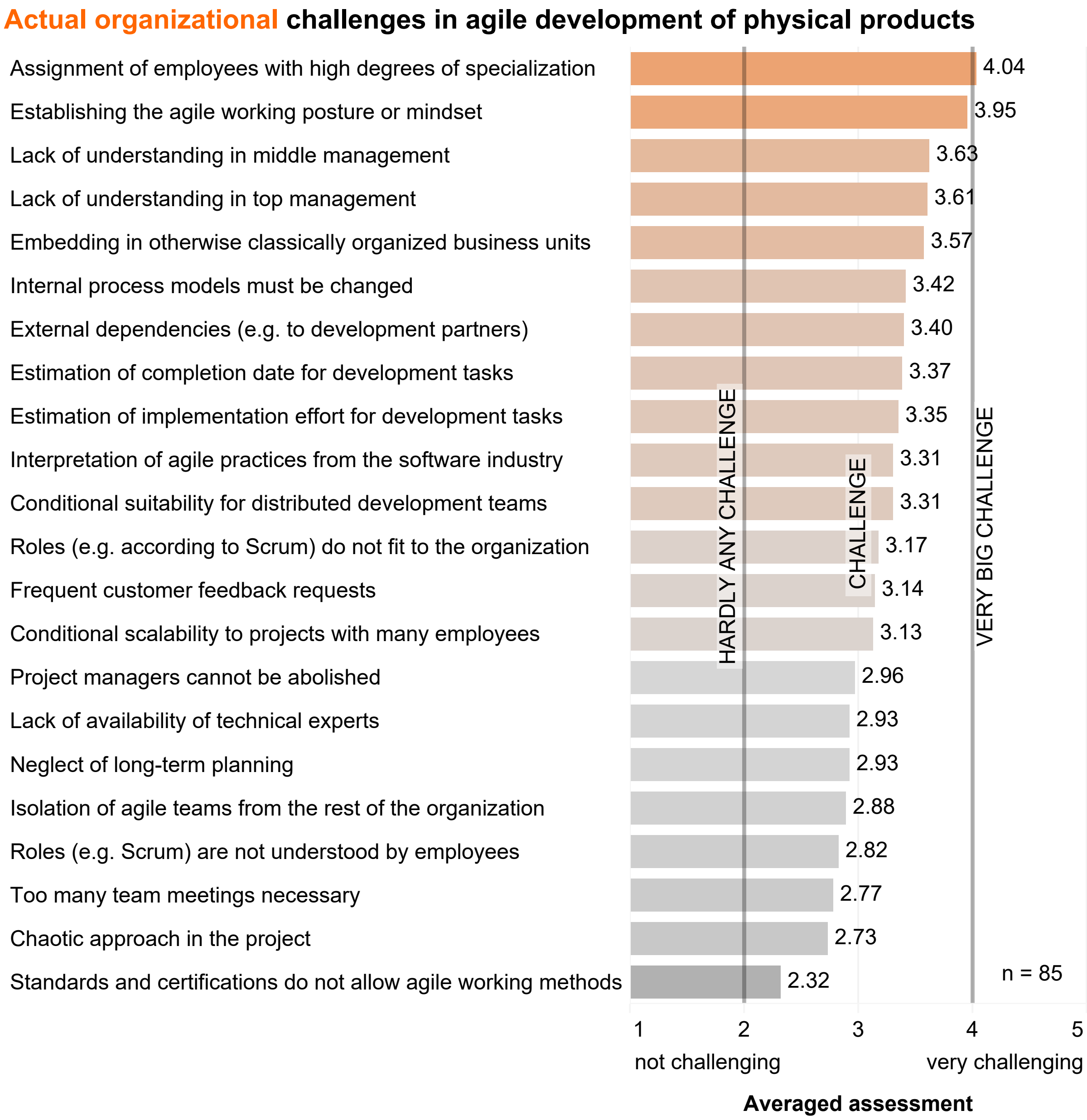

Figure 4.12.: Actual organizational challenges of agile hardware development.

Description

Experienced participants[5] were asked to state their opinion regarding the organizational challenges of agile hardware development they have experienced in practice. Each of the listed effects in Figure 4.12 was rated on a scale from 1 (not challenging) to 5 (very challenging).

[5] The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

Key learnings

- "Assignment of employees with a high degree of specialization" and "Establishing the agile working posture / mindset" are considered to be the biggest challenges by far.
- On the contrary, "standards and certifications not allowing agile working methods" is not perceived to be a big challenge, though still challenging.
- "The lack of understanding in middle as well as top management" are also considered to be big challenges, since being rated third and fourth.

Interpretation

- The topic of establishing an agile mindset is currently seen as one of the biggest challenges in agile hardware development, which is supported by the fact that a strong lack of understanding is apparent in the middle / top management.
- Due to the fact that experts of different domains are necessary to build mechatronic products, the availibility / assignment of highly specialized employees is the largest organizational challenge as of today.
- External boundaries such as standards or certifications do not seem to be in conflict with the application of agile methods, though still challenging.

⇒ As last year, establishing an agile mindset is still seen as a very big challenge. Yet, embedding agile teams inside a company has decreased compared to last year.

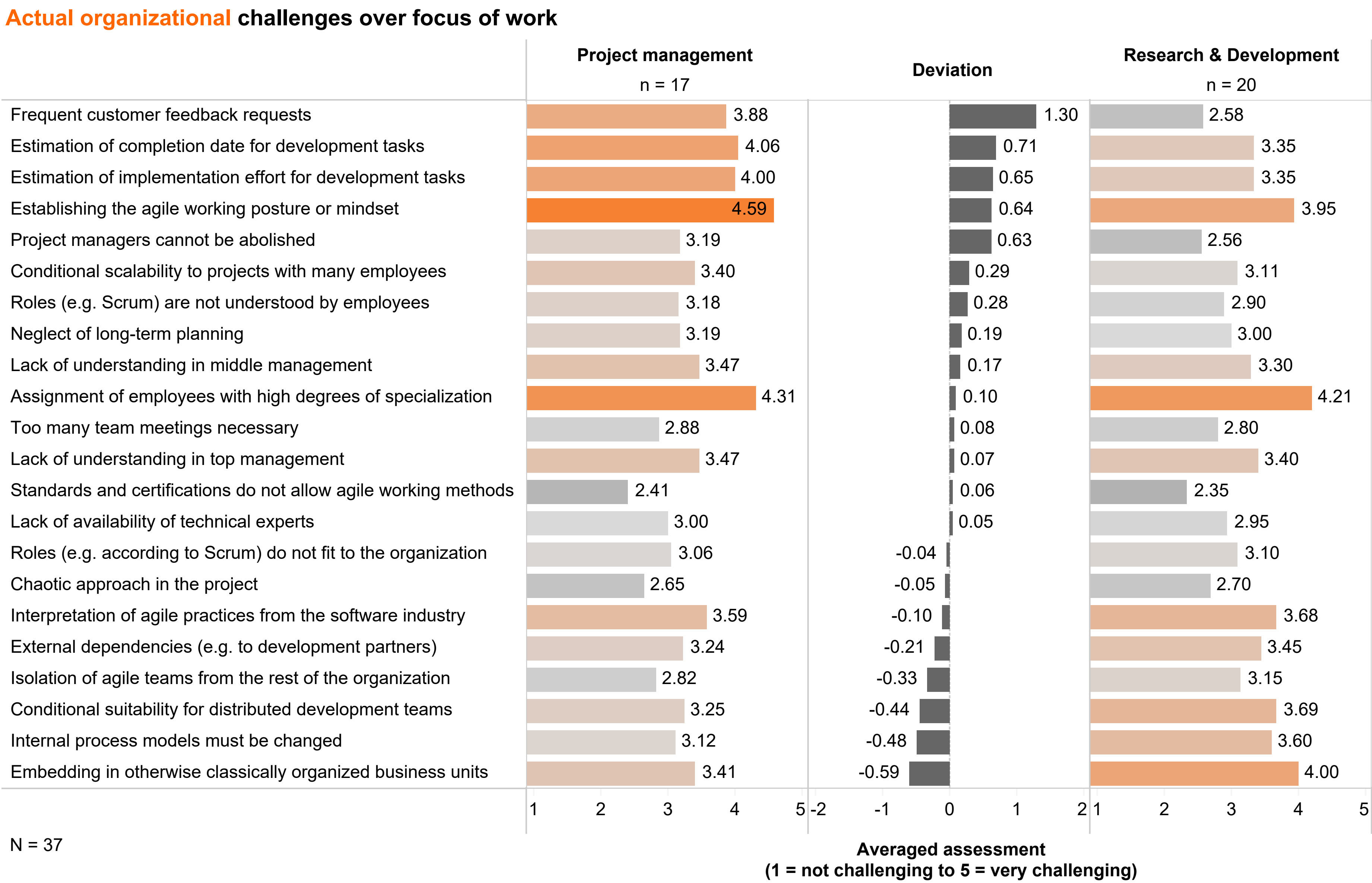

Figure 4.13.: Organizational challenges depending on the focus of work.

Description
In this figure, the results of the actual organizational challenges (compare Fig. 4.12) are displayed from the viewpoint of project management in contrast to R&D. The deviations on the respective benefits between both project management and R&D are visualized in the intermediate section (grey bars). Positive deviations refer to a higher value from people from project management, negative deviations to smaller values than employees from R&D.

Key learnings

- “Establishing an agile mindset“ is seen challenging by both groups, yet project management ranked it the biggest challenge by far overall.
- The highest deviation is seen in terms of “Frequent customer feedback requests“ with project management rating it much higher than R&D.
- The “Estimation of both the completion date as well as the implementation effort of development tasks“ is also seen more challenging by project management compared to R&D.
- The “Embedding in otherwise classical organized companies“ and the “Need to change internal process models“ is seen more challenging by R&D employees.
- Having highly specialized personnel available is seen as a great challenge by both project management and R&D.

Interpretation

- Project management tends to value stakeholder-related topics (Completion dates, Customer feedback requests) higher than R&D. Overall, project management tends to rate challenges higher they are held accountable for by stakeholders.
- R&D people tend to rate work environment-related topics higher than project management.

4.3.2. Technical Challenges

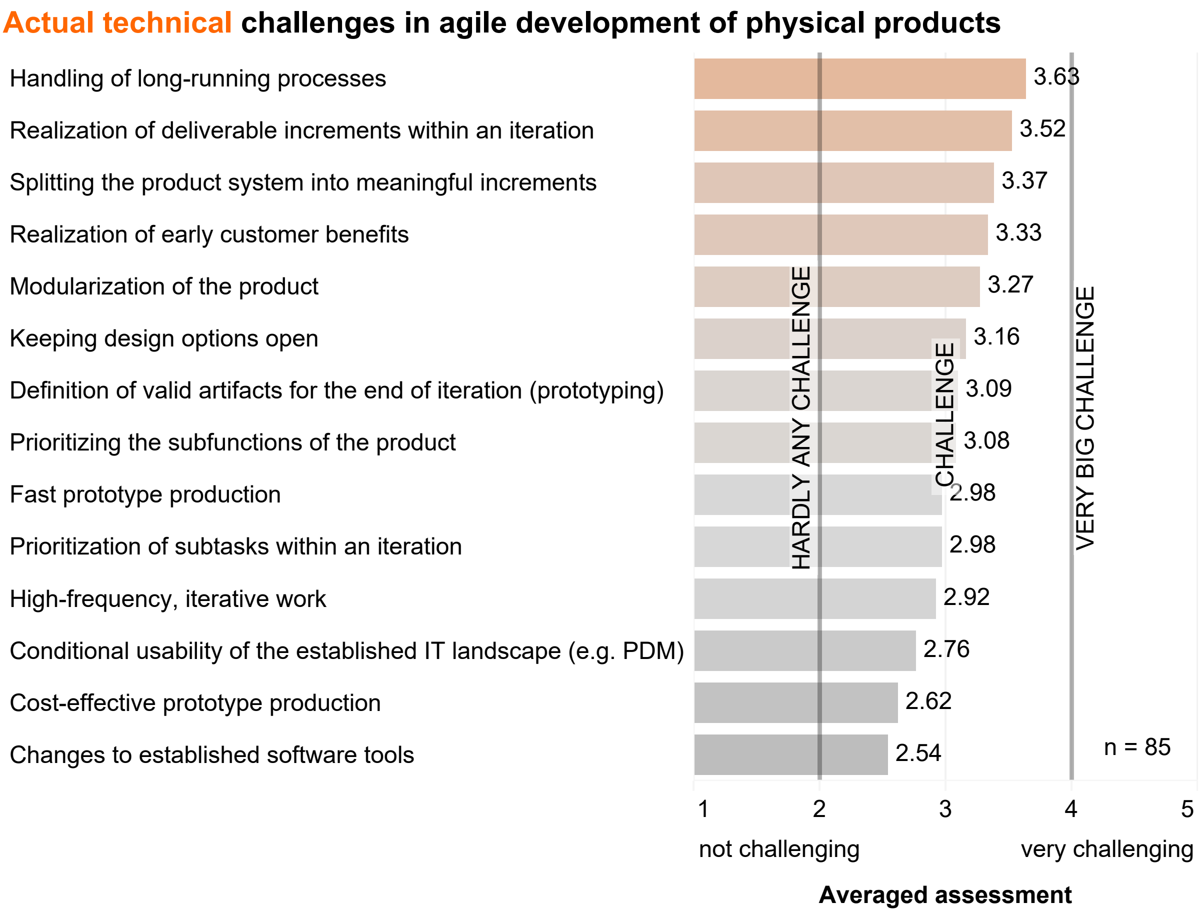

Figure 4.14.: Actual technical challenges of agile hardware development.

Description

Experienced participants[6] were asked to state their opinion regarding the technical challenges of agile hardware development they have experienced in practice. Each of the listed effects in Figure 4.14 was rated on a scale from 1 (not challenging) to 5 (very challenging).

Key learnings

- Listed issues are all perceived challenging. However none of them exceeds the threshold to a very big challenge, nor is below the border to being a minor challenge.
- “Long-running processes“ and thus the “Realization of deliverable increments within one iteration“ are seen as the highest challenges among all.
- Following, the “Breakdown into meaningful increments“ and “Product modularization“ are seen as challenging as well.
- Aspects regarding the “IT landscape needed“ or “Cost-effective prototype production“ are rated relatively low.

Interpretation

- Since many mechatronic products are highly sophisticated from a technical point of view, the realization of deliverable increments, as claimed by the Manifesto, is indeed a large challenge. Along with the issue of long-running processes these aspects are central which are summarized under the term “constraints of physicality“.

[6]The differentiation between “beginners“ and “experienced“ participants is explained in Chapter 9 elaborately.

- For several applications, workarounds like Rapid Prototyping might be meaningful in first iterations, yet not in later stages. Thus, approaches need to be found that are able to cope with these key aspects.
- Experienced practitioners do agree on those constraints, yet they have found tenable (yet not satisfactory) ways and means to deal with them.
  This indicates, that **agile development is applicable in the hardware**.

⇒ Compared to last year, this year's top-rated technical challenges have gained a lot more influence.

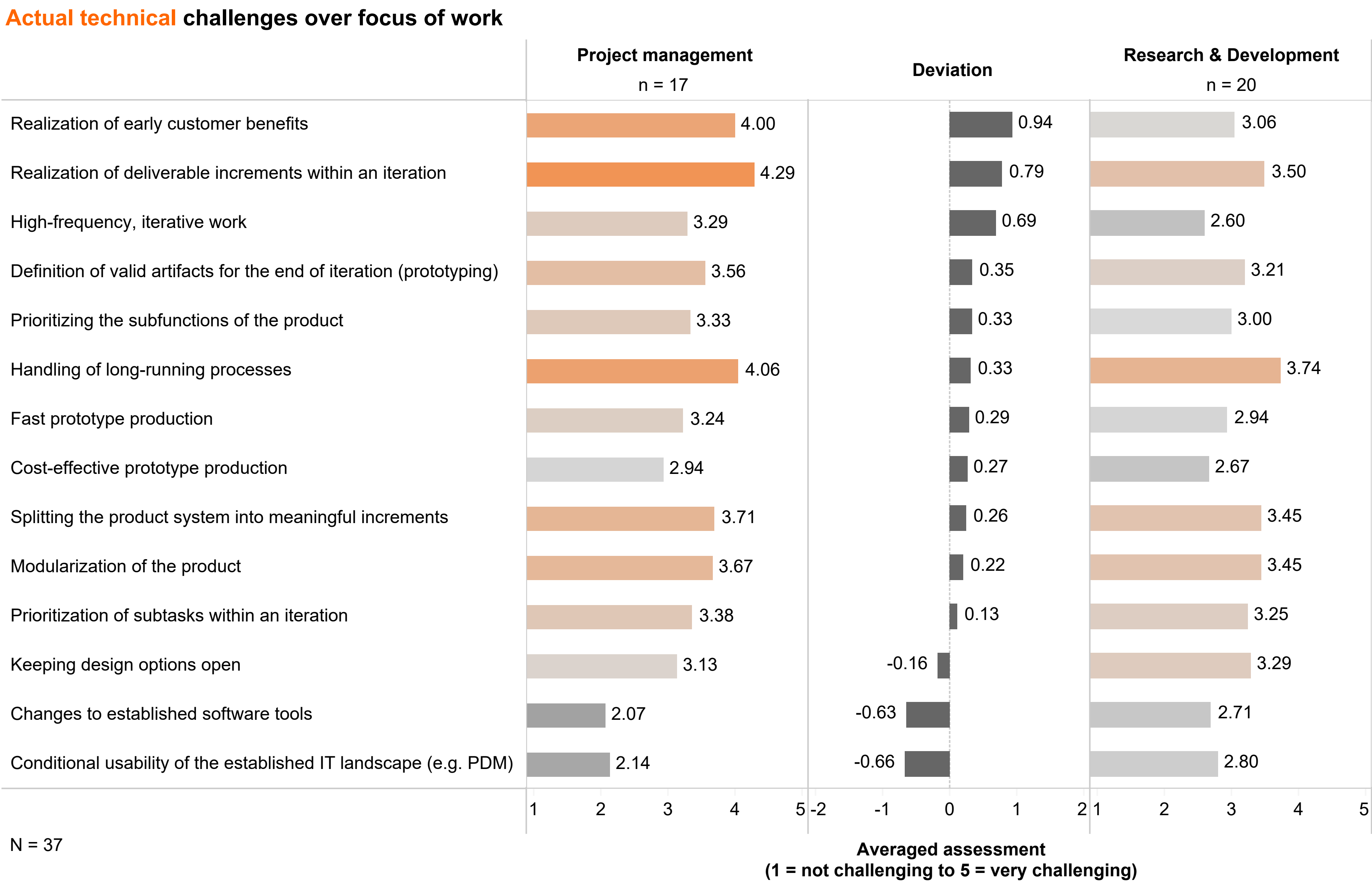

Figure 4.15.: Technical challenges depending on the focus of work.

Description
In this figure, the results of the actual technical challenges (compare Fig. 4.14) are displayed from the viewpoint of project management in contrast to R&D. The deviations on the respective benefits between both project management and R&D are visualized in the intermediate column (grey bars). Positive deviations refer to a higher rating by project management, negative deviations to smaller ratings than by R&D.

Key learnings
- “Realization of early customer benefits“ as well as “Deliverable increments within an iteration“ and “Iterative work-style“ are seen a lot more challenging by project management than by R&D.
- In terms of the “IT landscape“ project management is less concerned whereas R&D rates it rather medium.
- In terms of “Product modularization“ and the “Splitting into increments“ both groups see it as rather challenging, just like the “Handling of long-running processes“ with project management rating it even a bit more challenging. However, these challenges are among the top technical challenges in both groups.

Interpretation
- Project management tends to rate the technical challenges higher than people from R&D.
- Especially working style-related challenges in order to generate of an early customer benefit is seen more critical by project management than by R&D.

4.4. Conflicts

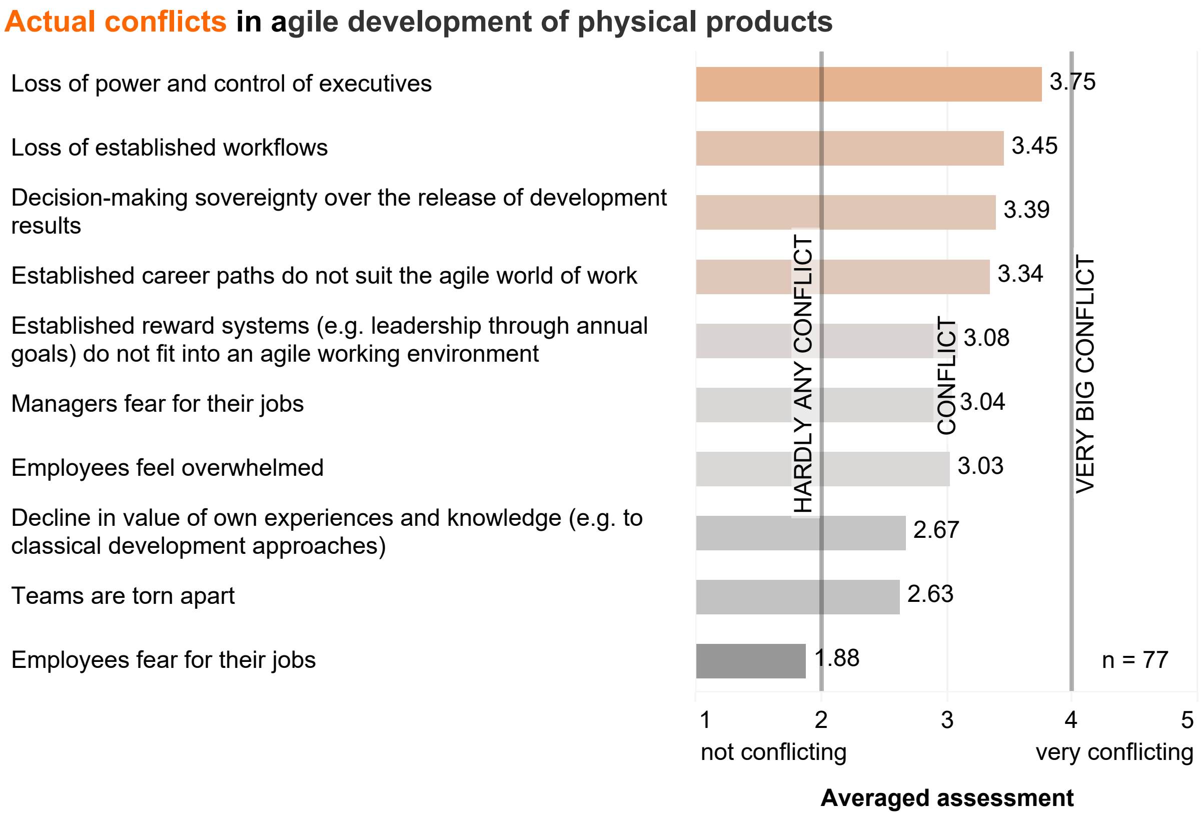

Figure 4.16.: Actual social conflicts due to agile hardware development.

Description

Experienced participants[7] were asked to state their opinion regarding the social conflicts of agile hardware development they have experienced in practice. Each of the listed effects in Figure 4.12 was rated on a scale from 1 (not conflicting) to 5 (very conflicting).

Key learnings

- None of the ten above mentioned statements is clearly marked a very big conflict (yet one is considered rather big).
- The "Loss of power and control of executives" is the highest social conflict overall by far.
- Familiar habits such as "Established workflows and career paths" as well as "Decision-making sovereignty" are also center of conflicts in agile development.
- "Employees fearing for their jobs" is no center of conflicts.

Interpretation

- Executives fear for their job and their existence a lot, whereas hardly any conflict potential is on the side of the employees.
- The leading and management system of the agile world does not fit to the classic one.

[7] The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

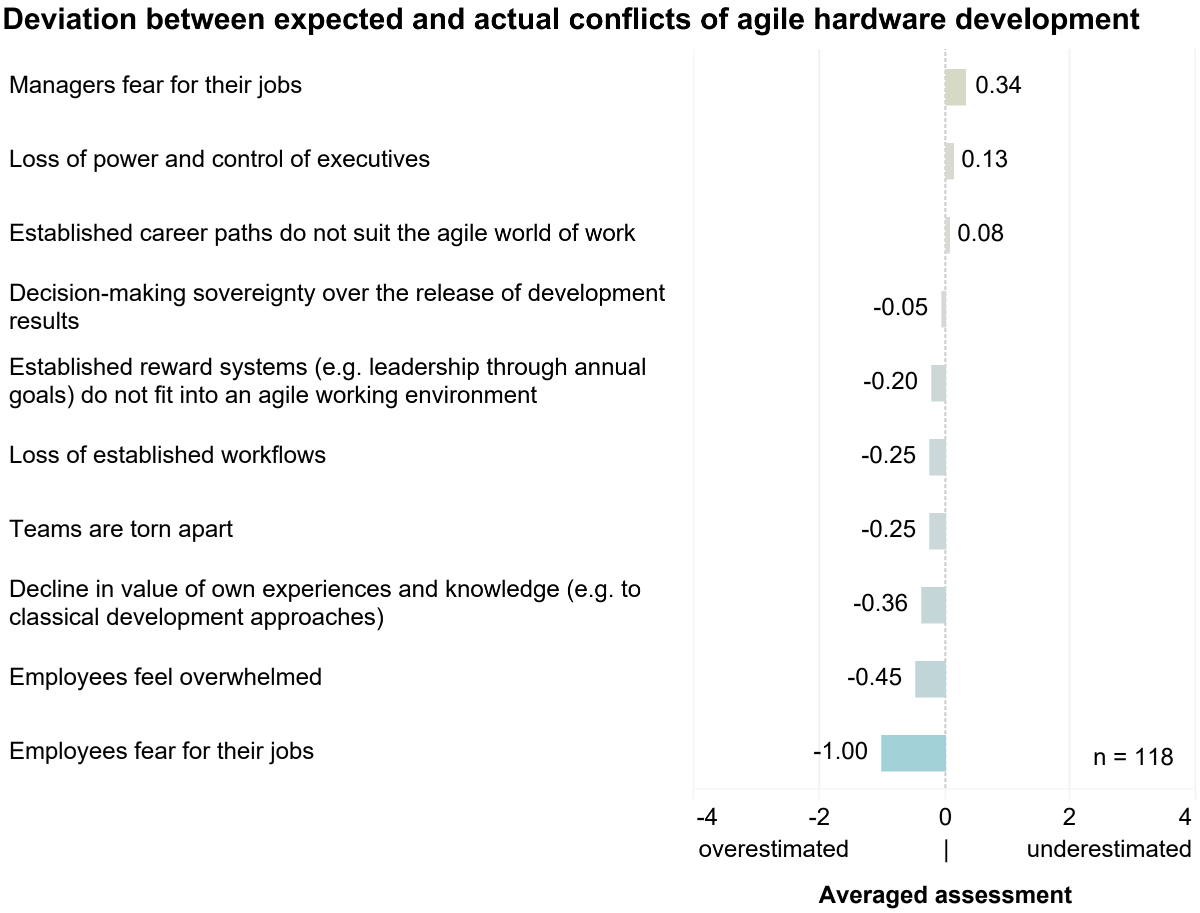

Figure 4.17.: Expected minus actual social conflicts due to agile hardware development.

Description

This figure visualizes the deviation between the expected and actual effects concerning conflicts of agile hardware development. Beginners[8] rated the expectations while experienced participants assessed the actual conflicts. Overall, the expectations and actual benefits diverge in several aspects. It is very important to understand that an effect can be intensive, although it is overestimated.

Key learnings

- The "Power and control loss of managers" and their "Fear in terms of job loss" are underestimated on average.
- "Employees fearing for their job" is very overestimated, also that they might "Feel overwhelmed" is overestimated.
- Most other conflicts do not show a great deviation between expected and actual conflicts on average.

Interpretation

- The fear of employees losing their job is very overestimated, whereas the executives underestimate losing their jobs.
- There is no great deviation in terms of the conflicts arising due to clash of the agile and the traditional world.

[8] The differentiation between "beginners" and "experienced" participants is explained in Chapter 9 elaborately.

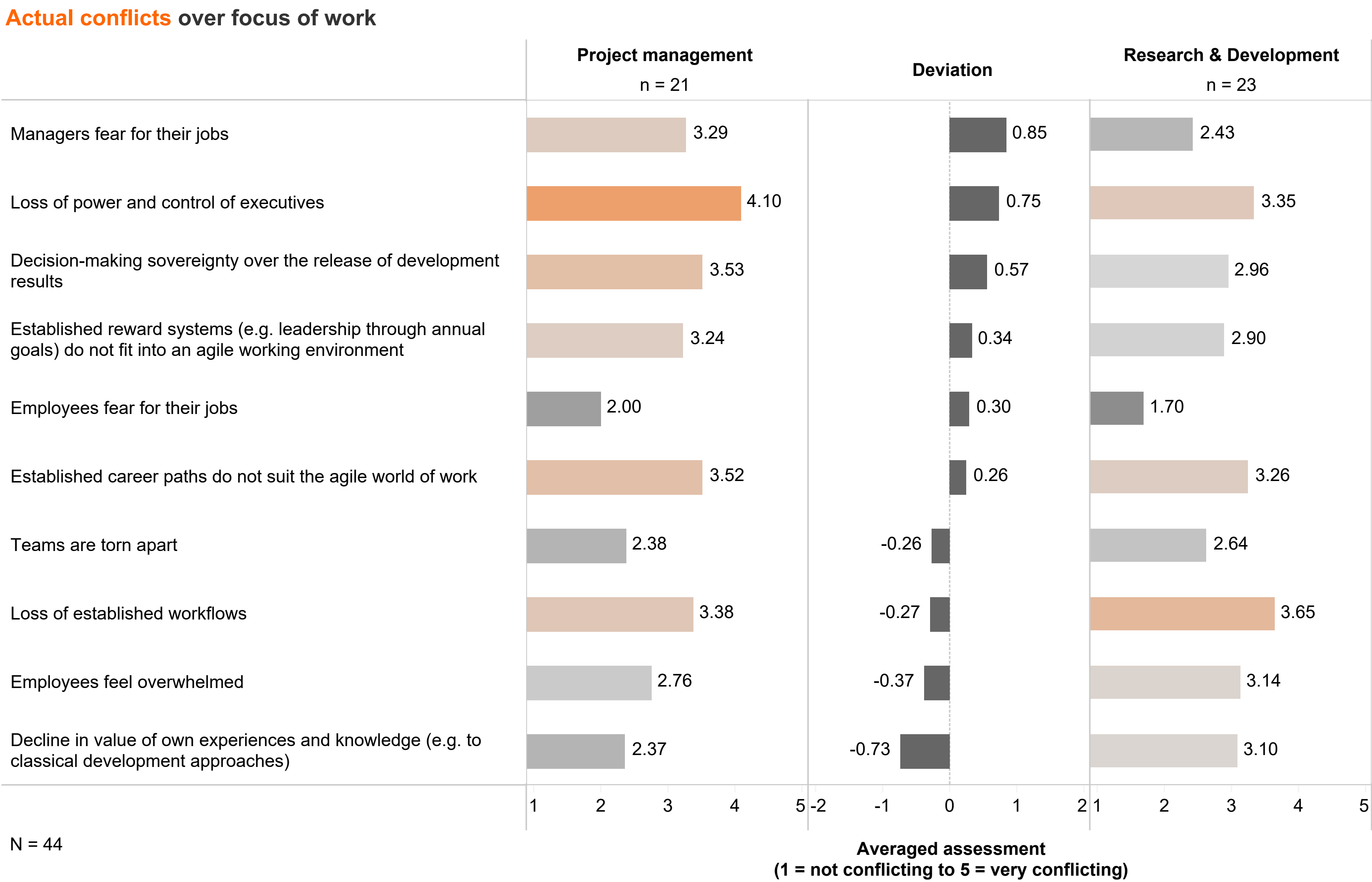

Figure 4.18.: Social conflicts of the participants depending on the focus of work.

Description
In this figure, the results of the actual conflicts (compare Fig. 4.16) are displayed from the viewpoint of project management in contrast to R&D. The deviations on the respective benefits between both project management and R&D are visualized in the intermediate column (grey bars). Positive deviations refer to a higher rating by project management, negative deviations to smaller ratings than by R&D.

Key learnings
- The greatest deviation can be seen in the "Fear of job loss and the loss of power and control of managers" rated a lot higher by project manager than by R&D.
- The "Decline in value of own experiences and knowledge" that could negatively influence the career potential, is rated a lot less by project management.
- The highest actual conflict from the viewpoint of project management is the "Power loss of executives"Ṙ&D rates the "Loss of established workflows" the highest.

Interpretation
- Project management rather sees conflicts in their spheres of influence. Being affected in terms of conflicts the most, one attempt to explain this assumption could be the fear of losing their right to exist (in the business world).
- R&D on the other hand sees conflicts rather in the way of working and their personal career, but also in the power loss of executives.

5. Transition towards Agile Hardware Development

Firstly, the chapter presents the transitional levels of the companies and differentiates between the current state and the future progression regarding the application towards agile hardware development. As the further diffusion of agile development increasingly involves organizational concerns / matters, the second part of the chapter deals with the topics of roll-out and scaling.

Structure of current chapter

5.1. Transitional Levels

5.1.1. Status of Implementing Agile Development

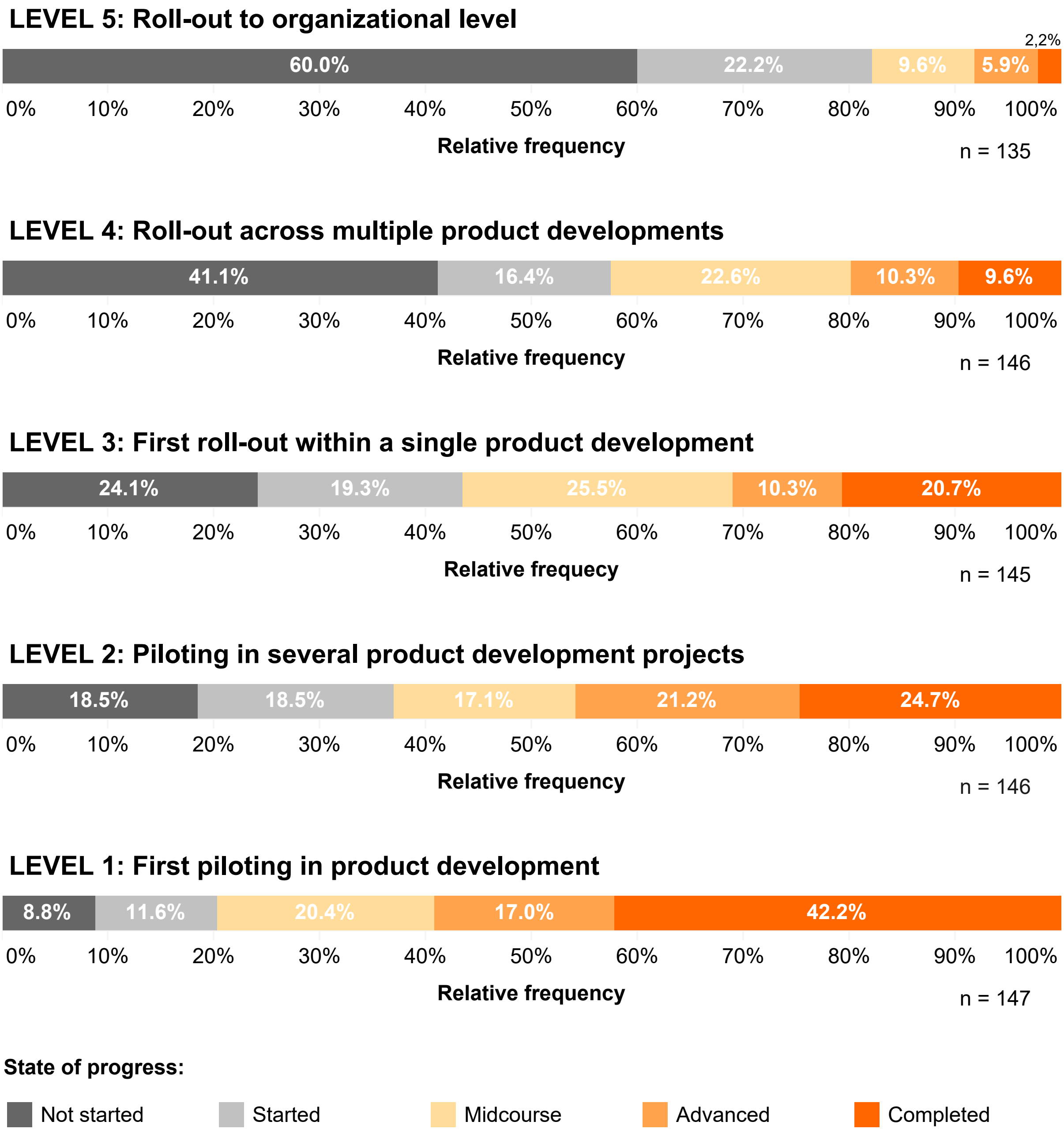

Figure 5.1.: Transitional progress of participating companies.

Description

Figure 5.1 shows which transitional level participating companies have reached already (compare Chapter 2 for an explanation of the respective levels). Each level represents a single survey question that was rated by the participants on a scale reaching from "not started" to "completed"The stacked bars display the relative frequency (to total number of participants) of the progress status rated. As the progress-related question was designed much less detailed last year (single question concerning the overall progress), a direct comparison does not seem to be possible.

Key learnings

- 42.2% of the participants have completed a pilot project, while 50% are running the pilot project and 8% have not started yet.
- There is a quite linear decrease of operational diffusion progress among the levels. In other words, the higher the level, the less companies are actively involved.
- Only 2.2% of the companies have completed Level 5.

Interpretation

- Agile hardware development is still diffusing and can still not be considered a standard approach in mechatronic product development.
- Most companies are engaged in diffusing agile development on several levels simultaneously (while completing the lower level, companies start with the next level already).

Company sizes according to the number of employees

Agile transition	1 - 249	250 - 4,999	5,000 - 49,999	50,000 - more	Grand total
Level 1	6.0%	8.7%	5.4%	2.0%	22.1%
Level 2	4.0%	9.4%	5.4%	5.4%	24.2%
Level 3	2.7%	10.1%	6.0%	9.4%	28.2%
Level 4	3.4%	8.1%	7.4%	1.3%	20.1%
Level 5	2.0%	2.7%		0.7%	5.4%
Grand total	18.1%	38.9%	24.2%	18.8%	n = 149

Figure 5.2.: Company size and transitional level of participating companies.

Description
Figure 5.2 visualizes the interdependence of company sizes and transitional level. Furthermore, the grand total column exhibits the progress distribution among the participants.

Key learnings

- Most participating companies belong to Level 3.
- Level 5 companies are still very rare.
- Remarkably, Level 5 companies are SME's; corporations are not that advanced in implementing agile hardware development.
- 50% of the large corporations that participated in the survey belong to Level 3.

Interpretation

- SME's are further into the agile transition due to less hindrances regarding the company size - this is rather the sweet spot for agile development and also represents the German mid-sized companies. Large corporations face significantly higher hindrances and thus are not as far as SME's.
- Despite this, there is no significant correlation between the company size and the transitional progress.

5.1.2. Time of Engagement for a Certain Transitional Level

Time of engagement in agile development of physical products

Agile transition	0 years	<1 year	1 - 2 years	3 - 5 years	6 - 10 years	> 10 years	Grand total
Level 1	6.3%	5.6%	5.6%	2.1%			19.4%
Level 2		4.9%	9.7%	9.0%	0.7%	0.7%	25.0%
Level 3		2.8%	12.5%	11.8%	2.1%		29.2%
Level 4		0.7%	4.2%	12.5%	2.1%	1.4%	20.8%
Level 5				3.5%		2.1%	5.6%
Grand total	6.3%	13.9%	31.9%	38.9%	4.9%	4.2%	n = 144

(a) Agile *hardware* development (can include a software share).

Time of engagement in agile development of software products

Agile transition	0 years	<1 year	1 - 2 years	3 - 5 years	6 - 10 years	> 10 years	Grand total
Level 1	4.1%	2.5%	2.5%	5.7%	2.5%	0.8%	18.0%
Level 2	4.1%	0.8%	3.3%	8.2%	6.6%	0.8%	23.8%
Level 3	3.3%		4.1%	16.4%	4.1%	1.6%	29.5%
Level 4	1.6%		1.6%	10.7%	5.7%	3.3%	23.0%
Level 5				2.5%	1.6%	1.6%	5.7%
Grand total	13.1%	3.3%	11.5%	43.4%	20.5%	8.2%	n = 122

(b) Agile *software* development.

Figure 5.3.: Time of engagement of participating companies to reach a certain transitional level.

Description

Both figures compare the time participating companies are engaged in agile development with the transitional level. Figure 5.3a relates to agile **hardware** development, while Figure 5.3b relates to agile **software** development.

Key learnings

- About 80% of the participating companies are engaged in agile hardware development longer than 1 year, 48% even longer than 3 years.
- The chance to reach at least Level 4 within 3 to 5 years is 41.1% in agile hardware development.
- The chance to reach at least Level 2 by the end of the second year equals 82.8% in agile hardware development.

Interpretation

- Implementing agile development is no quick fix but takes several years. According to the data, a company probably (91%) needs longer than 5 years to reach Level 5 (roll-out to organizational level).

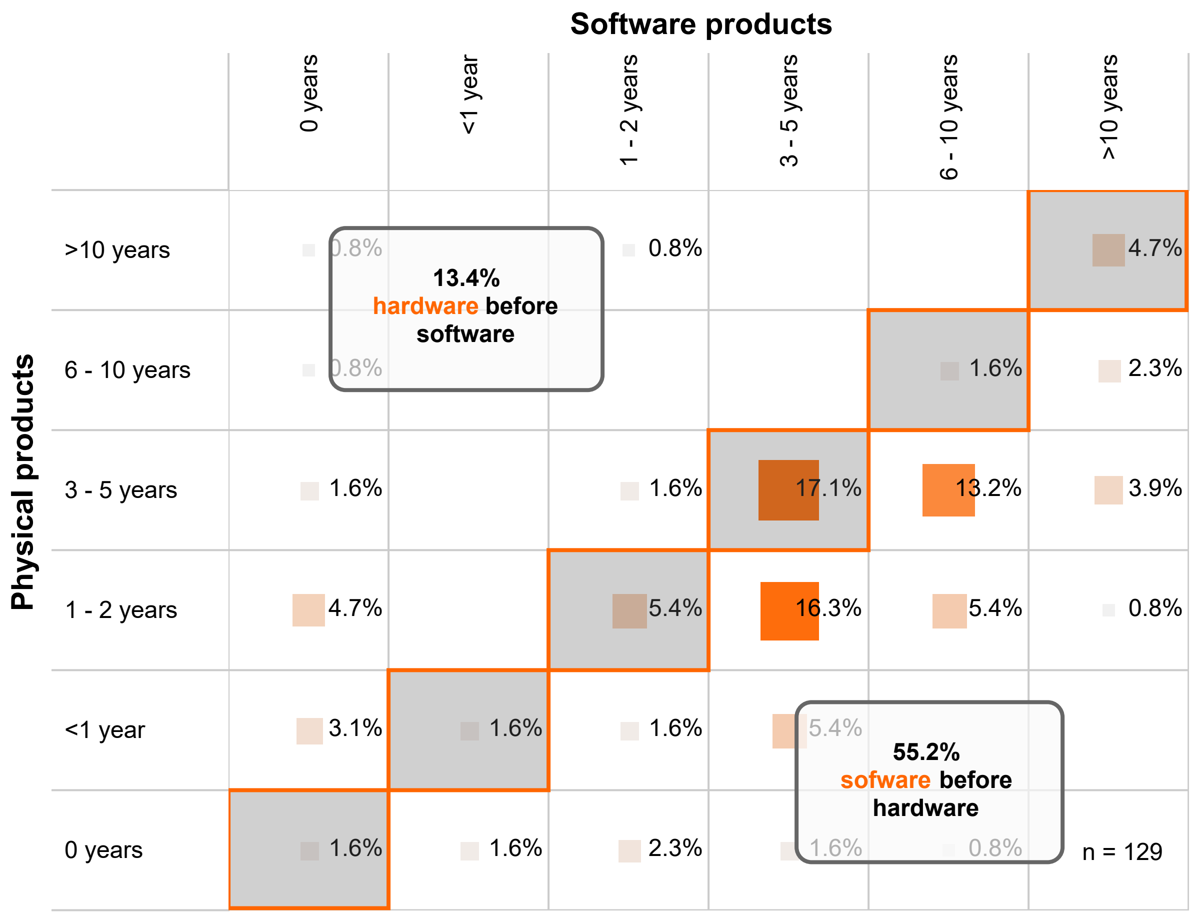

Figure 5.4.: Time engaged with agile software development vs. agile hardware development.

Description

Figure 5.4 contrasts the time a company has already spent in agile software development to the time spent in agile hardware development. The squares represent the relative frequency to the total number of records.

Key learnings

- 55.2% of the respondents have started with agile *software* development first before they have implemented agile hardware development. Only 13.4% did it the other way around. Thus, most companies get into agile hardware development through software development.
- About 50% of the participating companies are engaged in agile software development for 3 to 10 years and in agile hardware development for 1 to 5 years.

Interpretation

- For most companies, agile development as a concept is not new, but they extend the application to another department which faces different context conditions.

⇒ Compared to last year, the trend of being involved in agile software development before implementing it to mechatronics remains.

5.1.3. Current and Future Commitment Towards Roll-out of Agile Development

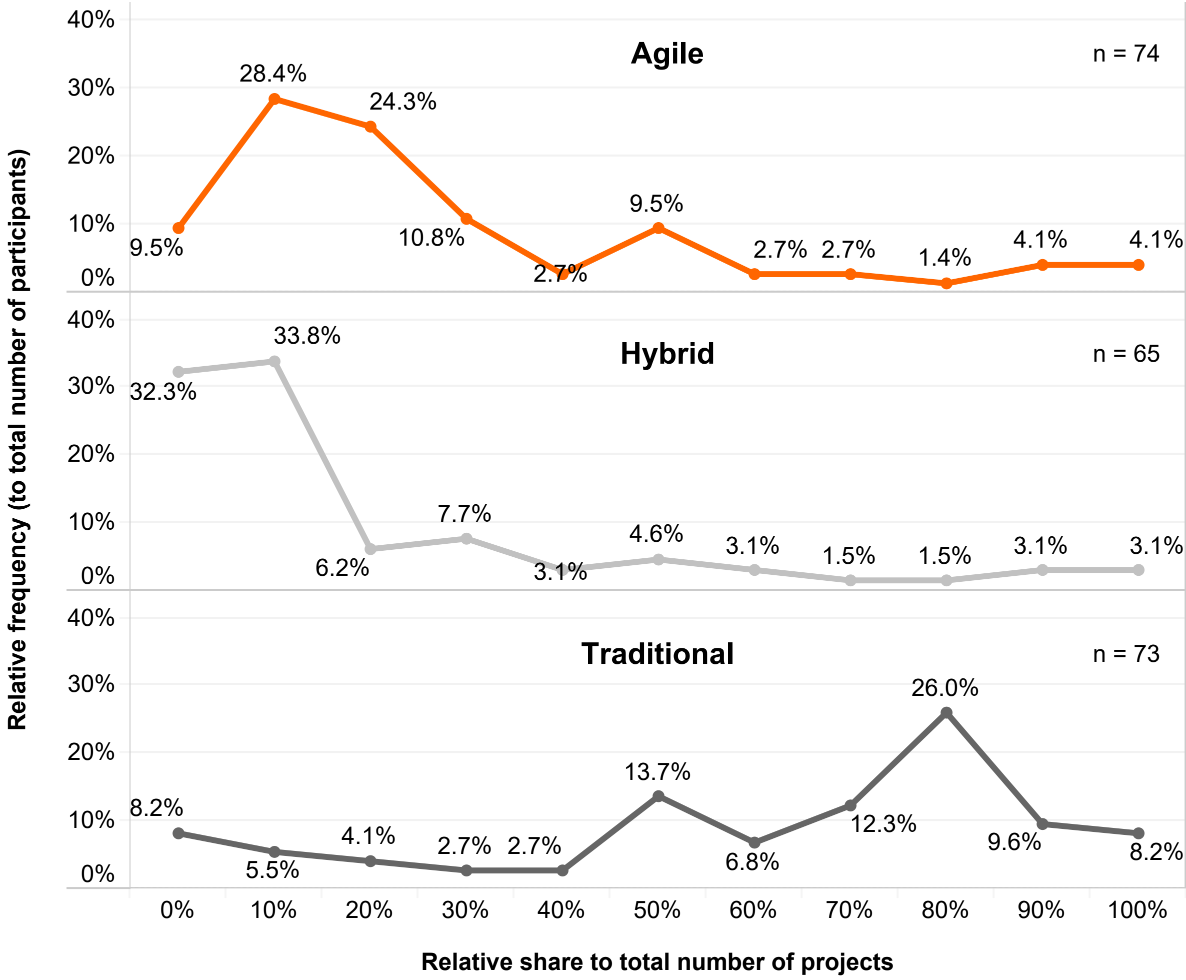

Figure 5.5.: Today's state of diffusion of agile hardware development in participating companies.

Description

The graphs in Figure 5.5 show a histogram concerning the share of the R&D project landscape of participating companies being carried out in an agile vs. hybrid vs. traditional manner. Thus, the area below each curve equals the total number of participants. "Agile" refers to developing in line with the Manifesto (Beck et al. 2001), "traditional" signifies heavy-weight, plan-driven development (e.g., V-model combined with Stage-Gate) and "hybrid" stands for a combination of agile and hybrid approaches (e.g., Stage-Gate on a macro level plus Scrum on a micro level).

Key learnings

- By far, most R&D projects are executed traditionally today.
- There is a small portion of companies (<10%) that carries out 90 to 100% of all R&D projects in an agile manner already today.
- More than 60% of the companies do not or only to a very limited extent apply hybrid models (<10% of all R&D projects).
- Agile approaches are used more often than hybrid approaches.
- About 80% of the participants state that less than 40% of their R&D landscape is executed in an agile manner currently.

Interpretation

- Agile hardware development cannot be considered a standard approach in the industry so far.
- Most companies still rely heavily on traditional development.
- Both schools of thoughts (agile and traditional) will most likely remain within the next 5 years. Companies should think about how to manage the (preliminary) coexistence.

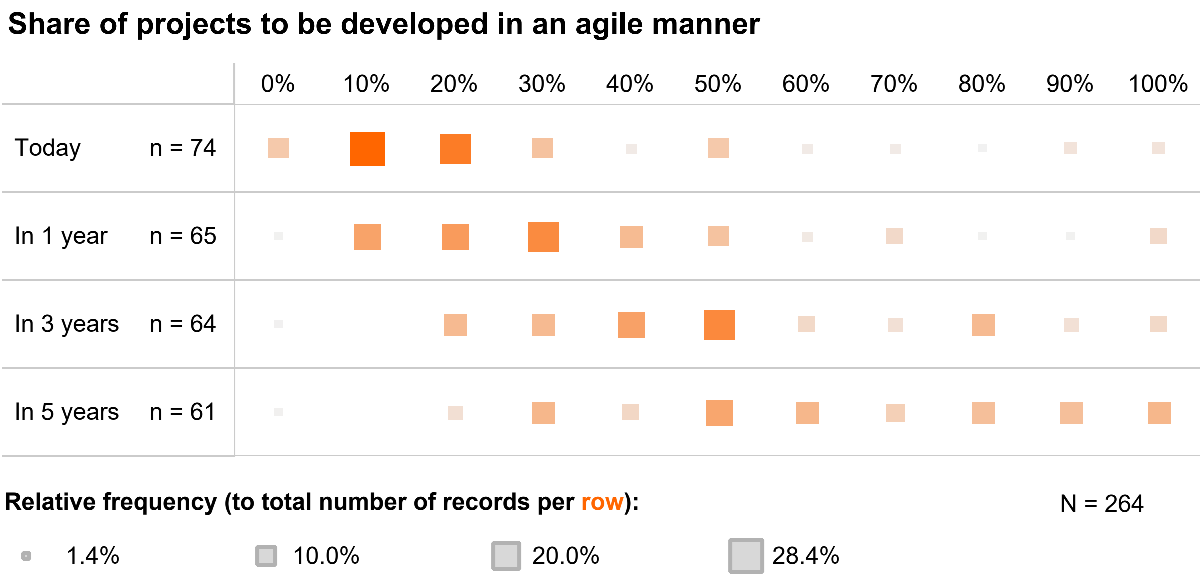

Figure 5.6.: Planned share of total R&D projects that will be carried out in an agile manner in participating companies on several time horizons.

Description

Figure 5.6 displays the future commitment towards agile hardware development of participating companies. The columns stand for the share of projects being carried out in an agile manner relative to the total number of R&D projects in the company. The squares represent how many participants rated for each share per year and are normalized to the total number participants per year (per row).

Key learnings

- Today, about 10 to 20% of all R&D projects are run in an agile manner (compare also Figure 5.5).
- In 3 years ahead, the majority of participants (65%) believe that their company will carry out approximately 20 to 50% of all R&D projects in an agile manner.
- However, 72% of the participants see potential for agile projects in more than 50% of all R&D projects in 5 years.
- Nevertheless, as expected, the participants are increasingly uncertain about the future share in 3 and 5 years ahead.

Interpretation

- Agile hardware development is still on the rise and has the potential to become a standard approach. This, however, might need 5 to about 10 years from now.
- Thus, companies should not wait long in order to not miss implementing agile hardware development because a thorough implementation lasts several years (compare Figure 5.3).
- However, agile hardware development does not seem to be worth considering for each project. It is recommended to start implementing agile hardware development in projects where the need (VUCA environment) for it is highest.

5.2. Scaling Approaches

5.2.1. Connotation of Scaling

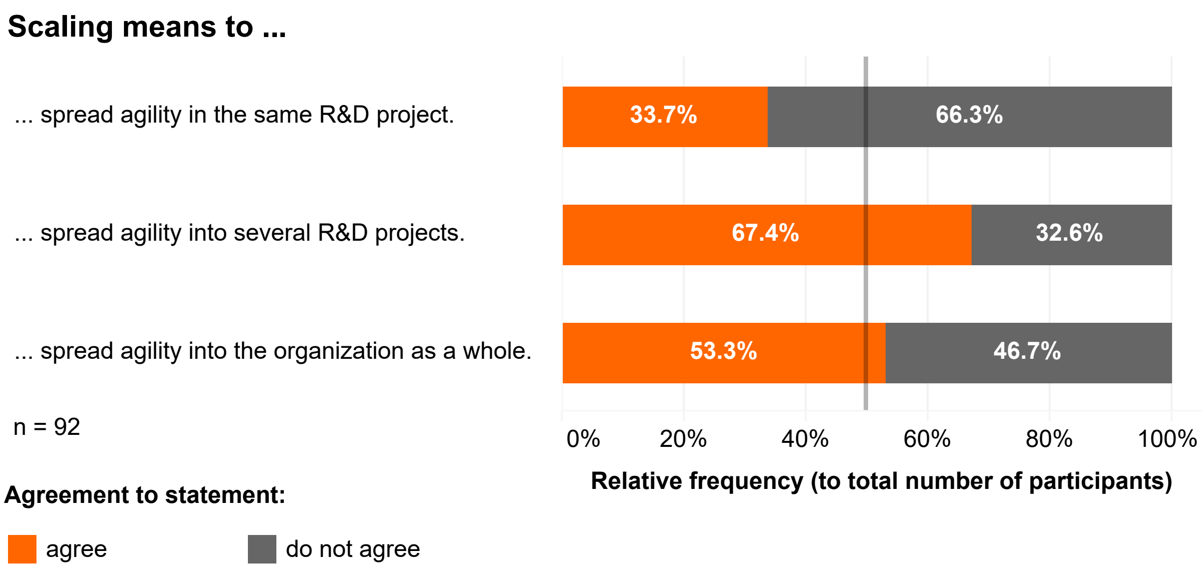

Figure 5.7.: Participants' connotation of the term "scaling".

Description
The survey tested three different meanings of the term "scaling". The participants were asked to tick those meanings that fit best to their connotation. Multiple answers allowed (besides *N/A* and *I do not know* that are excluded in the figure). The different stages represent the transitional level, as displayed in Figure 5.1.

Key learnings

- Practitioners do not have a common understanding of scaling.
- However, most participants stated that scaling means spreading agility into several R&D projects.
- None of the connotations can definitely be confirmed or neglected.

Interpretation

- Scaling in the context of agile hardware development has a multi-faceted meaning in the industry.
- When talking about scaling, the chance is high that practitioners have different connotations in mind.

5.2.2. Scaling Approaches Used

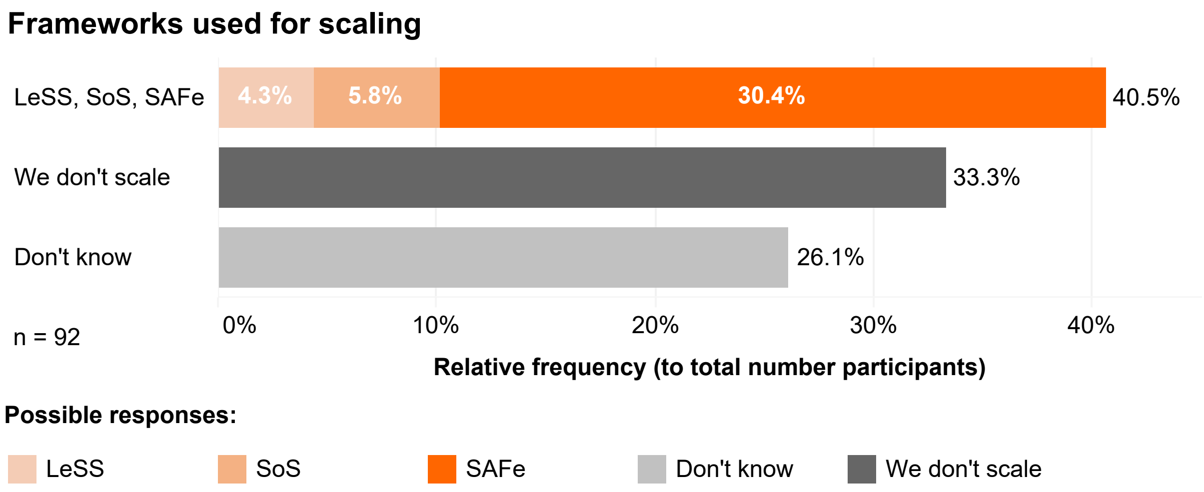

Figure 5.8.: Scaling frameworks used by participating companies.

Description
The participants were asked to state the scaling framework used in their company. Besides the popular frameworks SAFe, LeSS, and SoS, the survey provided also a *N/A* and a *I do not know* option.

Key learnings

- Less than one third of the companies do not scale currently.
- Roughly 40% of the companies use scaling frameworks.
- SAFe is the most used framework (25.3% of the participants) among those presented.

Interpretation

- Remarkably, a high share of participants (38.6%) used the options "N/A" or "I do not know". This is in line with the overall distribution of the companies on the transitional levels (compare Figures 5.1 and 5.2).
- SAFe and SoS complement Scrum towards the transition to an agile organization. Thus, it is in line with Figure 4.6 stating that the most used agile method is Scrum.
- The relatively small share of participants that use scaling framework might stem from the fact that (a) scaling is relevant especially for large enterprises and corporations, and (b) for companies that have already reached a certain transitional level. In both regards, there are not many companies actively involved as visualized in Figures 3.2 and 5.2.

6. Applicability of Agile Hardware Development

First, the impact of the degree of physicality of the product regarding the constraintness is investigated. Further on, the transferability of the well-known Manifesto of Agile Software Development to the hardware-specific context is presented. With the Manifesto creating a philosophy built upon values and principles, it is concretized by means of so-called agile methods and practices. Therefore, in order to being able to apply it in the context of hardware development, the transferability in terms of its core values is being analyzed. Thirdly, the types of teamwork are analyzed in terms of collaboration and cooperation.

Structure of current chapter

6.1. Degree of Physicality

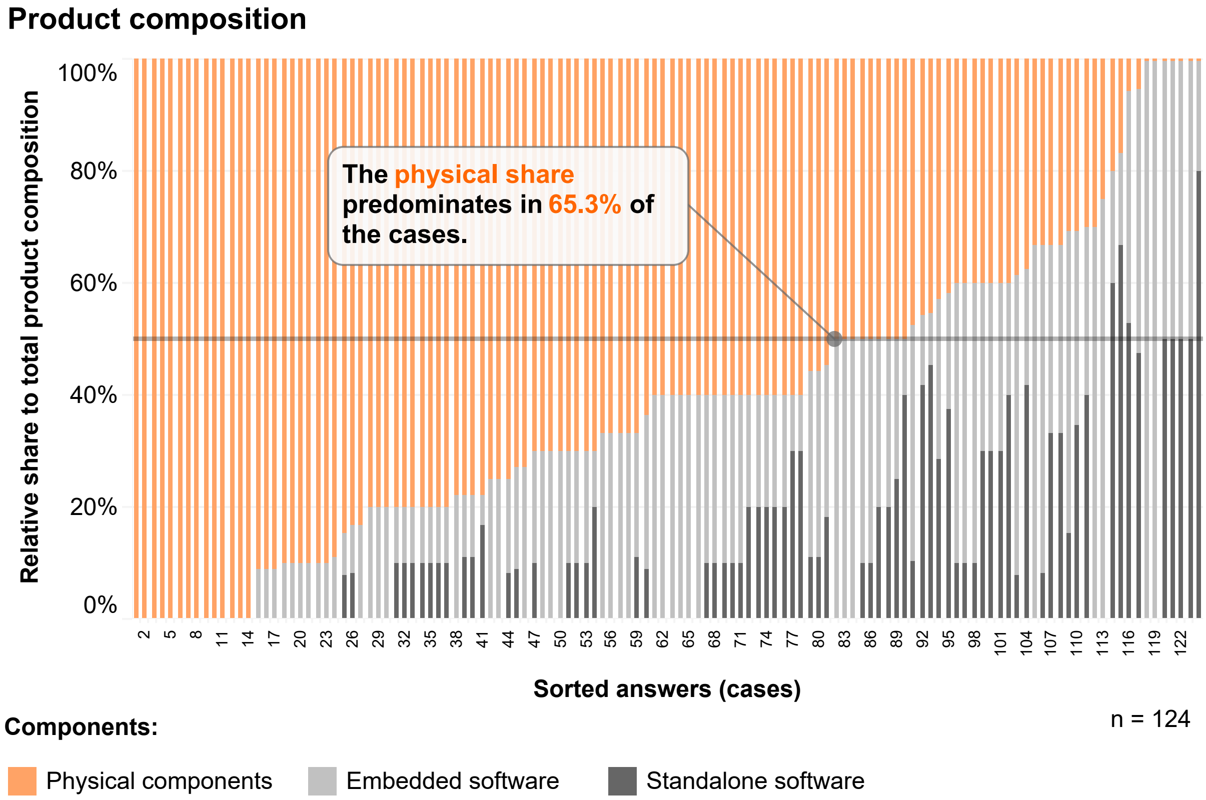

Figure 6.1.: Product composition of the different domains displayed over all cases.

Description

In this figure, the product composition in terms of the physical share (mechanical & electrical) compared to embedded software and standalone software is displayed over all cases rated. The input values of Figure 3.4 of each participant was transformed case-wise to display the tangible share.[1]

Important: The **physical share** is the sum of the mechanical and electrical **(M + E)** share.

Key learnings

- 2/3 of a all participants stated that their products have a physical (i.e. tangible) share greater than 50%.
- Only a very small number of cases (12 %) develop solemnly tangible products.
- Less than 10 % do consist of embedded and standalone software.

Interpretation

- Due to the high physical share, the vast majority of the participants suffer from the so-called "constraints of physicality", which hinder the mere translation from software to the hardware domain.
- Figure 6.1 confirms that most products investigated in the study are mechatronic in nature.

[1] The degree of physicality represents the amount of tangibility of a product and is elaborated in Chapter 9.

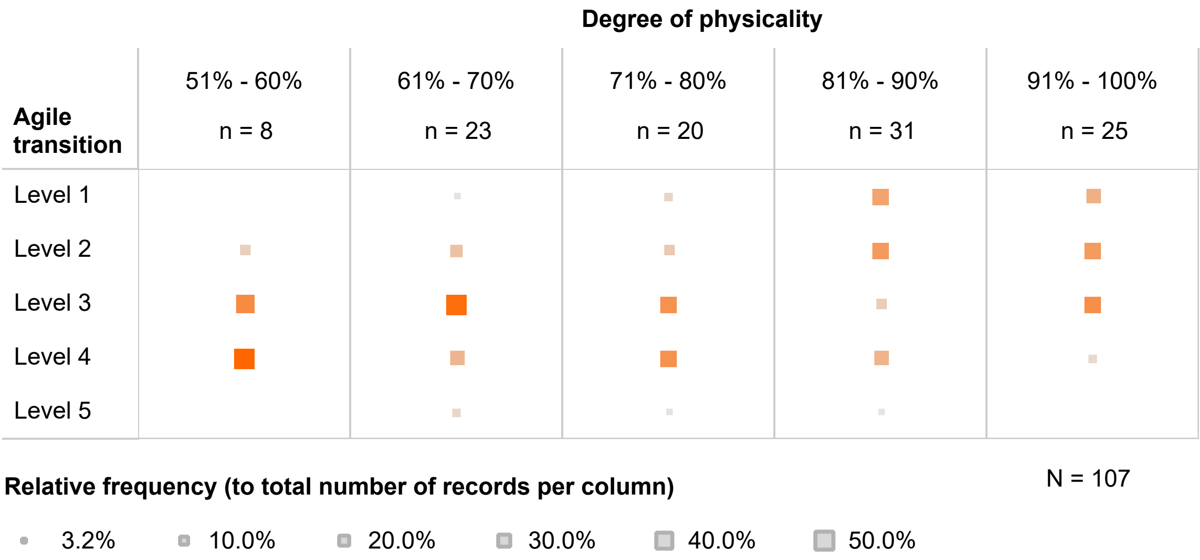

Figure 6.2.: Constraintness due to the product physicality and its dependence on the transitional level.

Description

Figure 6.2 shows the correlation between the progress in the agile transition and the degree of physicality the development department is facing. Please note that the values are standardized column-wise.[2]

Key learnings

- There is a clear tendency that companies being less affected by physicality (i.e., having a high software share in the product) have achieved a higher transitional level.
- 56% of the companies developing products with a physical share of more than 91% have not reached a transitional level higher than 2.
- In contrast, 50% of the companies facing a degree of physicality of 51 - 60% have accomplished Level 4.

Interpretation

- The lower the degree of physicality, the easier to become agile in development because the methods and experiences from the software industry can be applied more easily.
- Figure 6.2 proves that the degree of physicality is definitely a hindrance to become agile in hardware development.

[2]The degree of physicality represents the amount of tangibility of a product and is elaborated in Chapter 9.

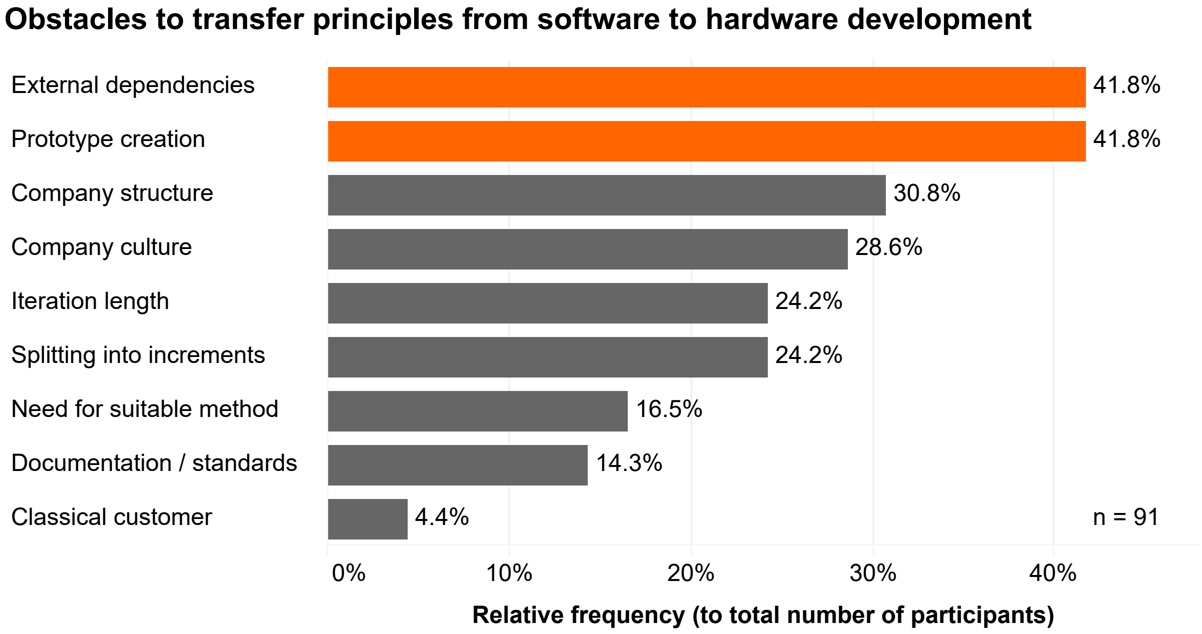

Figure 6.3.: Hindrances in terms of the transferability.

Description

The participants were asked to state which aspects hinder the transferability of agile approaches from software to hardware development. The participants were able to give a max. of 3 statements in a free-text field which they perceive to have a high impact. The results have been analyzed and clustered in nine groups. A total of 91 participants have contributed with their input.

Key learnings

- The results can be clustered into two groups, *organizational* and *technical* hindrances.
- "External dependencies" regarding external suppliers or delivery times have been ranked the highest, along with the "Creation of prototypes".
- The "Company structure" with the availability of technical experts and interdisciplinary teams and the "Company culture" with aspects such as the mindset and the interfaces with classical structures are the second largest group of hindrances.
- 16.5% of the participants explicitly stated that the available agile methods do not fit to the context of hardware development or even ask for a new, hardware-focused method.
- 24% of the participants argue that they are unable to generate "potentially deliverable prototypes" within one iteration, meaning the concept of short-term iterative development needs to be reconsidered for the hardware-related context.

Interpretation

- The obstacles in transferring from software to hardware development correlate with the answer regarding the *Technical and Organizational challenges*, which confirms their validity. Noticeably, 16.5% of the participants explicitly stated that the available agile methods do not fit to the context of hardware development or even ask for a new, hardware-focused method. This shows that there is a high need in assistance regarding method adaption / creation.

6.2. Transferability

6.2.1. Transferability of the Manifesto

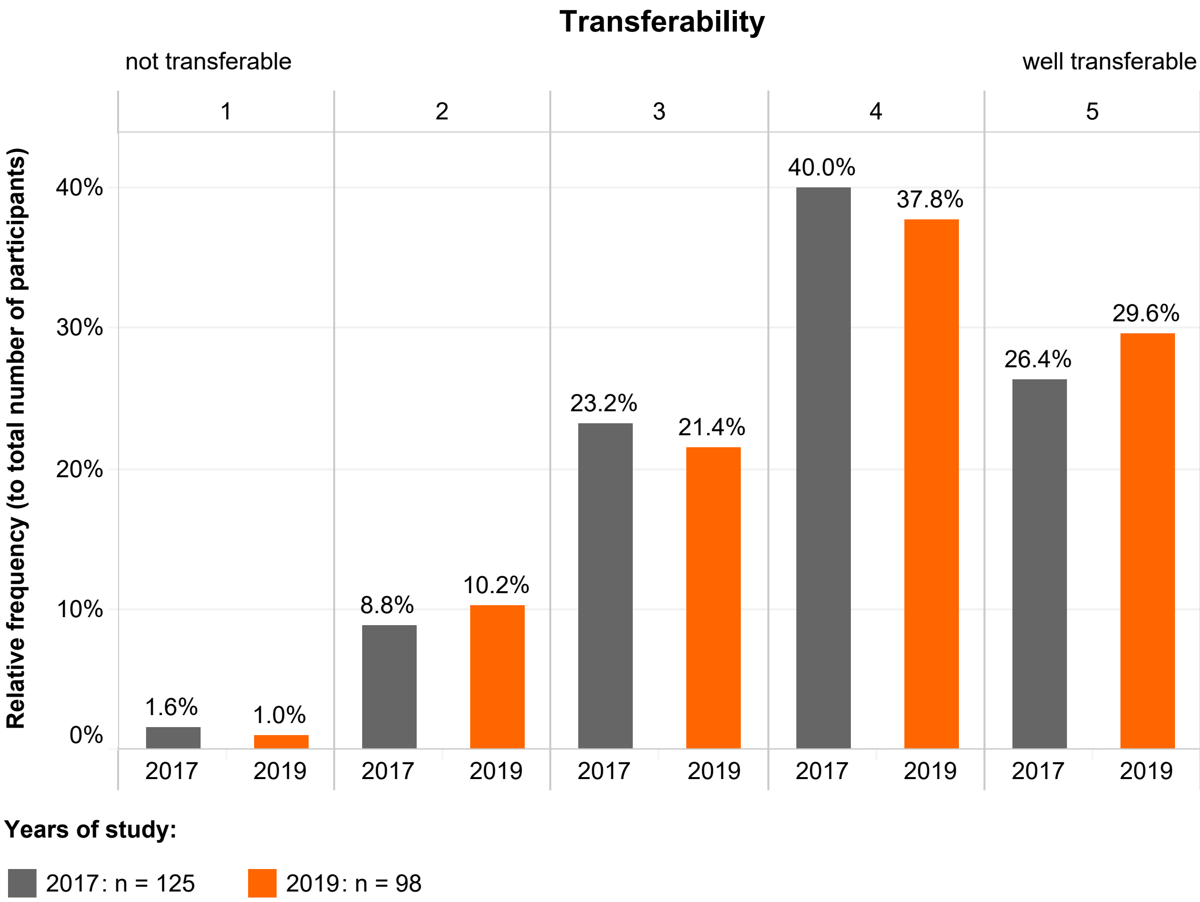

Figure 6.4.: Transferability of the Manifesto to agile hardware development.

Description

In the survey, the participants rated how well the Manifesto of agile software development (Beck et al. 2001) is transferable to hardware development in their opinion. Figure 6.4 shows the results of this year's survey and contrasts them to the ratings of last year.

Key learnings

- This year, almost 70% of the participants confirm that the Manifesto is rather or well transferable (≥ 4). Only about 10% of the participants do not confirm the transferability (≤ 2).

⇒ Although about the same share of participants confirmed its transferability as well last year, more chose the highest option this year.

⇒ Compared to last year, there is an increase in frequency for 2 and 5, while the remaining transferability options were chosen less frequent.

Interpretation

- As more participants chose the highest option this year, the participants might have found suitable solutions to adapt agile methods to the context of hardware development.
- However, it remains unclear whether agile principles and agile practices are transferable.

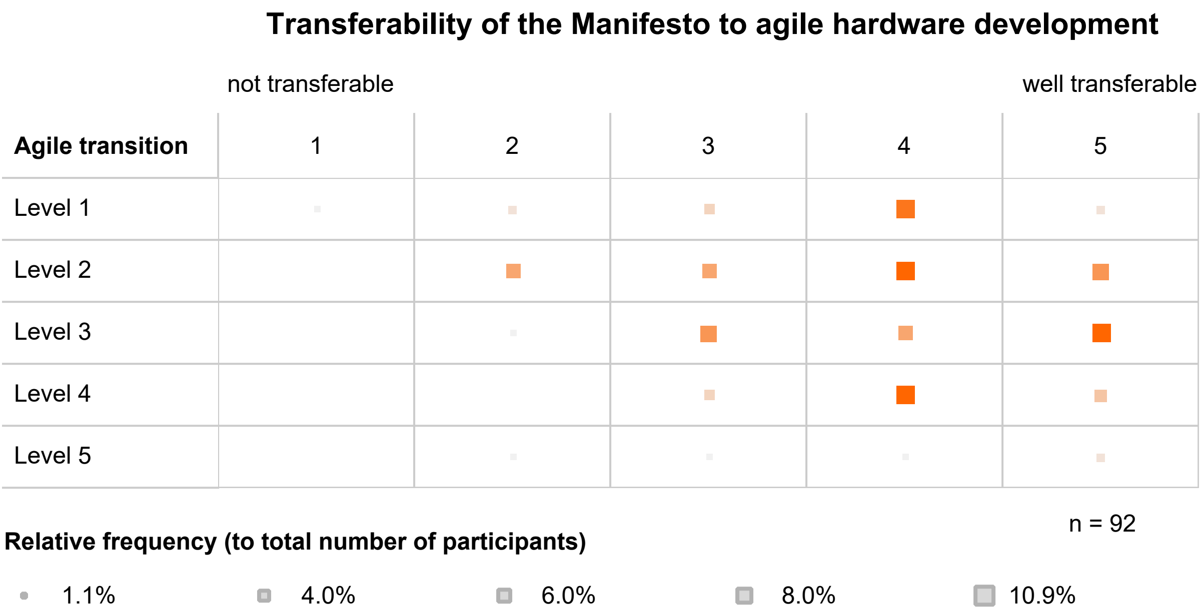

Figure 6.5.: Transferability of the Manifesto to agile hardware development depending on the transitional level.

Description

Figure 6.5 outlines the correlation between transitional progress and the transferability perception concerning the Manifesto. Please note that only a few participants fall into Level 5 so that those ratings are statistically not representative and only shown for the sake of completeness.

Key learnings

- The higher the level, the less participants say that the Manifesto is not or rather not transferable.
- The higher the level, the higher the average rating on transferability per level (Level 1: *3.53*; Level 2: *3.62*; Level 3: *4.04*; Level 4: *4.05*).
- 82.2% of the participants from Level 4 state that the Manifesto is well or rather transferable (≥ 4), whereas only 64.5% from Level 1 do so.
- 54.2% of those participants that do not confirm the transferability (≤ 2) fall into Level 2.

Interpretation

- The Manifesto of Agile Software Development is also valid for agile hardware development.
- Surprisingly many participants from Level 1 find the Manifesto rather transferable (4). This could be explained by the inflated expectations about agile development of beginners.

⇒ As last year, participants seem to become disillusioned while moving forward to Level 2 because more participants rate lower options.

⇒ However, the disillusion effect is less significant than last year.

⇒ Similarly to last year, the more advanced a company is in implementing agile development, the more the Manifesto is perceived as valid in hardware development.

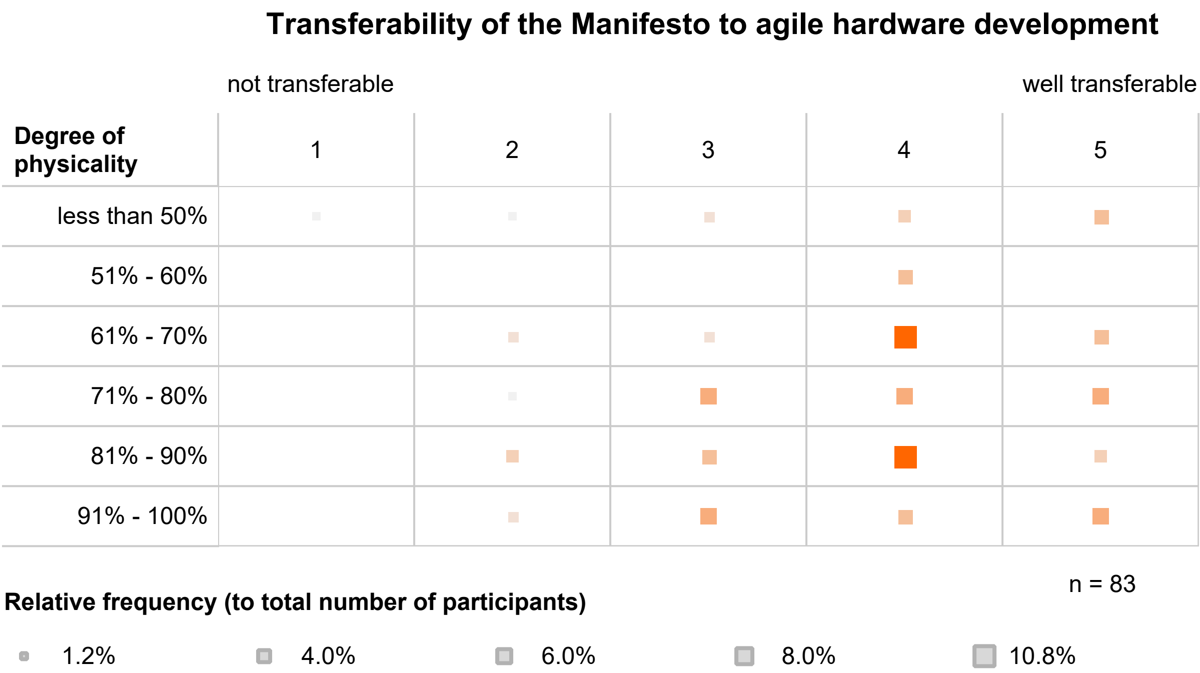

Figure 6.6.: Transferability of the Manifesto to agile hardware development depending on the degree of physicality.

Description

Figure 6.6 shows the correlation between the transferability ratings of the participants and the degree of physicality (as explained in Figure 6.1) they face within their product development. As there are only very few participants having a degree of physicality of less than 50%, they are grouped to a single cluster.[3]

Key learnings

- There is no significant correlation between the degree of physicality and the transferability ratings.

Interpretation

- Irrespective of the degree of physicality, the Manifesto is also valid in hardware development.

[3] The degree of physicality represents the amount of tangibility of a product and is elaborated in Chapter 9.

6.2.2. Iteration Length

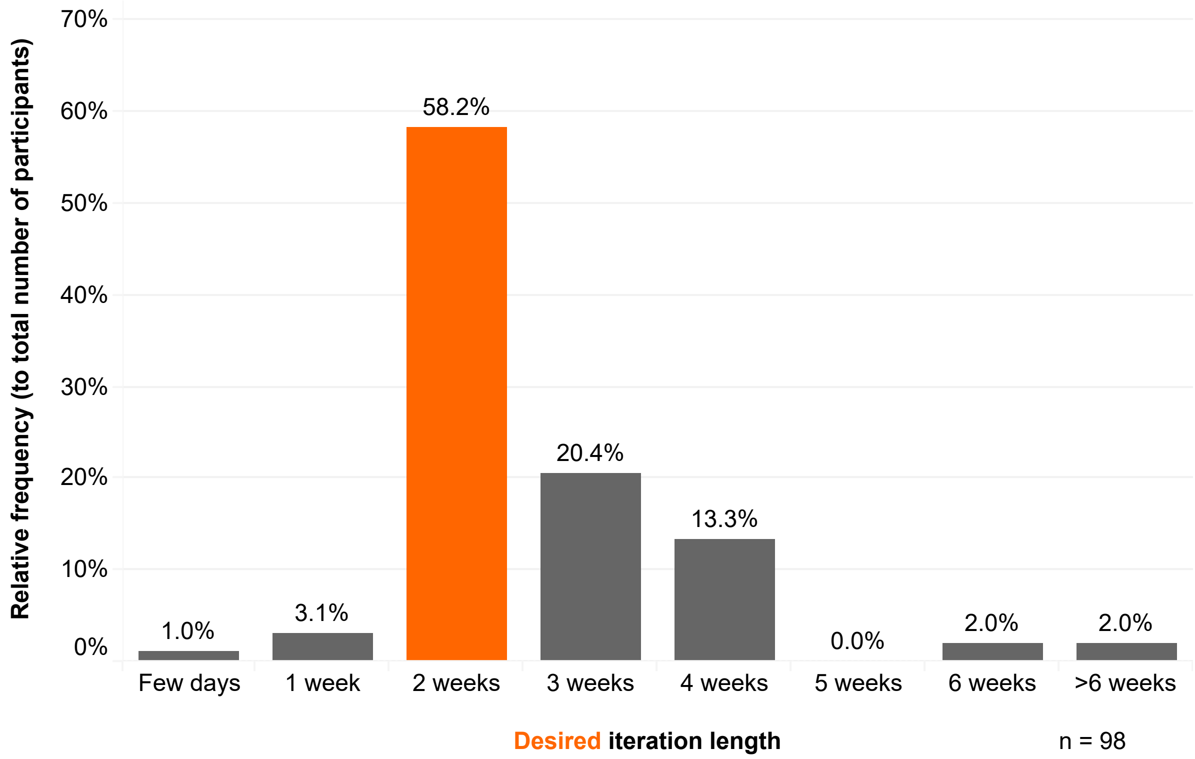

Figure 6.7.: Desired iteration length.

Description
The participants were asked to state their desired iteration length in agile hardware development. Figure 6.7 exhibits the relative frequency of the statements to the total number of participants.

Key learnings
- Almost 60% of the participants desire an iteration length of 2 weeks.
- 1/3 of the participants favor an iteration length of either 3 or 4 weeks.
- Only 4.1% would like to have iteration lengths of less than 2 weeks. Similarly, 4% strive towards iteration lengths of more than 4 weeks.

Interpretation
- Two-week iterations seem to fit best to the VUCA context of most participants.
- Depending on the context, in some cases 2 weeks is not feasible, thus choosing an iteration length of 3 to 4 weeks might be a feasible option for certain companies.
- Only a small portion of the participants face much harsher VUCA conditions that also requires shorter iteration lengths.

Figure 6.8.: Desired versus actual iteration length.

Description

Figure 6.8 contrasts the desired versus the actual iteration length of the participants regarding agile hardware development. The diagonal line signifies that the desired length equals the actual length. Participants stating a combination above that line desire a higher length, whereas those below desire a lower length.

Key learnings

- For 60.8% of the participants the desired length equals the actual length. They might have reached a satisfying iteration length for agile hardware development.
- The combination of 2 weeks being both desired and actually implemented is rated the most (38%).
- 13.1% desire a *higher* iteration length compared to their current situation.
- 26.2% desire a *lower* iteration length relative to the actual length.

Interpretation

- As also shown in Figure 6.7, two-week iterations are desired the most. 63.5% of this group have already reached their desired length.
- With the two-week iterations stemming from agile software development, it is also the most commonly applied iteration length in agile hardware development.
- Interestingly, those participants who iterate in less than 2 weeks currently desire a longer iteration length. However, this group is very small and statistically invalid.

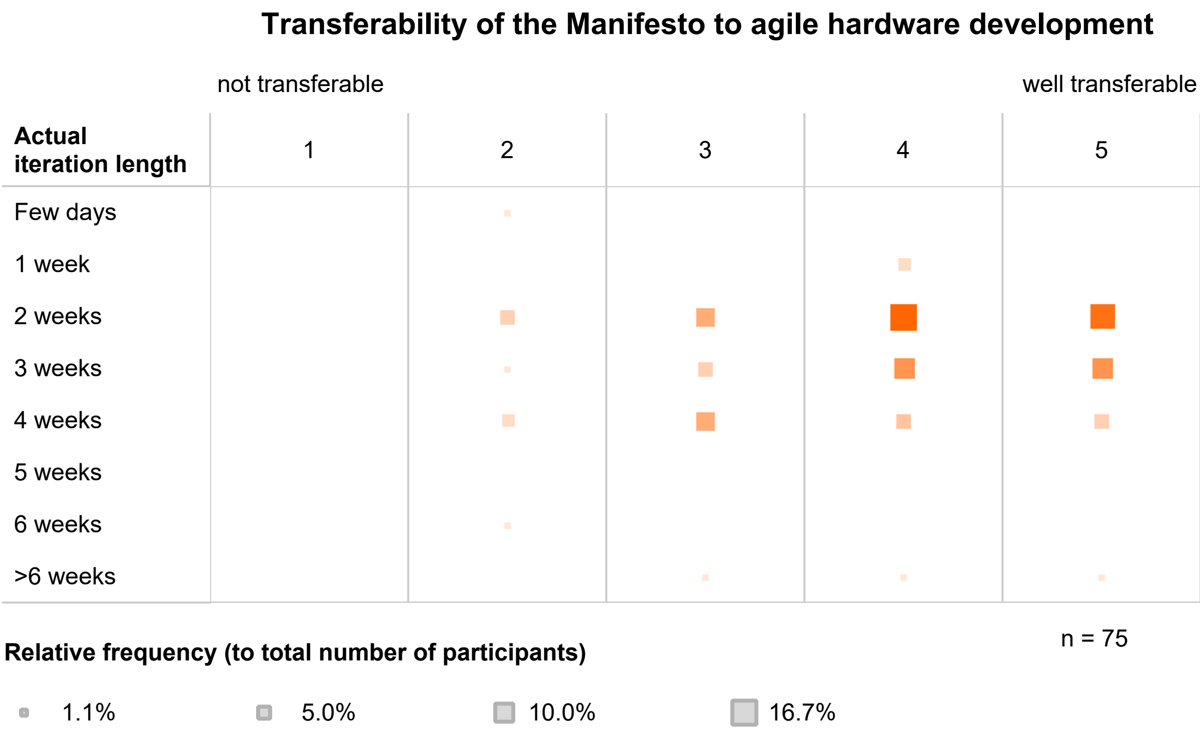

Figure 6.9.: Actual iteration length in contrast to the participants' transferability ratings concerning the Manifesto.

Description

Figure 6.9 represents the dependency between Manifesto transferability rating and the actual iteration length of the participants. The motivation for this analysis was to validate the following hypothesis: The more frequent the team can iterate, the easier it is to react to changes, the higher the transferability is rated.

Key learnings

- The participants that actually iterate in 2 weeks state the transferability to be 3.98 on average. Respectively: 3 weeks - 4.13; 4 weeks - 3.5
- No significant difference to the transferability ratings is recognizable.

Interpretation

- It could be possible that participants having a lower actual iteration length tend to higher transferability ratings. However, more data would be needed to prove that statistically.
- With the data at hand, it can be summarized that the iteration length and the transferability are invariant.

6.3. Teamwork

6.3.1. Types of Teamwork

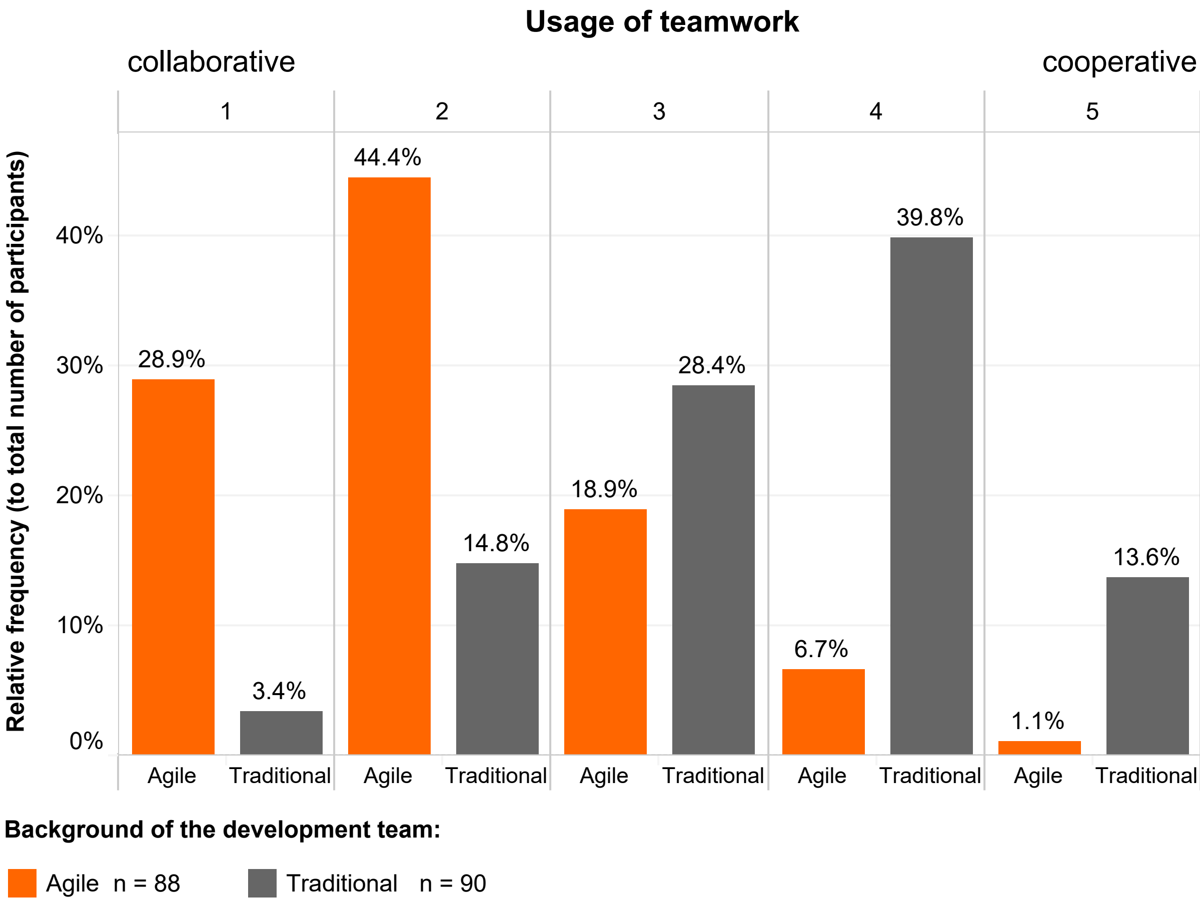

Figure 6.10.: Types of teamwork currently present in development teams of participating companies.

Description

Figure 6.10 shows the types of teamwork used by participating companies in traditional and agile development teams. The survey provided the participants a 5-point Likert scale reaching from cooperation (individual work packages) to collaboration (joint work packages) whereas the neutral position signifies a mixed use. The brief description of cooperation and collaboration (as written in the parentheses in the previous sentence) was given for both ends of the scale.

Key learnings

- In traditional development teams, cooperative teamwork is dominating. 73% of the respondents state that their teams rely on a cooperative or a rather cooperative teamwork.
- In agile development teams, collaborative teamwork is dominating. 54% of the respondents state that their teams work together in a collaborative or rather collaborative manner.

Interpretation

- Collaboration plays a crucial role in agile teams (as stated in the Manifesto (Beck et al. 2001)). However, the participants could be confused with differentiating between both kinds of teamwork.

⇒ Compared to last year, the importance of collaboration in agile teams increased significantly. Last year, about 46% of the respondents stated that their agile teams are based on cooperation, whereas 36% rely on collaboration.

⇒ In 2017, the respondents confirmed that collaboration is much more important than cooperation in agile development teams. This seems to take effect in the practical implementation because, today, there are much more agile teams collaborative or rather collaborative.

6.3.2. T- vs. I-shaped Staffing

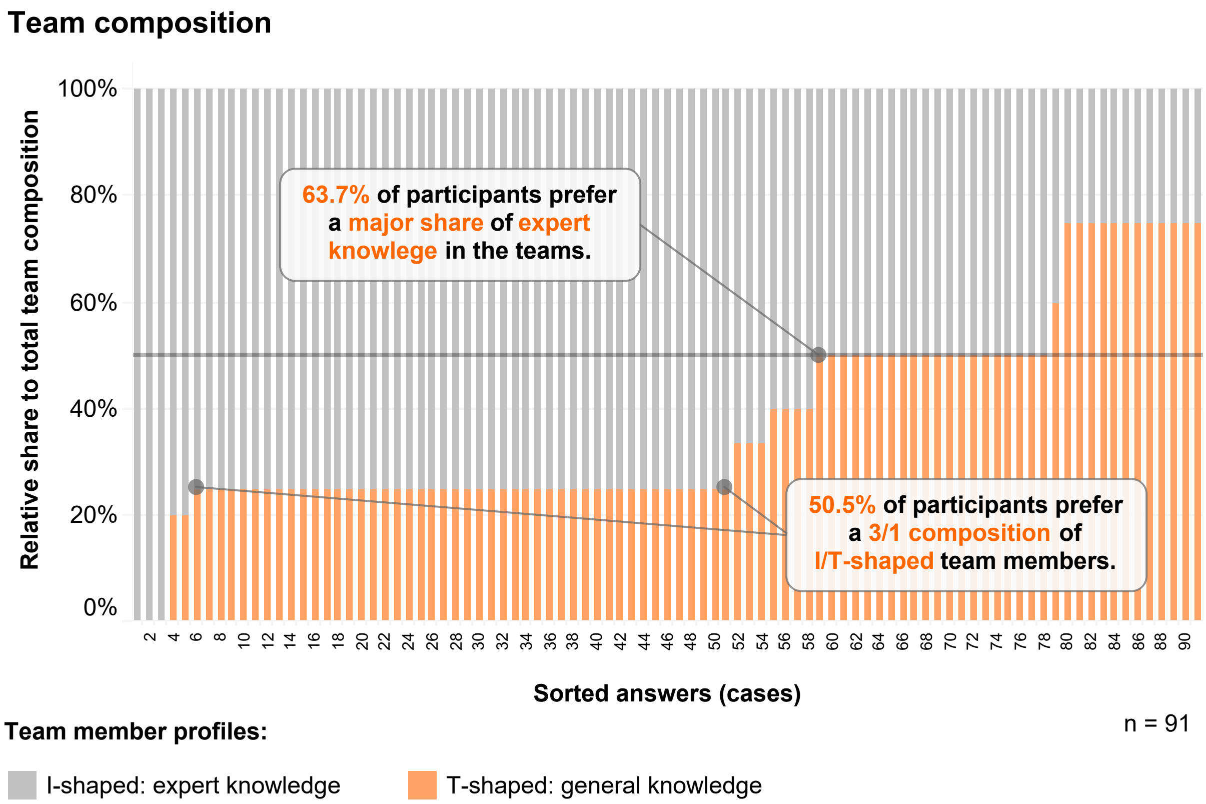

Figure 6.11.: Distribution of T- and I-shaped **employees** in product development teams of participating companies.

Description

The participants were asked to rate to which degree (0 - 100%) their agile hardware development teams consist of specialists (I-shaped, i.e. having a thorough expertise in a specific field) and generalists (T-shaped, i.e. having a broad knowledge in several fields). The concept of I- and T-shaped employees is borrowed from IDEO (Oskam 2009). The differences between I- and T-shaped employees were explained to the participants in the survey.

Key learnings

- Remarkably, the distributions have an opposing trend which signifies that the concept of specialists and generalists is contrary.
- 63.7% of participants prefer a major share of expert knowledge in the teams.
- 50.5% of participants prefer a 3/1 composition of I/T-shaped team members
- On the other hand, at least 1 out of 4 team members is a generalist.

Interpretation

- Agile development especially calls for generalists that can support each other in a collaborative manner, rather than in a cooperative manner (complementing). However, this is not common practice currently.
- One reasonable explanation attempt is the high degree of specialization necessary to build mechatronic products - mechanical engineers are commonly not experts in electrical or software engineering and vice versa - which explains the larger degree of I-shaped personnel.

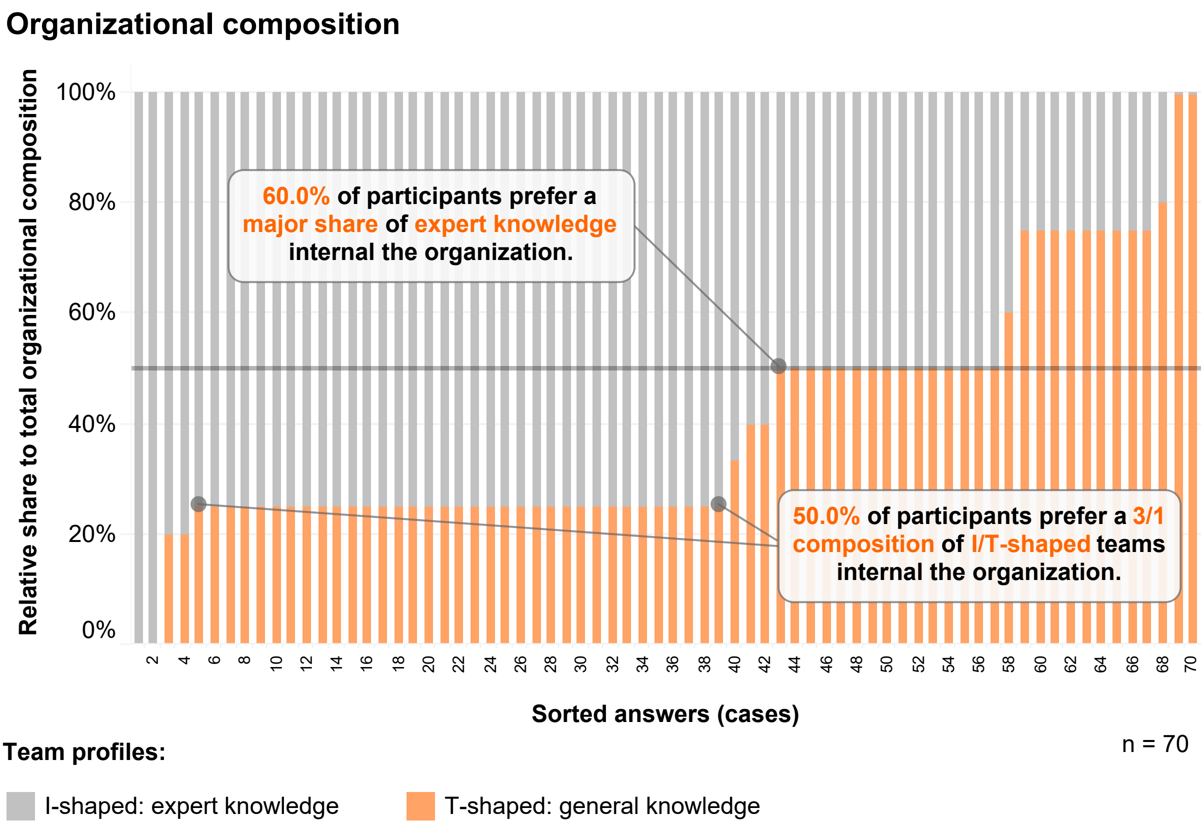

Figure 6.12.: Distribution of T- and I-shaped **teams** in participating companies.

Description

Analogously to Figure 6.11, the survey also dealt with I- and T-shaped characteristics among the teams. Thus, Figure 6.12 shows to which degree the agile project teams of participating companies are staffed with many experts (I-shaped team) or with many generalists (T-shaped team). The differences between I- and T-shaped employees were explained to the participants in the survey.

Key learnings

- Similarly to Figure 6.11, the distributions have an opposing trend which signifies that the concept of specialists and generalists is contrary.
- 60% of participants prefer a major share of expert knowledge internal the organization.
- 50% or participants prefer a 3/1 composition of I/T-shaped teams internal the organization.

Interpretation

- Interestingly, almost 20% of the participants mentioned that there are not enough teams inside the company to judge their composition - which corresponds with the agile transition levels of several participants not being at Level 3 yet.
- Analogously to Figure 6.11, the assumption of having a high degree of specialists necessary to build mechatronic products could also be alleged in order to explain the larger degree of I-shaped teams.

6.3.3. Workload

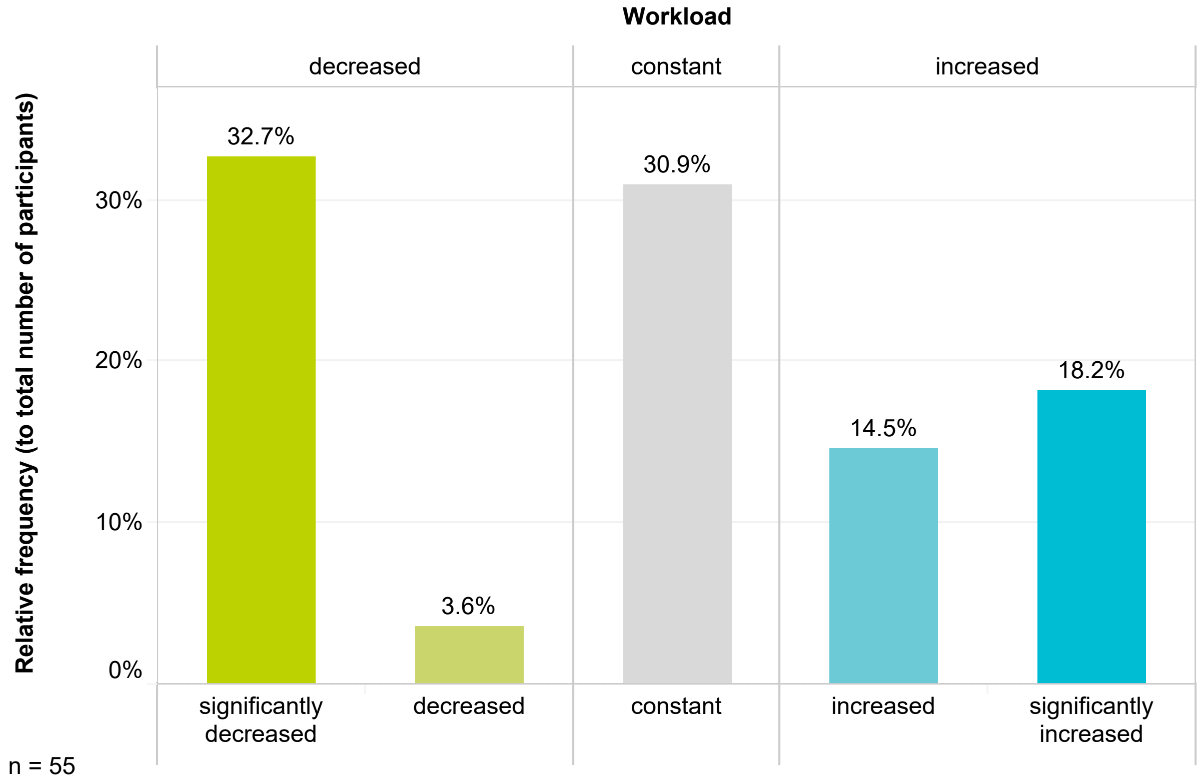

Figure 6.13.: Perceived workload change of participants due to the implementation of agile development.

Description
The participants were asked how their personal workload has been affected (changed) due to the roll-out of agile development. The particpants were able to give a max. of 3 statements regarding the resulting effects in a free-text field. The results have been textually analyzed and clustered into "significantly increased", "increased, but more pleasant", "constant", "more regular, thus decreased", "decreased". A total of 55 participants have contributed with their input.

Key learnings

- Around 1/3 stated, that their workload increased, 1/3 stated it stayed the same and the remaining third stated it (rather) diminished. The perception on how agile developments affects one's workload is very evenly distributed.
- From a different viewpoint, only 18% of the participants claim that agile development results in a higher (and thus more stressful) workload.

Interpretation
Given the qualitative nature of the answer, the following interpretations can be derived:

- Interestingly, the statements do vary greatly between the respondents, even throughout different transitional levels. No trend can be derived from the data at hand.
- Around 80% indicate that their workload is not affected in a negative way by having adopted agile development. 15% mentioned that even though the workload has increased, they perceive it as more pleasant.

Part IV.

Implications: So What

7. Summary and Final Remarks

Agile development of physical products is on the rise - and companies have high expectations regarding the benefits for their product development to ensure their competitive advantage. According to Gartner's hype cycle, agile development is still relatively immature for the use in the physical world, which has a significant impact on the motivation of application and thus on the importance and relevance of the methods (Schmidt, Weiss, and Paetzold 2018b). Not only changed ways of thinking in project management, but also adapting agile methods to the specific characteristic of physical product development are necessary in order to avoid failures or to exploit the potential of the methods. The goal of the study was to capture the current status of agile hardware development in the German-speaking region as of 2018. With this study being the second issue after last year's, comparisons to the results of 2017 (Schmidt, Weiss, and Paetzold 2018a) and consequently first trends are drawn to determine its further advancement. The present study provides a differentiated and neutral overview of the expectations and actual effects of agile methods for the development of physical products. The following key findings regarding the three main topics can be derived from the study:

Motivations: A shift in the understanding of agile developments in the course of maturing is recognizable – from fast, versatile, and lean to communicative, responsive, and beneficial. Moreover, the ability to quickly react to unforeseeable events, self-organization in the team in order to determine what the customer actually wants is associated with agile development. However, in order to being able to accomplish that, a certain mindset has to be established. In comparison to last year's study, this study shows that the expectations of agile development are almost overestimated in every aspect – with hard controlling KPI's (Quality, Cost, Time) being a lot more overestimated than soft factors such as commitment or transparency. Only in terms of communication, the expectations were slightly underestimated. This can be explained by an advancement on Gartner's hype cycle, with agile development of physical products spreading even deeper into the industry. In terms of the organizational challenges associated with agile hardware development, the assignment of highly specialized domain-specific personnel as well as the establishment of an agile mindset is seen as very critical. On the technical side, the realization of increments in one iteration and long-running processes hamper agile development. Shifting to conflicts, which arise due to the implementation of agile development inside a company, the so-called *prince problem* comes into play – meaning the loss of power and control of executives due to a flattening hierarchy.

Transition: Agile hardware development is still diffusing and cannot be considered a standard approach. Around 80% of the participants have stated that they are engaged in agile hardware development at least for one year, close to 50% for three years or more. Most companies get into agile hardware development through experiences in the software. Thus, agility as a concept is not new for them, they simply need to apply it in another department with different contextual boundaries. As of today, most projects are still executed in a traditional way. Only 8% have stated that they carry out almost all of their projects in an agile manner. The current share of hybrid approaches is very low, at around 15%. When comparing the state of projects to be carried out in an agile manner as of today, the current share is about 20%, with a rise to about 40% – 50% in the next 3 to 5 years.

The understanding of the term scaling is relatively fuzzy, with most companies referring to it as spreading agility across several branches inside the R&D departments. The most common approach used when scaling is SAFe, yet a large share is unsure whether or not to scale in the future.

Applicability: With this survey focusing on mechatronic products, participants state that around 2/3 of the products to be developed have a physical share (containing of tangible components, in contrast to software) of more than 50%. Products containing a higher software share, however, are further in adapting the concept of agility in their development. With the Agile Manifesto building the foundation of agile development, the translation of its values and core principles is rated high, as last year, with an increase when maturing. Obstacles which hinder the translation from software to hardware can be grouped into technical aspects, such as the creation of prototypes and external dependencies, and organizational aspects which are company-related, such as the company culture and its associated structure. The creation of a prototype in a 2-week sprint is also seen as challenging, yet it is the most common iteration length both used and desired. The types of teamwork are opposed, with a rather collaborative teamwork in agile teams in contrast to rather cooperating type of teamwork in traditional teams.

It can be concluded that agile development of physical products provides significant advantages for solving complex development tasks. As already stated last year, there is a need for action to adapt agile methods to the specifics of physical products, especially in terms of the challenges arising due to the hardware context.

With the benefits of the agile development of physical products being overestimated in almost every aspect, exaggerated expectations entail the risk that - if goals are not achieved - the application of agility will be discarded. This would neglect a considerable potential for product development. The editors of this study hope to clarify the performance potential of agile methods for physical product development with the differentiated consideration regarding the benefits, challenges, conflicts, and the evolution over time with the transitional level model. There is a clear interest in the agile development of physical products from practice, yet it needs further investigation and methodical support to overcome the current challenges for a successful implementation.

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Part V.

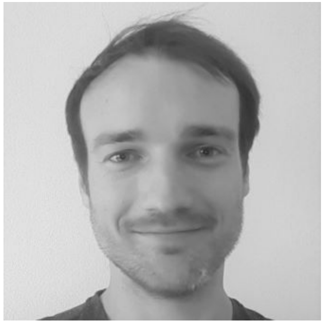
Appendix: Who We Are and How We Did It

8. About the Author Team

M.Sc. Tobias Sebastian Schmidt (ITPE) has studied mechanical engineering and engineering management in Germany, Finland and Sweden, and graduated with a Master of Science at the Technical University of Hamburg. Fascinated by innovation and new product development, he started a Ph.D. in agile hardware development at the University of the German Federal Armed Forces Munich in 2015. At the Institute of Technical Product Development (ITPE), he investigates how - and to which degree - agile development approaches can be transferred from software development to the development of physical products such as mechatronic systems. In his research, he focuses especially on prototyping and the so-called constraints of physicality. In this context, he has published several research papers and has given talks on international conferences about the challenges and potential solutions.

M.Sc. Alexander Atzberger (ITPE) has studied electrical engineering at the University of the German Federal Armed Forces, and graduated with a Master of Science. He started his Ph.D. at the ITPE in the field of agile hardware development in 2018. Working in the same area as Tobias, his research interests are in the further advancement of agile methods in order to make them applicable for the development of physical products. As stated in last and also this year's study, the methods currently used in agile hardware development are Scrum, Kanban & Co., which have originally been developed for and in the software environment. In this respect, he investigates which hindrances and shortcomings of those methods exist and thus, how they need to be aligned for the context of mechatronic or cyber-physical systems.

M.Sc. Christoph Gerling (ITPE) has studied aerospace as well as technology and management at the Technical University Munich in Germany, and graduated with a Master of Science. He worked in consultancy in the field of systems engineering and in a startup company creating a search funnel and building up a scalable e-commerce platform. Interested in service design and team mechanisms, he started a Ph.D. in agile project management at the University of the German Federal Armed Forces Munich in 2019. At the Institute of Technical Product Development (ITPE), he investigates on how new management styles following the idea of libertarian partialism can lead to more efficient project management in agile product development. In this respect, he focuses on choice architectures.



M.Sc. Julian Immanuel Schrof (ITPE) has studied industrial engineering in Germany and Chile, and graduated with a Master of Science at the Karlsruhe Institute of Technology (KIT). After working in an automotive start-up for two years, he started a Ph.D. in agile automotive product development at the University of the German Federal Armed Forces Munich in cooperation with the BMW group in 2017. He investigates how agile benefits can be obtained in industrial contexts and researches how organizational structures have to be adapted in order to transform these benefits into a competitive advantage. His current research focuses on the technological enablement in the context of agile product development.

Dr.-Ing. Stefan Weiss (AGENSIS Management Consultants) is Partner and cofounder of AGENSIS management consultants. Dr. Weiss has more than 20 years of professional experience in R&D Management and the design of holistic product development systems. He worked with numerous national and international clients and project teams from automotive, electronic, automation and consumer industry. In his work, he pioneered and applied the concepts of agile and lean development to R&D improvement programs for physical product development. In recent years, he is co-authoring several publications concerning lean and agile development. He has a profound industrial experience from different positions in R&D organizations of automotive and consumer industries. He graduated at Karlsruhe Institute of Technology (Germany) with a diploma in chemical engineering followed by a doctorate in material sciences.

Prof. Dr.-Ing. Kristin Paetzold (ITPE) is head of the Institute of Technical Product Development at the Faculty of Aerospace Engineering at the University of the German Federal Armed Forces. After completing her doctorate, Dr. Paetzold worked as a senior engineer at the Chair of Design Engineering at the University of Erlangen, focusing on research in the fields of mechatronics especially in supporting and optimization of development processes. There she started to set up a working group dealing with challenges in describing, analyzing and optimizing development processes based on data and information flows. With becoming a full professor at the University of the German Armed Forces in 2009, the research focus has expanded to include systems engineering. She is involved in the VDI department of product development and mechatronics and is also Co-Chair of the SIG "Human Behavior in Design" of the Design Society.

9. Survey Design and Execution

Survey Design

Motivated by capturing the current state of agile hardware development in industry, the author team designed a questionnaire that was published as an online survey. The survey design based on experience from industrial projects and research, which the cooperation partners provided to the study team.

The survey included 31 questions, which were divided into nine sections as listed in Table 9.1. The first section was about demographics in order to find out who participated concerning key characteristics such as industry affiliation, company size, and focus of work. Section two dealt with the company and individual experiences, i.e., methods used, time of engagement, and implementation progress. At the end of this section, the participants were asked to tick those topics of section three that they were able to contribute the most to based on their experience. Depending on their choice, subsequent sections were activated accordingly so that only these questions were shown to them. Section four concludes the survey.

Focusing on the participants areas of interests is a special feature of the survey. It ensures both a high attractiveness for the participant and a high chance to achieve statistically valid answers because less participants answer randomly (e.g., because they are not interested in the particular question). For the undecided, there was the option to choose „Everything“ or „Surprise me“ . Besides that, the survey was also time boxed, again, to increase the participants attractiveness. Knowing that the survey will be finished by a pre-defined time offers an incentive

Table 9.1.: Survey design.

ID		Section	Content
1		Demographics	Industry affiliation, company size, R&D size, and focus of work
2		Experiences	Personal time of engagement, methods used, implementation progress, product composition, and areas of interest
3		**Areas of interest**	
	i	Conflicts	Expected or actual conflicts
	ii	Challenges	Expected or actual challenges
	iii	Value	Expected or actual value
	iv	Teamwork	Type of teamwork, division of work within team, division of work among teams, and workload
	v	Roll-out	Share of agile projects, future commitment, scaling connotation, scaling frameworks used, and scaling challenges
	vi	Transferability	Transferability of Manifesto, constraints of physicality, actual and intended iteration length
	vii	Conception	Associations and agreement to hypotheses
4		Final notes	Thanks, contacts, offers, and interest in future contribution

to practitioners who are constrained by their daily business. Two time boxes, 10 and 20 min, were provided and needed to be selected beforehand. As soon as the countdown expired, the participants were asked whether to continue or to jump to section four. The questions were designed in different formatting types, being either in the Yes/No-format, approval scales (1-5 Likert scale) or as free text. Which question format was used is also shown, where necessary, in the graphs or text of Part III. Through the online process, the order of answer options was randomized for each participant in order to avoid desirability biases that could be caused by pre-ordered answer options.

Differentiation between beginners and experienced participants

In order to be able to distinguish between beginners (those who just started with agile development) and advanced participants (having gained knowledge due to dealing with agile development for a certain amount of time already), an initial question was used to distinguish these two groups. The participants were asked to rate their implementation status of agile development on a scale of “not started“, “started“, “midcourse“, “advanced“, “completed“(or *N/A*, which was then excluded for the further distinction.) They were asked to rank five levels of implementation progress, starting with Level 1 being “First piloting in a product development project“, Level 2 being “Piloting in several product development projects“. Level 1 and 2 correspond to piloting on the project level, whereas Level 3 and 4 deal with the roll-out inside the R&D department. Level 3 refers to the “Roll-out within a single product development“ and Level 4 to “Roll-out across multiple product development projects“. Level 5 being the top of the agile transition refers to the “Roll-out to departments other than R&D“.
Each of the five levels had to be rated on the aforementioned scale, with “not started“ counting as “1“, ranging to “completed“ counting as “5“. The values of all five levels are summed up per participant and if the sum is greater than 10 (of max. 25), the participant is classified as “experienced“, if it was less or equal than 10, they were added to the group of “beginners“. As beginners who just started in the field of agile hardware development cannot evaluate the actual effects due to a lack of experience, questions regarding the actual values were only visible for people of the “experienced“ group, whereas questions regarding the expected effects were only visible for “beginners“.

Degree of physicality

The degree of physicality represents the amount of tangibility of a product and has been come up with by the authors in order to explain the possible constraints arising due to a high physicality of a product. The physicality index is calculated by the tangible share of the product divided by the sum of both tangible and virtual share:

$$PI[] = \frac{(M+E) + \frac{1}{2} * ES}{((M+E) + \frac{1}{2} * ES) + (\frac{1}{2} * ES + SW)} = \frac{Tangible\ share}{Tangible + Virtual\ share} \tag{9.1}$$

with: **PI** = Physicality index, **M** + **E** = Physical components (Mechanics + Electronics), **ES** = Embedded Software, **SW** = Standalone Software

Embedded Software is halved and added to both shares since it consists of Tangible and Virtual components. Of course, this is just a rough estimate, yet appeared to be the most reasonable approach to the authors.

Survey Distribution

The survey link was distributed via email to personal contacts (reach of about 1,400), in Xing and LinkedIn groups (reach of about 10,000), and via the VDI monthly newsletter (reach of about 16,000). In total, about 27,000 persons were invited to contribute to the survey. In the end, 187 responses were found to be valid that form the basis for the analysis undertaken in Part III. Please note that due to the areas of interest selection and partially incomplete answers the total number of participants per analysis differs. The participants responded voluntarily and without assistance from the author team. To prevent translation biases, the survey was written in German to attract only participants from the German-speaking countries (Germany, Austria, Switzerland). The survey was online between September and December 2018.

About the Organizations

Institute of Technical Product Development: The research activities at ITPE focus on mastering complex socio-technical systems. For the description of complex technical systems, methods for the context-specific use of MBSE must be developed, which represent both product structures and process-driven information flows in the development processes. At the same time, classical process analysis approaches are coupled with methods of network theory in order to understand and analyze data and information flows within the company. The method linkage serves not only to optimize IT structures but also to support communication and collaboration processes in development. The increasingly dynamic environment for development makes it necessary to embed stronger aspects of adaptability and flexibility in product development. For this, agile methods prove to be an adequate solution and are therefore the focus of research activities.

AGENSIS Management Consultants: Founded 2002 in Munich (Germany), AGENSIS is dedicated to optimize product development systems and R&D Management. The customer portfolio built up over the years includes both global players and mid-sized companies, each with a strong technology and engineering focus. AGENSIS supports its clients with its unique knowledge and a specialized tool-set based on the lean development and agile development concepts and methods. Our experienced teams cover and support all domains of mechanic, mechatronic and software development and the corresponding process areas of project management, purchasing, sales and manufacturing. In our projects we advise and accompany both the workforce and the management of our clients towards the analysis of the status quo and the change transition to a more efficient and high competitive product innovator and technology leader. Aiming at excellence is our stimulus to focus our clients on sustainable values in product development.

Agile Development of Physical Products

More and more companies feel confronted with rising volatility, uncertainty, complexity, and ambiguity (VUCA) in their development of physical products. To encounter such environments, they try to become more agile. However, many myths, misunderstandings, and misinterpretations exist in agile hardware development. This empirical study sheds light on companies' potentials (expected versus actual improvements and challenges through agile hardware development), transition, and the concept's applicability in hardware development. It provides quantitative facts by means of scientific methods.

In collaboration with:

Institut für Technische Produktentwicklung

AGENSIS MANAGEMENT CONSULTANTS

Universität der Bundeswehr München

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