

Implementing lean and agile project management in low maturity technical organizations

Egas Guimarães Marçal

Master Dissertation

Supervisors:

Prof. Dr. Marcus Vinicius Pereira Pessôa, Faculty of Engineering Technology, University of Twente, The Netherlands.

Prof. Dra. Maria Teresa Galvão Dias, Faculty of Engineering, University of Porto, Portugal.



Master in Mechanical Engineering

2022-07-27

To my family, friends, and professors, without whom this work would not be possible.

Resumo

Atualmente, as pequenas e médias empresas ainda enfrentam um conjunto considerável de problemas que afetam os seus projetos de desenvolvimento de produto e, consequentemente, atrasam o estabelecimento e proliferação das empresas no mercado. Alguns destes problemas são o financiamento reduzido, falta de competências técnicas e de gestão dos empregados, e dificuldade em cumprir um conjunto alargado de normas e regulamentos. De forma a garantir sustentabilidade a longo prazo, as empresas de baixa maturidade devem ser capazes de gerir os seus projetos de desenvolvimento de produto nos cada vez mais dinâmicos e imprevisíveis ambientes atuais. Nestes, as mudanças no mercado e os requisitos e exigências dos clientes são progressivamente mais complexos. Portanto, as pequenas e médias empresas devem adotar estratégias de gestão, tais como a gestão de projetos lean e ágil, que sejam capazes de otimizar a eficiência do ciclo de desenvolvimento do produto, fornecer rapidamente valor ao cliente, criar e disseminar conhecimento pelos empregados, e adaptar a empresa a requisitos variáveis dos clientes e produtos.

Esta dissertação foca-se na criação de um método de diagnóstico para determinar a extensão com que pequenas e médias empresas estão a tirar proveito dos principais benefícios de técnicas e ferramentas dos métodos de gestão de projeto lean e ágil. O método de avaliação proposto é composto por um conjunto de questões de resposta aberta e fechada perguntadas a um membro de cada uma das empresas durante entrevistas presenciais. O método sugerido também inclui um momento de observação direta, no qual as práticas das empresas são fotografadas e documentadas. As empresas analisadas são 3 organizações estudantis não lucrativas e uma geradora de start-ups, que também funciona como empresa prestadora de serviços. Todas as 4 empresas encontram-se sediadas na cidade de Enschede, na região de Twente, nos Países Baixos. Para cada empresa e para cada um dos principais benefícios, feedback e recomendações são dados. As recomendações são técnicas e ferramentas dos métodos de gestão de projeto lean e ágil.

Foi concluído que as 4 empresas dos casos de estudo já tiram vantagem dos benefícios dos métodos lean e ágil durante a gestão das suas atividades de desenvolvimento a um nível bastante razoável. As empresas conseguem-no ao implementar práticas específicas dos métodos de gestão de projeto lean e ágil, suas adaptações ou práticas semelhantes. No entanto, as 4 empresas ainda têm algum espaço para melhorar, o que pode ser conseguido se as recomendações propostas forem seguidas.

O método de diagnóstico sugerido provou ser bastante eficaz, uma vez que foi capaz de recolher a informação necessária para avaliar as empresas relativamente aos benefícios das técnicas e ferramentas dos métodos de gestão de projeto lean e ágil de uma forma rápida e prática. Os entrevistados sempre demonstraram grande entusiasmo e motivação durante a realização das entrevistas. Diferentes técnicas e ferramentas foram, de facto, detetadas em todas as 4 empresas. Pequenos ajustes no método de diagnóstico proposto terão de ser feitos em trabalhos futuros.

Implementing lean and agile project management in low maturity technical organizations

Abstract

At present, small and medium-sized enterprises face a considerable number of problems that hinder their product development projects and ultimately jeopardize the thriving in the industrial global market. Such issues include limited financing, lack of management and technical skills of employees, and difficulties in complying with a multitude of regulations. Consequently, the call for low maturity technical organizations to adequately manage their product development projects in today's increasingly dynamic and unpredictable environment is essential for long term sustainability, as market changes and stakeholders' requirements become more and more complex. Small and medium-sized enterprises must adopt management strategies, such as agile project management and lean project management, which are capable of optimizing the efficiency of the product's development cycle, quickly delivering value to the clients, creating and spreading knowledge amongst employees, and adequately adapting the company to changing customer/product requirements.

This dissertation focuses on the creation of an assessment methodology to determine the extent to which low maturity technical organizations are reaping the main benefits of specific tools and techniques of agile and lean project management approaches. The proposed evaluation method is composed of a mix of close and open-ended questions asked in face-to-face interviews held with one member of each company. The suggested method also comprises a direct observation moment, in which practices are documented and photographed. The case study businesses are 3 non-profit student-led organizations and a start-up generator/service provision corporation. All firms are based in the city of Enschede, in the region of Twente, in The Netherlands. For each company and for each core benefit feedback and recommendations are given. The recommendations are specific lean and agile project management tools/techniques.

It was concluded that the 4 companies from the case studies are already taking advantage of the benefits of lean and agile during the management of their development activities in a reasonable extent. They do it by implementing specific lean and agile project management tools/techniques, adapting them, or doing similar practices. Nonetheless, the 4 firms still have a considerable room for improvement, which can be fulfilled if they adopt the set of recommended actions.

The proposed assessment tool proved to be quite effective since it was able to retrieve the necessary information to assess the companies on the main benefits of lean and agile project management tools/techniques in a quick and practical way. Respondents always displayed great enthusiasm and motivation over the course of the interviews. Several different agile and lean project management tools/techniques were indeed detected in all 4 companies. Small adjustments in the suggested assessment tool will have to be made in future works.

Acknowledgments

Words cannot express my gratitude to Prof. Dr. Marcus Vinicius Pereira Pessôa, my supervisor at the Faculty of Engineering Technology of University of Twente, for his invaluable patience and feedback throughout the 5 months that were necessary to complete this Master thesis. I also could not have undertaken this journey without my thesis supervisor at the Faculty of Engineering of University of Porto, Prof. Dra. Maria Teresa Galvão Dias, who generously provided knowledge and expertise. Additionally, this endeavor would not have been possible without the generous support from the Erasmus+ Program and Dutch Ministry of Finance, who have financed my research and stay in the Netherlands, respectively.

I would like to express my deepest gratitude to all members of Green Team Twente, Drone Team Twente, Electric Superbike Twente, and Game Lab Oost who contributed to my research. These individuals' time availability to establish face-to-face conversations with me and their openness in sharing information about the companies they work for were deeply appreciated.

I am also thankful to Prof. Catarina Rosa Santos Ferreira de Castro, Prof. Manuel Augusto de Pina Marques, and Prof. João Pedro Gomes Moreira Pêgo, from the Faculty of Engineering of University of Porto for their contribution in the exhaustive bureaucratic process that was required for me to do the Master thesis in The Netherlands. Many thanks to all the secretariat's personnel from the University of Twente and University of Porto who assisted me throughout the entirety of the exchange semester.

Lastly, I would be remiss in not mentioning my family, especially my parents, brother, and grandparents. Their belief in me has kept my spirits and motivation high during the process.

Contents

1. Introduction	1
1.1 Low maturity technical organizations	1
1.2 Thesis objective	3
1.3 Research methodology	3
1.4 Thesis structure	4
2. Literature study	5
2.1 Management approaches of product development projects	5
2.2 Definition, tools, and techniques of APM	6
2.3 Definition, tools, and techniques of LPM	11
2.4 APM and LPM diagnostic tools	13
3. Proposed APM and LPM diagnostic tool	16
3.1 Interpretation of APM tools and techniques	16
3.2 Interpretation of LPM tools and techniques	18
3.3 Explanation of the diagnosis instrument	21
3.3.1 Detailed guideline questionnaire	24
4. Case studies	27
4.1 Green Team Twente	27
4.2 Drone Team Twente	32
4.3 Electric Superbike Twente	35
4.4 Game Lab Oost	39
5. Discussion	43
5.1 Diagnosis assessment and recommendations for Green Team Twente	43
5.2 Diagnosis assessment and recommendations for Drone Team Twente	45
5.3 Diagnosis assessment and recommendations for Electric Superbike Twente	46
5.4 Diagnosis assessment and recommendations for Game Lab Oost	48
5.5 Reflection about the proposed diagnosis assessment instrument	50
6. Conclusions	52
6.1 Recommendations and future work	53
References	54
Appendix A – APM/LPM assessment tools found in the literature	60
Appendix B – Simplified version of the guideline questionnaire	62
Appendix C – Future Factory	64
Appendix D – Green Team Twente	66
Appendix E – Drone Team Twente	72
Appendix F – Electric Superbike Twente	78
Appendix G – Game Lab Oost	83

Acronyms

2D – 2-Dimensional.
3D – 3-Dimensional.
5S – Sort, Set in order, Shine, Standardize, Sustain.
APM – Agile Project Management.
CAD – Computer-Aided Design.
CAE – Computer-Aided Engineering.
CATIA – Computer-Aided Three-dimensional Interactive Application.
CE – Chief Engineering.
CFD – Computational Fluid Dynamics.
CV – Curriculum Vitae.
DMU – Digital MockUp.
DRM – Design Research Methodology.
DTT – Drone Team Twente.
DUT – Delft University of Technology.
EU – European Union.
FEA – Finite Element Analysis.
FEM – Finite Element Method.
FHR – Forze Hydrogen Racing.
GLO – Game Lab Oost.
GTT – Green Team Twente.
HR – Human Resources.
HUD – Heads-Up Display.
iMechE – institution of Mechanical Engineers.
LPM – Lean Project Management.
MarCom – Marketing & Communication.
MBD – MultiBody Dynamics.
OEA – Operational Excellence Assessment.
PD – Product Development.
PLA – PolyLactic Acid.
PM – Project Management.
PPP – Principles, Processes, Practices.
SBCE – Set-Based Concurrent Engineering.
SME – Small and Medium-sized Enterprises.
SUAS – Saxion University of Applied Sciences.
UAS – Unmanned Aerial System.
UAV – Unmanned Aerial Vehicle.
UI – User Interaction.
UT – University of Twente.
UX – User Experience.
XP – eXtreme Programming.
XR – eXtended Reality.

List of Figures

- Figure 1 – Number and distribution of SME in the EU between 2008 and 2021.
- Figure 2 – Steps of the product development project.
- Figure 3 – Scrum overview.
- Figure 4 – Overview of the proposed assessment tool.
- Figure 5 – Student-led organizations based in the Future Factory.
- Figure 6 – 2011/2012 GTT team (left) and the car developed by them (right).
- Figure 7 – Similarities between the chassis of the 2015 (left) and 2016 (right) car models.
- Figure 8 – GTT team of the academic year 2021/2022 together with the previous year's car model (left), and the firm's logo prior to and since 2017 (right, top and bottom, respectively).
- Figure 9 – Functional structure of GTT, which has 3 sub-teams.
- Figure 10 – DTT logo (left, top), the 2021/2022 team (left, bottom), and the drone developed by them (right).
- Figure 11 – Functional structure of DTT, which has 3 sub-teams.
- Figure 12 – Some of the drone requirements set by the yearly iMechE UAS competition.
- Figure 13 – DTT usage of Miro platform.
- Figure 14 – EST logo (left) and a few of the educational backgrounds of the 2021/2022 team (right).
- Figure 15 – Functional structure of EST, which has 4 sub-teams.
- Figure 16 – 2021/2022 EST team and the motorcycles developed in the 2 previous academic years (left) and the most important specifications of EST motorbikes (right).
- Figure 17 – EST usage of ClickUp digital application.
- Figure 18 – The GLO logo (left) and the 3 stages of the company's development cycle (right).
- Figure 19 – GTT diagnostic assessment results.
- Figure 20 – DTT diagnostic assessment results.
- Figure 21 – EST diagnostic assessment results.
- Figure 22 – GLO diagnostic assessment results.
- Figure C1 – Exterior view of the Future Factory.
- Figure C2 – One of the workspaces shared by the 5 companies based in the Future Factory.
- Figure C3 – Meeting room used by the firms established in the Future Factory.
- Figure C4 – Meeting room used by the firms established in the Future Factory.
- Figure C5 – Meeting room used by the firms established in the Future Factory.
- Figure D1 – One of the exclusive working spaces of GTT.
- Figure D2 – Overview of the Wikipedia used by GTT.
- Figure D3 – Partially completed technical plan of GTT.
- Figure D4 – One of the white boards used by GTT to display information.
- Figure D5 – Online boards utilized by GTT management and technical sub-teams to track the progress of activities.
- Figure D6 – Sticky notes utilized by GTT technical sub-team to track the progress of activities.
- Figure E1 – Overview of the Google Drive database used by DTT.
- Figure E2 – File of the DTT Google Drive database dedicated to the team manager.
- Figure E3 – File of the DTT Google Drive database dedicated to the structural designer.
- Figure E4 – One of the exclusive working spaces of DTT.
- Figure E5 – One of the exclusive working spaces of DTT.
- Figure E6 – Plan developed by DTT at the beginning of the development cycle.
- Figure E7 – Major tasks, events, and milestones of the DTT development cycle.
- Figure E8 – Tasks assigned to each DTT sub-team.
- Figure E9 – Representation and evaluation of individual tasks at DTT.
- Figure E10 – Area where DTT conducts semiweekly meetings.
- Figure E11 – Some of the 3D printers used by DTT.
- Figure F1 – One of EST exclusive working spaces.

Figure F2 – One of EST exclusive working spaces.

Figure F3 – Sticky notes used by EST until November 2021.

Figure F4 – White board used by EST to convey general information about the development process.

Figure F5 – Major tasks, events, and milestones of the EST chassis sub-team.

Figure F6 – Status of the activities assigned to the EST chassis sub-team.

Figure F7 – Individual reflection done by EST team members through ClickUp digital app.

Figure G1 – Building where GLO is based in.

Figure G2 – Workspace shared by all companies based in the GLO building.

Figure G3 – Workspace shared by all companies based in the GLO building.

Figure G4 – Workspace shared by all companies based in the GLO building.

Figure G5 – GLO exclusive working space.

Figure G6 – Tex Town Games' exclusive working space.

List of Tables

Table 1 – Subcategories of low maturity technical organizations.

Table 2 – Differences between traditional, agile, and lean PD project management methods.

Table 3 – APM tools and techniques currently being employed in companies.

Table 4 – LPM tools and techniques currently being employed in companies.

Table 5 – APM and LPM diagnostic tools found in the literature.

Table 6 – Description and main benefits of the APM tools and techniques found in the literature.

Table 7 – Description and main benefits of the LPM tools and techniques found in the literature.

Table 8 – General part of the proposed guideline questionnaire.

Table 9 – Specific part of the proposed guideline questionnaire.

Table 10 – Work functions at GLO.

Table 11 – Content of the GLO design document.

Table 12 – Capacity of the proposed assessment method to detect LPM tools/techniques in the 4 case study companies (Grey cells: no detection; Green cells: detection and similarity with the definition).

Table 13 – Capacity of the proposed assessment method to detect APM tools/techniques in the 4 case study companies (Grey cells: no detection; Green cells: detection and similarity with the definition).

Table A1 – Description of the APM/LPM assessment tools found in the literature.

Table B1 – Simplified version of the guideline questionnaire.

Table D1 – Explanation about each working function of GTT.

Table D2 – List of all GTT partner companies.

Table E1 – Explanation about each working function of DTT.

Table E2 – List of all DTT partner companies.

Table F1 – Explanation about each working function of EST.

Table F2 – List of all EST partners.

Table G1 – Explanation about each working function of GLO.

1. Introduction

This thesis is focused on developing a diagnostic tool to assess the extent to which low maturity technical organizations are taking advantage of the benefits of agile project management (APM) and lean project management (LPM) tools and techniques. The diagnosis instrument, which is also aimed at understanding what specific APM & LPM tools and techniques can be done to better align such companies with lean and agile principles, is practically applied to several firms, such as a start-up and 3 student-led organizations, all based in the city of Enschede in the region of Twente (Netherlands). This chapter presents not only the definition of a low maturity technical organization, but also the thesis' objective, research methodology, and structure.

1.1 Low maturity technical organizations

The maturity of a company is a measure of its ability to adapt to the environment, to learn, to improve results and economic and/or social performance (Güell, 2020). According to the European Commission (2019), a company's maturity level is assessed having into account 3 different criteria: staff headcount, annual turnover, and annual balance sheet total. These authors advocate that a corporation is considered having low maturity if employs fewer than 250 persons and has either an annual turnover not exceeding € 50 million or an annual balance sheet total not surpassing € 43 million. This type of companies can be further divided into medium-sized, small, or micro enterprises, considering certain value thresholds for the criteria previously mentioned. Such subcategorization is presented in Table 1.

Table 1 – Subcategories of low maturity technical organizations (European Commission, 2019).

Enterprise category	Staff headcount	Annual turnover	Annual balance sheet total
Medium-sized	<250	≤ € 50 million	≤ € 43 million
Small	<50	≤ € 10 million	≤ € 10 million
Micro	<10	≤ € 2 million	≤ € 2 million

The research conducted by Clark (2021) asserted that there are approximately 22.6 million low maturity technical organizations or small and medium-sized enterprises (SME) in the European Union (EU) as of 2021. Out of these, 21.1 million are micro companies, 1.3 million small firms and 200 000 medium-sized corporations. Figure 1 not only shows that the total number of SME in the EU has been slightly increasing since 2008, but also that the majority of SME over the 14-year period are in fact micro companies. Overall, SME account for 99.8% of the total number of enterprises in the EU (Velthuisen et al, 2018).

In accordance with Clark (2021), SME are an important part of the European economy, but their value in each country varies quite significantly. For the EU, the average value that SME contribute to the economy is around 56%, which corresponds to about € 4030 billions of value added (Velthuisen et al, 2018; Clark, 2021). Furthermore, in 2021, SME in the EU employed

almost 84 million people (Clark, 2021), which accounts for approximately 67% of the total employment in the geographic area (Velthuisen et al, 2018).

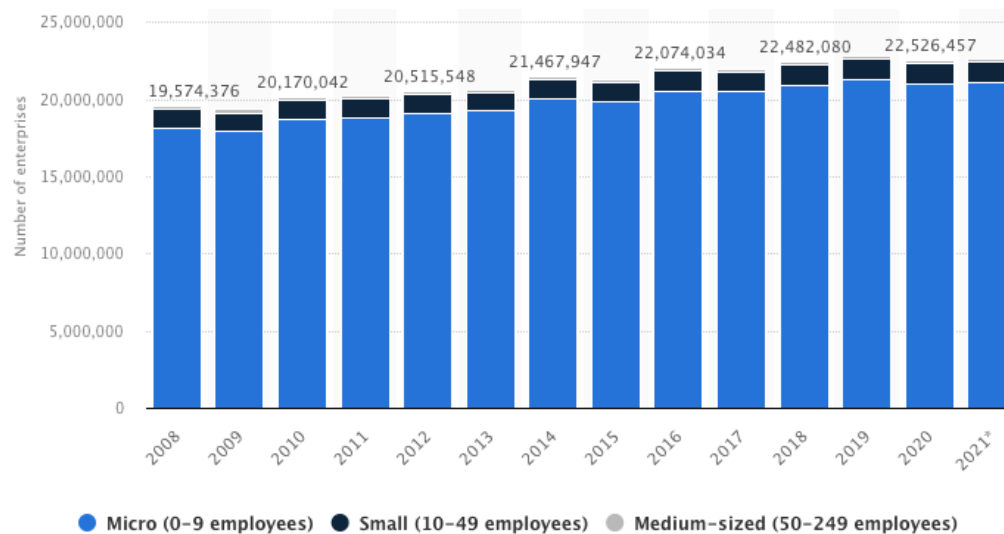


Figure 1 – Number and distribution of SME in the EU between 2008 and 2021 (Clark, 2021).

Startups are entrepreneurial and highly innovative companies who want to successfully bring their product or service to the market (Braak, 2018). Scott & Bruce (1987) indicate that the managers of startups are normally also their owners, capital is provided through external funding, the company's ownership is held by an individual or small group of people and the area of operations is local. Even though startups fall within the definition of an SME in terms of size, they have distinctive characteristics, such as (Kollmann et al, 2017):

- Startups are younger than 10 years old.
- Startups feature (highly) innovative technologies and/or business models.
- Startups have (strive for) significant employee and/or sales growth.

While the business models and products/services of all the other SME exist primarily to secure the livelihood of the founders and employees without any substantial growth perspective, startups are young undertakings specifically built to create wealth and innovation (Kollmann et al, 2017; Aronsson, 2004). According to Kollmann et al (2017), most startups in Europe are independent venture creations (73.3%), followed by spin-offs from a university or company (9.7% and 9.6%, respectively).

Compared to large enterprises, SME are confronted with a different set of issues. On one hand, low maturity technical organizations may be unable to access finance or invest in research and innovation or they may lack the resources to comply with environmental regulations. On the other hand, this type of companies must also overcome structural barriers such as lack of management and technical skills, rigidities in labor markets and a limited knowledge of opportunities for international expansion (European Commission, 2019).

Therefore, the call for low maturity technical enterprises to adequately manage their product development projects in today's increasingly dynamic and unpredictable environment is essential for long term sustainability as market changes and stakeholders' requirements become successively complex. SME must adopt management strategies, such as APM and LPM, capable of optimizing the efficiency of the development process, quickly delivering value to the clients, creating and spreading knowledge amongst employees, and adequately adapting to changing requirements.

1.2 Thesis objective

The main objective of this dissertation is the development of an APM & LPM diagnostic tool for SME to understand the extent to which they are reaping the benefits of APM & LPM techniques and what specific APM & LPM techniques SME can do to be better aligned with lean and agile principles. To help answer the main goal of the present research, the following sub-objectives are defined:

1. Investigate the definition of APM and respective techniques and tools.
2. Investigate the definition of LPM and respective techniques and tools.
3. Understand the state of the art of current APM and LPM diagnostic tools.
4. Propose an APM and LPM diagnostic tool.
5. Verify and validate the proposed diagnostic tool by applying it in 4 case studies.

1.3 Research methodology

The research method used in this thesis is the design research methodology (DRM). DRM is frequently applied as a supporting framework for doing complex multidisciplinary design research as it is aimed at providing a group of supporting methods and guidelines which helps develop justified argumentation (Saldierna & Lino, 2010). Even though this methodology has multiple variations and iterations to create flexibility, it consists of the following 4 stages (Blessing & Chakrabarti, 2009):

- **Research clarification** – clarifies the current situation for defining a research goal and plan. In this thesis, a systematic literature study was conducted on the definition, tools, and techniques of both APM and LPM. Relevant studies on the matter were summarized. The objective was to obtain a better understanding on the current situation regarding project management techniques. The research clarification step is related to this dissertation's sub-objectives 1 and 2, both included in chapter 2.
- **Descriptive study I** – performs specific research based on the research goal. Can be review-based or comprehensive depending on the type of research. In the present work, having into account its main objective, a comprehensive research was done on the diagnostic instruments of both agile and lean project management. The descriptive study I stage is associated with the thesis' sub-objective 3, presented in chapter 2.
- **Prescriptive study** – develops a method to achieve the proposed research goal. Can either be one or a combination of more than one review-based, comprehensive, and initial studies. In the present dissertation, a specific APM and LPM diagnostic tool is proposed. Prescriptive study is related to the thesis' sub-objective number 4, presented in chapter 3.
- **Descriptive study II** – evaluating the usability and applicability of the developed method. In the scope of the current work, the proposed diagnostic tool is practically implemented in 4 low maturity technical organizations. Descriptive study II is correlated to the dissertation's sub-objective 5, presented throughout chapters 4 and 5.

1.4 Thesis structure

This thesis is organized as follows. Chapter 2 includes the literature review, which is divided into 4 different sections. First, a definition of a product development project is presented. Secondly, the definition, tools and techniques of agile project management are mentioned. Then, the definition, tools and techniques of lean project management are analyzed. Lastly, the current diagnostic tools of APM and LPM are discussed. In chapter 3, the proposed lean and agile diagnostic tool for managing projects is introduced and thoroughly explained. Chapter 4 includes the results of the assessment method for each one of the 4 studied companies. Chapter 5 consists of an analysis of the data retrieved from the case study companies. A diagnosis assessment and a set of recommended APM & LPM tools and techniques are presented for each business. In this chapter, a reflection is also made on the practical viability and functionality of the proposed assessment method. The present work is finished in chapter 6, where conclusions, and recommendations for future research are stated.

2. Literature study

2.1 Management approaches of product development projects

A product development (PD) project can be defined as a series of actions that begin with the product idea and end with the product release to the market (Braak, 2018). Radeka (2013) states that during a PD project, an idea is transformed into something which an external stakeholder can purchase and practically use. The set of activities necessary to generate a fully functional product are people-based, complex, non-linear, and having a high uncertainty (Pessôa & Trabasso, 2017). According to Carter (2021), the PD project is composed of 6 different steps, as illustrated in Figure 2.



Figure 2 – Steps of the product development project (Adapted from Carter, 2021).

During ideation, businesses normally create internal small teams to brainstorm and explore multiple product ideas and designs. Teams can also scan the market and analyze the products of other companies. The objective is achieving an innovative product idea. Next, in product definition, developers and managers define technical, functional, and business aspects of the new product, which are its key points of differentiation. During the prototyping phase, physical or digital models of the product are created to assess its manufacturability and practical feasibility. Next, in detailed design, the focus is on product design but also refinement of the product's prototype. Internal and external stakeholders provide their feedback, which is in turn incorporated into the prototype. In parallel, marketing, sales and manufacturing begin to create the launch and manufacturing platforms to support the emerging product. The fifth step involves comprehensive testing of the prototype to ensure it works as planned and validating the product in the eyes of customers and internal stakeholders. Finally, at the commercialization step, the team begins to operationalize the manufacture of the product (Carter, 2021; Ulrich & Eppinger, 2004).

Traditional PD project management approaches, such as the waterfall model, focus on completing the stages of the project in a step-by-step (linear or sequential) manner. Only when a given step of the project is totally completed can the next one start (Casteren, 2017; Davis, 2012; Chappell, 2020). With these methods, stakeholder requirements are gathered at the beginning of the project, and an upfront fixed plan is developed to accommodate them (Thesing et al, 2021). According to conventional management methodologies, once the initial requirements are set and every goal has been cleared of any ambiguities, there is an unobstructed road which the development team will rigidly follow towards finishing the product development project (Andrei et al, 2019).

Conventional methods are adequate when the end goal of the project is clearly defined, the stakeholders' requirements are fixed throughout the development activities and the project is predictable, consistent and in need for extensive documentation (Balaji & Murugaiyan, 2012). In other words, methods such as the waterfall are adequate when the product development process is not subjected to considerable risks and uncertainties in the technology and in the market. Nevertheless, nowadays companies are subjected to constant changing market conditions, new technologies, shorter time-to-market cycles, and stakeholders with more flexible requirements (Thesing et al, 2021). Methods such as the waterfall, are not only bureaucratic and hierarchical (Borba et al, 2019), but also incapable of adapting to these highly

unpredictable and competitive environments (Stavru, 2014; Magistretti et al, 2019). Therefore, companies should adopt better and more modern management procedures to control their PD projects and ultimately add more value to their products. Agile and lean focus on constant adaptation to new requirements and producing more with less resources, respectively, and are 2 of the viable options (Lynn, 2022). The most significant differences between traditional, lean, and agile PD project management approaches are highlighted in Table 2.

Table 2 – Differences between traditional, agile, and lean PD project management methods (Adapted from Hoda et al, 2008; Morgan & Liker, 2006).

Categories	Traditional	Agile	Lean
Development model	Traditional	Iterative	Continuous improvement cycle
Focus	Process	People	Waste elimination
Management	Controlling	Facilitating	Facilitating
Customer involvement	Only when needed	On-site and constant	On-site and constant
Developers	Work individually within teams	Collaborative or in pairs	Collaborative
Technology	Any	Mostly object oriented	People and process oriented
Product features	All included	Most important first	Most complex first
Testing	At the end of the development cycle	Iterative	Continuous
Documentation	Thorough	Only when required	Only when required

2.2 Definition, tools, and techniques of APM

Agile first emerged in software development industries in the mid 1990s as an alternative to traditional approaches that developed software in a sequential manner (Highsmith, 2002). Agile became widely popular with the release of *The Agile Manifesto* in 2001, where renown practitioners presented better ways of developing software. Through their work they have come to value (Beck et al, 2001):

- 1) Individuals and interactions instead of processes and tools.
- 2) Working software over comprehensive documentation.
- 3) Customer collaboration over contract negotiation.
- 4) Responding to change instead of following a strict plan.

According to Ju et al (2020) and Serrador & Pinto (2015) agility is the company's ability to quickly respond and adapt to changes in requirements and in internal and external environments. From the researchers' perspective, agile corporations can select better partners, and improve operational processes, thereby increasing their earnings and reduce costs. Conforto et al (2016) assert that the 2 core elements of agility are the ability to change the project plan rapidly and active customer involvement. For Serrador & Pinto (2015), minimizing bureaucracy and upfront planning are essential to ensure the typical flexibility of agile organizations.

Nowadays, agile is consolidated in software development companies, and its adoption keeps growing year after year. In fact, in VersionOne's *13th Annual State of Agile Report* on the use of agile software development in companies around the world, 97 percent of respondents mentioned that their corporations apply agile methods, an increase of 17% from the 2011 study (Borba et al, 2019).

The documented benefits agile has brought to the software industry have attracted the attention of companies that are not exclusively software based, such as the ones focused on developing

and designing a product. In product development projects managed through agility, the entire development process is partitioned into short iterations. After each iteration, a working product is delivered to the customer. The consumer, who is proactively involved in the development process, tests the working products, and regularly provides feedback. This allows for faster identification of discrepancies, rapid response to changing requirements, and more efficient development of the expected product (Žužek et al, 2021). Serrador & Pinto (2015) analyzed the implementation of agile principles in 1002 projects across multiple industries and countries. These investigators concluded that agility positively impacts the project's success, mainly on 2 dimensions: efficiency and stakeholder satisfaction.

Agile tools and techniques are practices used to develop and manage complex projects in a manner consistent with the agile principles advocated by *The Agile Manifesto* (Sidky et al, 2007). These practices are currently being adopted by more and more projects, including large projects with complex product architectures (Pfahl et al, 2012). To investigate the practical usage of APM tools and techniques in scientific projects, a literature review was performed. 16 different practices were identified. The results of the bibliographic review are presented in Table 3, where a “✓” in a cell indicates that the practice was indeed mentioned by the respective researchers. Blank fields indicate that it was not possible to determine whether a practice was followed from the available information. Being relevant for the scope of the present work, a detailed description of each one of the 16 APM techniques and tools is presented in chapter 3.

Table 3 – APM tools and techniques currently being employed in companies.

Alternate external stakeholder representation	Bjarnason et al (2011)	Fraser et al (2001)	Hoda et al (2011)	Jalali & Wohlin (2011)	Newkirk & Martin (2001)
Burndown chart	✓	✓	✓	✓	✓
Constant planning				✓	✓
Daily stand-up meetings				✓	
Employee colocation				✓	
Frequent value delivery					✓
On-site external stakeholders					
Optimal working area					✓
Physical task board					
Product backlog				✓	
Retrospective sessions				✓	
Review period				✓	
Self-organized interdisciplinary teams	✓				✓
Simple product design				✓	
Time boxing				✓	✓
User stories	✓			✓	

(To be continued)

(Continued)

	Vallon et al (2018)	Zerfass et al (2018)	Žužek et al (2020)	Žužek et al (2021)	Agile tools and techniques (2019)	Cohn (2005)	Elssamadisy (2006)	Jun et al (2010)	Schwaber & Beedle (2002)	The 10 th annual State of Agile Report (2016)	Bang (2007)
Alternate external stakeholder representation											
Burndown chart	✓	✓		✓							
Constant planning	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Daily stand-up meetings	✓	✓	✓	✓	✓			✓		✓	✓
Employee collocation			✓	✓		✓			✓		
Frequent value delivery				✓							
On-site external stakeholders											
Optimal working area										✓	
Physical task board					✓					✓	
Product backlog	✓			✓	✓					✓	
Retrospective sessions	✓	✓		✓	✓			✓			
Review period	✓				✓					✓	
Self-organized interdisciplinary teams			✓	✓		✓			✓		
Simple product design	✓			✓							
Time boxing	✓	✓		✓						✓	
User stories	✓	✓		✓	✓					✓	

(To be continued)

(Continued)

	Cao & Ramesh (2008)	Law & Charron (2005)	Ramesh et al (2010)	Sililiti et al (2005)	Beck (2000)	Beck et al (2001)	Boehm & Turner (2003)	Highsmith & Fowler (2001)	Hunt (2006)	Pukinskis (2005)	Lundh & Sandberg (2002)	Pichler et al (2006)
Alternate external stakeholder representation												
Burndown chart												
Constant planning												
Daily stand-up meetings	✓	✓	✓	✓								
Employee collocation					✓	✓	✓	✓				
Frequent value delivery		✓			✓				✓	✓		
On-site external stakeholders	✓										✓	✓
Optimal working area												
Physical task board												
Product backlog	✓	✓	✓									
Retrospective sessions	✓		✓									
Review period	✓		✓									
Self-organized interdisciplinary teams		✓				✓						
Simple product design					✓							
Time boxing												
User stories												

(To be continued)

(Continued)

		Wake (2001)	Ambler (2002)	Carlson & Matuzic (2010)	Fowler et al (1999)	Paetsch et al (2003)
Alternate external stakeholder representation						
Burndown chart						
Constant planning						
Daily stand-up meetings						
Employee collocation						
Frequent value delivery						
On-site external stakeholders						
Optimal working area						
Physical task board						
Product backlog						
Retrospective sessions						
Review period	✓					
Self-organized interdisciplinary teams						
Simple product design		✓				
Time boxing						
User stories		✓		✓	✓	✓

Constant planning, daily stand-up meetings and user stories were the APM practices most frequently described by the researchers. Some authors have already reported significant benefits that resulted from the application of APM practices in SME, which will be the focus of the present work. Žužek et al (2021) described improvements in communication amongst team members, faster detection of discrepancies during the product development process, more effective problem solving, and greater flexibility. Overall, these investigators mentioned relevant enhancements in project efficiency and stakeholder satisfaction.

Based on the APM tools and techniques, many different structured agile methods have been developed over the years (Žužek et al, 2021). They are all grounded on iterative and incremental development, collaboration, simplicity, and adaptability (Abrahamsson et al, 2003). Among the most popular APM methods are scrum and extreme programming (XP) (Abrahamsson et al, 2003; Williams, 2010).

Scrum is a framework in which cross-functional teams develop products in an iterative, incremental manner. Each iteration normally takes 2 to 4 weeks and ends on a specific date, without possible extension. At the beginning of each sprint, the team selects customer requirements from a prioritized list and defines a strategy to accomplish these small, clear goals. Every day the team gathers to briefly inspect the progress of the work and adjust its course if needed. At the end of the sprint, there are collective work reviews and demonstrations that involve all relevant stakeholders. Feedback is obtained so that it can be incorporated in the next iteration. Scrum emphasizes the release of a working product at the end of each working cycle (Deemer et al, 2012). Important roles, elements, and events of scrum are presented in Figure 3.

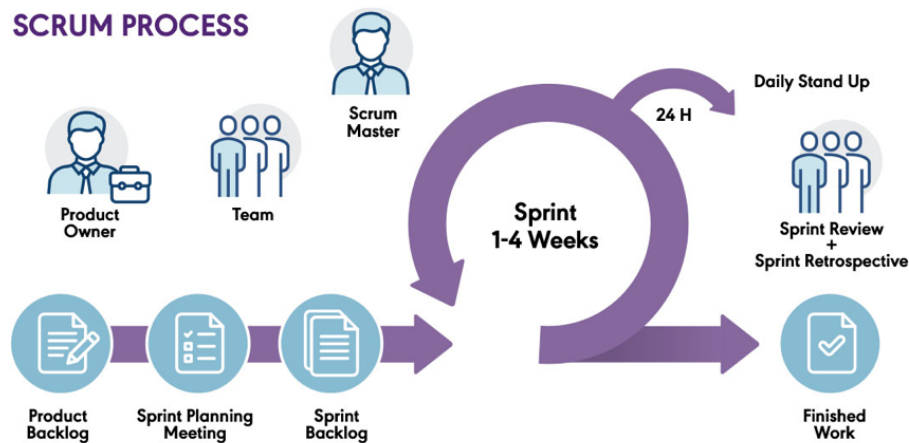


Figure 3 – Scrum overview (The Agile Journey: A Scrum overview, 2021).

Extreme programming is a software development method focused on practical application of programming techniques, clear communication, and teamwork. It is distinguished from conventional software development approaches by (Beck & Andres, 2005):

- Shorter development cycles, resulting in early and continuous feedback.
- Incremental planning, which enables an overall evolving plan of the project.
- Flexible implementation of software functionalities, adapting to changing business needs.
- Reliance on automated tests written by developers to monitor the progress of the work and to detect inconsistencies and errors early on the development cycle.
- Dependence on oral communication between developers to understand the system's structure and objectives.
- Evolutionary design process that lasts for as long as the system does.
- Close collaboration of actively engaged employees.

2.3 Definition, tools, and techniques of LPM

The term lean was first used by Womack, Jones, and Roos in their book *The Machine That Changed The World*, where the investigators compiled theories of management and production used by manufacturing Japanese companies during the decade of 1980s (Womack et al, 1994). Lean principles are followed when a product is produced by simultaneously maximizing the value established by the client and minimizing time, physical resources, and costs (Ballard & Howell, 2003). Womack et al (1994) believe that lean is an approach to do more with less. The concept of lean is also considered a way of thinking to achieve a totally waste-free production operation that is focused on customers' satisfaction. It can be accomplished by simplifying and continuously improving all processes and relationships in an environment of trust, respect, and full employee involvement. Lean is about people, simplicity, flow, visibility, partnerships, and true value as perceived by the customer (Jurado, 2012).

Initially identified for manufacturing, lean principles have since been applicable to other areas, such as product development (Morgan & Liker, 2006; Ward, 2007). PD projects are frequently structured and managed using the lean propositions (Karlsson & Ahlstrom, 1996). In the process of developing a product an idea is transformed into something that a customer can use (Radeka, 2013). Knowledge plays an important role, since it is not widely available, which creates a competitive advantage. Examples of knowledge are insights, know how, and skills which are derived from experiences, value, and emotion (Braak, 2018). In this development process, the physical appearance of the product, the materials to be used and the production stages employed to manufacture the product are determined (Hoppmann, 2009). As a result of

this, product development has a direct impact on costs, product quality, time-to-market, and customer satisfaction. The design of a product determines the manufacturability which plays a significant part in the production costs (Braak, 2018). Lean project management involves suppliers, cross-functional teams, simultaneous engineering, etc. It focuses on integration of activities instead of coordinated, strategic management and on visions and objectives instead of rigid predefined product specifications (Karlsson & Ahlstrom, 1996). After properly understanding customer wishes and needs (Pessôa & Trabasso, 2017), the goal of LPM is maximizing the quality of the product, minimizing its costs and time to market, and ultimately satisfying the clients (Braak, 2018).

While lean manufacturing has been extensively applied, researched, and documented on literature, there is comparably less research on how to apply lean to manage the product development project of a given company (Marodin et al, 2018). Research done on how to implement LPM mostly discusses its application to large companies (Morgan & Liker, 2006; Ward & Sobek, 2014). After a thorough review of the literature, 30 LPM tools and techniques were found, as illustrated in Table 4. Here a “✓” in a cell indicates that the practice was indeed mentioned by the respective researchers. Blank fields indicate that it was not possible to determine whether a practice was followed from the available information. Being relevant for the scope of the present work, an interpretation of each one of the 30 LPM tools and techniques will be presented in chapter 3.

Table 4 – LPM tools and techniques currently being employed in companies.

	Ward et al (1995)	Sobek et al (1998)	Pessôa & Trabasso (2017)	Kennedy (2003)	Oliver et al (2004)	Braak (2018)	Hines et al (2006)	Ward (2007)	Morgan & Liker (2006)
5 whys			✓			✓			✓
A3 problem solving report		✓	✓			✓		✓	✓
Chief engineer (CE)	✓	✓	✓	✓	✓			✓	✓
Competitor teardown			✓						✓
Computer aided three- dimensional interactive application (CATIA)	✓		✓			✓			✓
Computerized know how databases			✓	✓			✓		✓
Concept paper	✓	✓					✓		✓
Constant omnidirectional communication			✓						
Cross checking			✓						✓
Cross functional teams	✓		✓			✓	✓		✓
Daily wrap-up meetings			✓						✓
Decision matrices									✓
Design standardization		✓	✓	✓	✓	✓		✓	✓

(To be continued)

(Continued)

	Ward et al (1995)	Sobek et al (1998)	Pessôa & Trabasso (2017)	Kennedy (2003)	Oliver et al (2004)	Braak (2018)	Hines et al (2006)	Ward (2007)	Morgan & Liker (2006)
Engineering checklists	✓	✓	✓	✓		✓		✓	✓
Guest engineers			✓						✓
Inspection at the source			✓						✓
Mentoring employees		✓	✓	✓		✓	✓	✓	✓
Milestone table			✓						
Process standardization		✓	✓	✓	✓	✓		✓	✓
Product development value stream mapping (PDVSM)			✓			✓		✓	✓
Redundancy of parts	✓		✓	✓					✓
Rigorous application selection process		✓	✓	✓		✓	✓	✓	✓
Rigorous supplier selection process	✓		✓	✓		✓			✓
Risk assessment matrix			✓			✓			
Set-based concurrent engineering (SBCE)	✓		✓	✓	✓	✓		✓	✓
Status boards			✓						✓
Supplier technology demonstrations	✓		✓	✓					✓
Team room			✓	✓		✓		✓	✓
Test to failure			✓			✓			✓
Trade-off curves	✓	✓	✓			✓	✓		✓

These practices can help a company improve and manage their product development process, but they are not a solution to their problems. These tools and techniques need to be adapted and immersed in the companies' environment and without the full commitment of higher management and employees, it will be challenging to achieve the desired long-term results. According to the researchers, chief engineers, design standardization, engineering checklists, mentoring employees, process standardization, rigorous application selection process and set-based concurrent engineering are the most common LPM techniques currently being used by corporations.

2.4 APM and LPM diagnostic tools

APM and LPM diagnostic tools are used to evaluate the current state of a company regarding the alignment with agile and lean principles. To continuously improve, firms must properly understand their present state before striving to achieve a future improved state (Sensei, 2021). After a literature review, 12 APM and LPM assessment tools were found. Synthesized

information about each method is presented in Table 5. Blank fields indicate that it was not possible to determine that specific characteristic for the tool. A more comprehensive description about each assessment instrument is presented in Table A1 (Appendix A).

According to the available literature, agile and lean project management assessment tools are on-site observations (Benjamin, 2022; Sidky, 2006) and evaluations (Sensei, 2021; LeanMap, 2022), questionnaires (Denning, 2021; Thabit et al, 2017; Clayton, 2014; Sidky, 2006; Waters, n.d., Campbell & Iver, n.d.; Schumacher, 2009; Sacco, 2022; LeanMap, 2022), interviews (Sensei, 2021; Benjamin, 2022), and audits (TXM, 2021).

According to Fumagali et al (2011), a good diagnostic instrument is simultaneously aligned with the specific characteristics of the company and with lean and agile principles. Such tool must be developed having into account the firm's particular objectives, financial and time capability, and number of employees. Regarding the questionnaires commonly used, Sladeczek (2021) highlights the importance of its questions or statements being clear, concise, and easily interpreted by the company's personnel. The number of questions of the inquiries found in the literature varies from 6 (Campbell & Iver, n.d.) to 300 (Sidky, 2006).

Sensei (2021) and LeanMap (2022) recommend a duration of between 3 to 5 days to properly conduct an assessment. These authors, together with TXM (2021), advocate the need to hire external experts to execute the evaluation. Naturally, compared to the other researchers' tools, their methods are also much more expensive. The extreme complexity of *The Agile Adoption Process Framework*, proposed by Sidky (2006), also implies significant costs for the company. On the other hand, questionnaires with a moderate or reduced number of questions do not have associated high costs. Examples of this are the models of Denning (2021), Clayton (2014), Waters (n.d.), Campbell & Iver (n.d.), Schumacher (2009) and Sacco (2022).

While Sensei (2021), Denning (2021), Campbell & Iver (n.d.) and LeanMap (2022) evaluate specific pre-defined categories of the company and then sum the results to obtain a company's overall score, other authors such as Benjamin (2022), Thabit et al (2017), Clayton (2014), TXM (2021), Sidky (2006) and Schumacher (2009) solely focus on evaluating certain pre-defined categories. The questionnaires proposed by Waters (n.d.) and Sacco (2022) do not define any category, and therefore evaluate the company at once.

Almost all questionnaire and interview based diagnostic tools require the participation of either just one or all team members. The *Principles, Processes, and Practices (PPP) Worksheet* proposed by Denning (2021) is the only method suitable for an individual and collective participation. The assessment instruments proposed by Sensei (2021), Sidky (2006), Waters (n.d.), Schumacher (2009), Sacco (2022) and LeanMap (2022) require the participation of all team members. The tools implemented by Clayton (2014) and Campbell & Iver (n.d.) only involve the participation of 1 respondent.

Regarding the presentation of the final assessment results, 4 methods accomplish that through spider diagrams, either with points (TXM, 2021; LeanMap, 2022) or with percentage (Thabit et al, 2017; Clayton, 2014). 4 other tools do it simply with a punctuation score (Benjamin, 2022; Waters, n.d.; Campbell & Iver, n.d.; Sacco, 2022). The *Lean Agile Diagnostic Assessment*, which is the only method evaluating the company simultaneously on lean and agile compliance, uses a final report and a point scale. Benjamin's *Tool for assessing "leanness"* presents the results via text. Schumacher (2009) describes the results of the agile assessment on a diagnostic profile, which helps the firm identifying areas for improvement in their project management.

Table 5 – APM and LPM diagnostic tools found in the literature.

	Authors	Type	Questions	Time	Cost	APM/ LPM	Evaluation	Outcome
42 Point Test	Waters (n.d.)	Questionnaire	42	High	Low	APM	Total	Points
Agility Maturity Self-Assessment	Campbell & Iver (n.d.)	Questionnaire	6	Low	Low	APM	Categories & total	Points
Borland Agile Assessment	Schumacher (2009)	Questionnaire	12	High	Low	APM	Categories	Profile
Lean Agile Diagnostic Assessment	Sensei (2021)	Site evaluation & interviews		Very high (3-4 days)	High	Both	Categories & total	Final report & points
Lean Diagnosis Tool	Thabit et al (2017)	Questionnaire				LPM	Categories	Spider diagram with percentage
Lean Diagnostic Tool	Clayton (2014)	Questionnaire	56	Medium	Low	LPM	Categories	Spider diagram with percentage
Lean Diagnostic Tool (a)	TXM (2021)	Audit			High	LPM	Categories	Spider diagram with points
PPP Worksheet	Denning (2021)	Questionnaire	20	Variable	Low	APM	Categories & total	Points
The Agile Adoption Process Framework	Sidky (2006)	Questionnaire & observation	300	Very high	High	APM	Categories	Table with percentage
The Operational Excellence Assessment (OEA)	LeanMap (2022)	Site evaluation & questionnaire		Very high (5 days)	High	LPM	Categories & total	Spider diagram with points & final report
The 50 Point Test	Sacco (2022)	Questionnaire	50	High	Low	APM	Total	Points
Tool for assessing “leanness”	Benjamin (2022)	Observation & interviews				LPM	Categories	Text

3. Proposed APM and LPM diagnostic tool

In this chapter, the proposed diagnostic instrument to assess the degree to which low maturity technical corporations take advantage of the benefits of APM & LPM tools and techniques will be presented and thoroughly explained. The assessment method will be face-to-face interviews based on a guideline questionnaire and direct observations of the firm's working practices. Both activities will be conducted on the corporation's working site.

The section will start with a comprehensive description of the specific APM and LPM tools and techniques found in the literature. Their main benefits, from which the reference questions are based on, will be mentioned. Then, the assessment methodology adopted in the present dissertation will be described. Here, the necessity of developing a new APM and LPM diagnostic tool is going to be explained. The distinctive and common traits between the newly developed solution and already established methodologies will be analyzed. Also, the reasons how the diagnosis instrument is expected to be used will also be exposed. Extra attention will be paid to the set of proposed questions, given its importance in determining the presence or practical viability of lean and agile practices. Each question will be explained. For each query the associated practical APM and LPM tools and techniques will be identified.

3.1 Interpretation of APM tools and techniques

After thoroughly analyzing the available literature on practical tools and techniques of agile project management, it was deemed relevant to present an interpretation of each one of the tools and techniques, encompassing a description of the method itself and its main benefits. Table 6 presents this analysis.

Table 6 – Description and main benefits of the APM tools and techniques found in the literature.

Techniques & tools	Description	Main benefits
Alternative external stakeholder representation	Technique that consists of having a person authorized to represent and act for suppliers, customers or users on the PD working site. The external stakeholders' proxy (representative) attends all company events, such as meetings and product reviews.	Effective communication between stakeholders.
Burndown chart	Graphical representation of work left to do versus time. The horizontal axis of the burndown chart shows the time (for example in days), and the vertical axis shows the amount of work remaining (normally in hours).	Visualize and monitor the progress of the work.
Constant planning	Collective action in which a set of working tasks is lined up to accomplish a product feature during a time-fixed activity of the PD project. Both the product features and the planned work can be altered and refined during the development activities. Sometimes to achieve a single product characteristic multiple time boxed activities are required. Based on time and materials availability, the team decides how many working tasks can be committed to a single PD project activity. This type of planning is cyclic and starts with the most important product attributes, such as architectural and technical characteristics.	Common knowledge about how to accomplish a product feature.
Daily stand-up meetings	At the start of each working day a 15-minute meeting is held with all team members to share the previous day's issues and discuss any challenges to complete the PD activities and delivery schedule for that day. Daily stand-up meetings are set at the same place at the same time.	Uniform understanding of the PD project and its problems.

(To be continued)

(Continued)

Techniques & tools	Description	Main benefits
Employee colocation	Technique that advocates that all company employees should work in the same room, or at least in the same building.	Easy and effective communication between company members.
Frequent value delivery	Release of working products, such as initial drawings, 3-dimensional (3D) models, simulations, samples, prototypes, and measurement results after each PD project activity. Such materials ought to be shared and used by internal and external stakeholders.	Stakeholders can keep track of the PD project progress.
On-site external stakeholders	Suppliers, customers, or users should be represented on-site and attend company's events such as meetings.	Effective communication between stakeholders.
Optimal working area	Arrange the working environment in a way that people can work in physical proximity in the most efficient and productive way as possible. Removing the furniture to ensure more working space and easier access to materials, having shared tables and computers placed near the center to allow team members to work closer to each other, putting whiteboards and sticky notes on the walls to visualize ideas and work-in-progress, cleaning and waste removal are some measures that can be taken by the company.	Knowledge about the whereabouts of things, materials, and product parts. Less distractions to focus on individual work.
Physical task board	Method that consists of using a board to organize the activities of the project into 3 different categories – to do, in progress and done. The status of the activities is represented in columns. Tasks, which are normally described through sticky notes or cards, are placed in those columns accordingly.	Easily understand the status of a given PD project activity.
Product backlog	Ordered list of everything known to be needed in the product, such as features and requirements.	Awareness about the most important product functionalities.
Retrospective sessions	Gatherings that occur at the end of a given PD project activity where the development team discusses and documents what worked well and what did not, what obstacles were faced, and any issues related to tools, techniques, people, and relationships. Having into account the issues and problems encountered, a plan for improving the next PD activity is developed collaboratively.	Common knowledge about the strengths and weaknesses of a given PD project activity.
Review period	Relaxed or formal presentation of the completed work. It can be an internal exercise, or it can include external stakeholders. It is meant to demonstrate what was achieved during a given period and to determine if the results match the scope and requirements of the product.	Understand other departments' work deliverables.
Self-organized interdisciplinary teams	Division of the company's employees into groups of 7 to 9 elements from different functional departments. There is neither a hierarchical division nor the assignment of a team leader. The team identifies work that needs to be done, prioritizes tasks that are required and manages timelines on their own. Even though tasks are internally rearranged between team members each person can take on each activity.	Fast actions and decisions. Team leaders spend less time planning and tracking the work of their subordinates. Use of full human potential.
Simple product design	Technique that consists of maintaining the product's design as simple as possible throughout the PD project. Designs based on practical knowledge must be preferred over speculative ones to prevent mistakes and corrections. The more complex product components should be designed first. Smaller parts must be designed in context, but only when immediately required.	Stakeholders' clear understanding of the product.

(To be continued)

(Continued)

Techniques & tools	Description	Main benefits
Time boxing	Technique that consists of assigning a specific time duration (normally between 1 day and 4 weeks) for an activity of the PD project.	Good control and management of the PD project.
User stories	Short and simple descriptions of product features desired by the end user or customer. User stories can be written by all employees on index cards, or sticky notes. User stories are normally arranged on walls or tables to facilitate planning and discussion.	Easy collective understanding and interpretation of product's features and requirements.

3.2 Interpretation of LPM tools and techniques

After thoroughly analyzing the available literature on practical tools and techniques of lean project management, it was deemed relevant to present an interpretation of each one of the tools and techniques, encompassing a description of the method itself and the main benefits. Table 7 presents this analysis.

Table 7 – Description and main benefits of the LPM tools and techniques found in the literature.

Techniques & tools	Description	Main benefits
5 whys	Asking 5 consecutive times why a problem happened to identify its root causes.	Quick identification of the causes of problems.
A3 problem solving report	Template on a conventional A3 paper sheet used to solve problems. It includes sections to describe the problem, analyze its causes, identify countermeasures, and the required actions to implement such measures. It normally also contains fields to insert the intended goal and the necessary follow-up activities.	Plan to fix the problems.
Chief engineer (CE)	Extremely technically experienced and knowledgeable engineer who leads and manages the PD project from concept definition to market, being ultimately responsible for the project's results. The CE is tasked with defining and engineering the product concept, the program objectives, the product architecture, performance, characteristics, and timing. He is also responsible for overseeing design projects and making sure they are on time and on budget. The project leader breaks down complex product level performance targets into a set of specific individual actions for everyone in the company. Finally, he assists in difficult decisions by encouraging consensus across engineering functions.	Have a general idea of the product before any design work is undertaken. Know the exact status of the PD project. Understand how individual tasks contribute to the final product. Collectively resolve complicated situations.
Competitor teardown	Process that consists of breaking competitor's similar products down to individual parts, subjecting them to tests and comparing the respective results with internal ones.	Know where the competition is falling short.

(To be continued)

(Continued)

Techniques & tools	Description	Main benefits
Computer aided three-dimensional interactive application (CATIA)	CATIA is a software collection that includes computer-aided design (CAD), computer-aided engineering (CAE), and 3D digital mockups (DMU). CAD is used to create, modify, analyze, and optimize the design of the product and its components. It can be used to design curves, figures, and product components' drawings in 2 dimensions (2D) but also 3D surfaces and solids. CAE, which uses CAD software, is utilized to evaluate the robustness and performance of product designs and components. It includes stress analysis of product parts and interfaces using finite element analysis (FEA), thermal and fluid flow analysis making use of computational fluid dynamics (CFD), and multibody dynamics (MBD) and kinematics. DMU are 3D digital representations of the final product. They can be achieved with the CAD software.	Detection of design incompatibilities. Have performance insights earlier in the development process. Accurate visual representation of the final product.
Computerized know how databases	Digital database where engineering guidelines and practices are explained in detail. Information is normally arranged by product parts. Employees have access to teardown analysis of competitor's products and design studies of the company's products.	Employees know the reason why they are doing things.
Concept paper	Document developed by managers before the beginning of the PD process that includes objectives for broad product characteristics, such as weight, performance, cost, and quality.	Understand how the management envisions the product.
Constant omnidirectional communication	Technique that consists of frequently communicating with other employees to exchange opinions, feedback, and advice.	Individual assignments keep progressing on schedule.
Cross checking	People with different backgrounds or from distinct departments/sub-teams check and analyze the same product parts or data. The end goal is detecting problems and solve them at the root cause.	Identify problems. Fix the causes of problems.
Cross functional teams	People from different functional organizations informally working together. The group identifies and resolves technical problems, defines component goals, develops strategies to achieve them, and analyzes new designs.	No problems in the handoff.
Daily wrap-up meetings	All PD project participants gather at the build site at the end of each day to discuss issues encountered during that day's work, elaborate countermeasures, reflect on lessons learned, and clarify assignments and strategies.	Common understanding of the PD process, its status, and problems. Clear understanding of individual tasks.
Decision matrices	Tool used to compare design alternatives. While these are listed on one axis of the matrix, specific evaluation criteria are listed on the other. Each design alternative is then evaluated against those criteria and a quantitative or qualitative value is entered in the appropriate cell.	Know how multiple product designs relate to each other.
Design standardization	Practice of utilizing the same components, technology, or architecture across different versions of the product. The new product's innovation is achieved through modifications of previous releases or variations on a theme (e.g., color).	Consistent and predictable component/product performance.
Engineering checklists	List of steps and things necessary to complete an activity.	Know how to do a task without forgetting something.

(To be continued)

(Continued)

Techniques & tools	Description	Main benefits
Guest engineers	Temporary exchange of engineers between the company and current and/or potential suppliers. In the company, supplier's engineers are inserted in sub-teams to work on specific components as needed.	Supplier is familiar with the company's PD practices. Company understands how suppliers operate.
Inspection at the source	Managers walk around at the company and talk to people from different departments to check the status of components, identify issues and propose countermeasures.	Identify problems. Fix the causes of problems.
Mentoring employees	More experienced and knowledgeable employees transmit highly technical and tacit skills to other colleagues. For example, they are taught on how to use specific engineering tools, like CAD. Mentees are forced to get their hands dirty and see for themselves how the PD work is conducted. They are encouraged to think critically about the impact of several potential solutions. Mentoring, which is a cyclic process, includes strategic assignments and regular evaluations for technical excellence and adherence to the company's principles.	Employees (recently hired or not) know how things get done.
Milestone table	Major events and activities of the project are represented horizontally and specific dates vertically. Employees use marks or symbols to connect both variables and/or to assign specific durations to tasks.	Keep track of the most important steps of the PD project.
Process standardization	Technique that consists of having common tasks, sequence of tasks, task durations, and working instructions across different departments/sub-teams/functional organizations.	Know what inputs are necessary from different departments and when they are needed (no problems in the handoff).
Product development value stream mapping (PDVSM)	Method that consists of representing on a time scale the flow of information and data between simultaneous functional activities of the PD process. PDVSM can also be used on a micro scale. The time frame is presented along the X axis and the activities are laid out along the Y axis. The data/information flows can be data releases, feedback, engineering changes, scheduling, and milestone dates. They ought to be differentiated by color, types of lines, and specific icons.	Understand how the actions from functional departments affect other departments. No problems in the handoff.
Redundancy of parts	Have identical or very similar product parts from at least 2 different suppliers.	Prevent major failures of product parts.
Rigorous application selection process	Applicants are individually interviewed and examined to determine if they fit within the company's culture and, if so, what is the ideal functional organization for them to work in. Technical skills are always prioritized. Sources of information include professors who have a relationship with the firm and current employees. Recruiting events at universities are scheduled to learn about possible applicants at a personal level.	Employees are technically capable of doing their job.
Rigorous supplier selection process	Selecting the supplier based on an optimal trade-off between price, delivery times, and the ability to meet the product performance requirements imposed by the company.	Satisfaction with the service provided by the supplier.

(To be continued)

(Continued)

Techniques & tools	Description	Main benefits
Risk assessment matrix	Tool that helps visualize the relationship between probability of occurrence and consequence of a potential risk affecting the PD process. The risk probability scale is represented vertically and the risk severity one horizontally. Different colors are used for the cells in between.	Understanding the most severe risks of the PD project.
Set-based concurrent engineering (SBCE)	Technique that consists of the simultaneous examination of multiple design solutions proposed by people from different departments with the objective to narrow the set down to a final superior choice. Design alternatives are gradually eliminated based on criteria such as manufacturability and system compatibility.	Inclusion of innovative solutions during the development cycle.
Status boards	Technique used to visualize the workflow. Different work phases and activities are represented as columns, and cards or sticky notes, respectively. Each card contains information such as the task's deadline, assignee, and description. The cards go through the workflow until their full completion.	Easily understand the status of a given PD project activity. Awareness of scheduling requirements and work to meet them.
Supplier technology demonstrations	Suppliers demonstrate technology that might be appropriate for the new product at the beginning of each project.	Knowledge about new technological developments.
Team room	Room where people from different departments regularly meet to review the status of the PD program, formulate ideas, address issues, communicate day-to-day decisions and make on-the-spot decisions. Visual information is posted on the walls of the room.	Uniform understanding about the status of the PD project and the impacts of changes.
Test to failure	Test components under both normal and abnormal conditions and push designs to the point of failure.	Understand the absolute physical limitations of parts and designs.
Trade-off curves	In a trade-off curve, a given product, component, or design characteristic is mapped on the Y-axis while another attribute is depicted on the X-axis. A curve is then plotted to illustrate the performance of the elements relatively to the 2 characteristics.	Understand the relationship between technical performance attributes.

3.3 Explanation of the diagnosis instrument

After thoroughly analyzing the APM and LPM diagnostic instruments and practical tools and techniques found in the literature a new and differentiated diagnosis instrument was developed. The creation of a distinct and improved assessment tool, which is the core objective of the present dissertation, was deemed necessary having into account the ineffective content and extensive and high-priced application process of many of the diagnosis tools found in the literature.

The main goal of the newly proposed tool is to be a quick and affordable method to understand if companies are reaping the benefits of APM & LPM tools and techniques during their PD projects. Therefore, considering the cost-effective approaches proposed by Waters (n.d.), Campbell & Iver (n.d.), Schumacher (2009), Clayton (2014), Denning (2021) and Sacco (2022), a questionnaire was also elaborated. In fact, Debois (2022) states that questionnaires are extremely advantageous due to their low-price and good practicability. Therefore, the suggested assessment tool distinguishes itself from the financial demanding method types proposed by authors such as TXM (2021), Sidky (2006), LeanMap (2022), and Sensei (2021). The reduced

application time of the recommended questionnaire was accomplished in several ways. Firstly, the number of questions was kept short, which allowed the respondent to maintain its focus throughout the reply process, thus conveying information efficiently. Authors such as Waters (n.d.), Campbell & Iver (n.d.), Schumacher (2009), and Denning (2021) also strived to maintain a reduced number of questions (maximum of 42) in their methods. Then, the proposed set of questions was applied to solely one member of the company, a practice advocated by Clayton (2014) and Campbell & Iver (n.d.), rather than submitting all members of the firm to the questionnaire like Waters (n.d.), Sidky (2006), Schumacher (2009), and Sacco (2022) did.

The main difference between the assessment questionnaires found in the literature and the one proposed in this thesis resides in the content of the questions. To begin with, all sets of questions encountered in the bibliography focused on assessing either the agility or leanness of the corporation. No mixed questionnaires were ever found. The suggested method, however, will be composed of inquiries to evaluate the presence of lean and agile practices as well as common aspects of both management methodologies. Moreover, the questions proposed by the researchers are not only general ones and not adapted to the characteristics of each company but also closed answer ones centered directly on the specific tools and techniques of agile and lean project management. Such inflexible questioning approaches can result in inaccurate assessments. On one hand, respondents might not be acquainted with the specific technical terms of APM and LPM, which makes them confused and unable to answer a specific question. On the other hand, maintaining a constant and broad sentencing of questions will misguide answerers, since different companies normally have distinct operational procedures.

Alternatively, the suggested set of questions, which will be presented and explained in the next section of this document, focus on understanding if the specific benefits of APM and LPM tools and techniques are being achieved by a given company. Instead of providing a strict list of queries that respondents can answer by themselves, the method developed in this thesis will be based on open-ended questions asked in interviews held with only one company member, as previously mentioned. Rather than a straightforward question and answer format, a discussion with the interviewee will be allowed, to gather precious insights about the specific management practices of firms. Such procedure is known as semi-structured interview. At first, general questions will be asked to understand broad aspects of the company, such as its structure, development procedures and objectives. Once the firm's way of work is properly understood, the set of proposed questions will be specifically adapted to the corporation in question. In fact, Fumagali et al (2011) express that a good diagnostic instrument is simultaneously aligned with the traits of corporations and with lean and agile principles. Therefore, the inquiries shown in the following section are general guidelines that are subjected to small changes and alterations according to the analyzed company. Neither one of the authors that developed questionnaires as lean and agile assessment tools has chosen semi-structured interviews as the way to conduct the questionnaire. They have opted by physical or digital lists of strict questions meant to be answered by company members. Even though all those researchers have opted by categorizing the questions into different classes, in the present case study a holistic evaluation will be preferred, since it can simplify the assessment process and the company's understanding of the results.

Besides the interview session, a brief observation moment will also be contemplated. During this time, which can be concurrent to the interview, the evaluator will be shown specific working practices that companies do when developing their products. Photographs and notes will be taken throughout such part of the assessment tool. Only Sidky (2006) and Benjamin (2022) also implemented direct observations in their assessment tools. The entire assessment method developed under the scope of this thesis is presented in Figure 4.

The collection of data will be done in the companies' premises. The whole process is not expected to last longer than 1 hour. Participants will be appropriately briefed and informed about the objective of the research prior to the start of the interview. A written ethical consent will be signed by both parties. No personal data about the interviewees will be presented here or elsewhere.

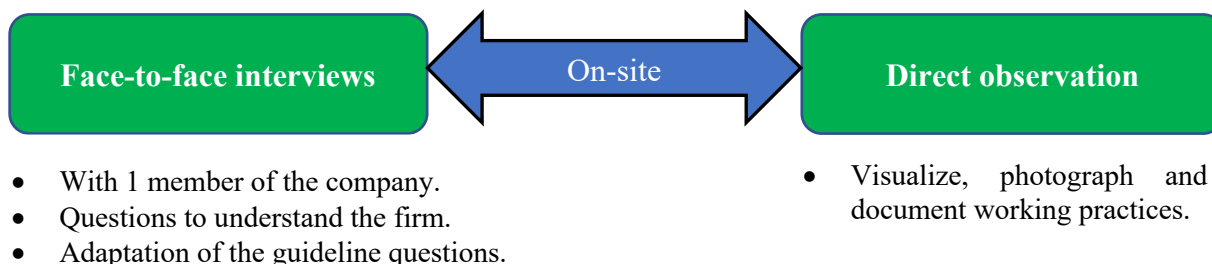


Figure 4 – Overview of the proposed assessment tool.

After direct and indirect collection, through observations and interviews, respectively, data from each company will be presented in text. Information will be disclosed in a structured way, together with some generic and historic details about the firms to facilitate the reader's comprehension. Benjamin (2022), LeanMap (2022) and Sensei (2021) also made this choice. Later, in the Discussion chapter, and having into account the retrieved data, a diagnostic assessment will be made for each company. It will be focused on determining if firms are fully reaping the benefits of APM & LPM tools and techniques. Even though all 46 APM & LPM tools and techniques found in the literature possess specific benefits, some of these advantages are common and extremely similar. Therefore, all benefits were compacted into the following:

- 1) Problem identification and resolution.
- 2) Knowledge about the product.
- 3) Knowledge about the project.
- 4) Good relationship with external stakeholders.
- 5) Knowledge sharing amongst employees.
- 6) Task execution know how.
- 7) Consistent and innovative product.

Companies will be assessed on all 7 core benefits of APM & LPM tools and techniques. The evaluation results will be presented in radar charts accompanied by a textual explanation. Thabit et al (2017), Clayton (2014), TXM (2021), and LeanMap (2022) have also adopted radar/spider charts/diagrams. In fact, radar diagrams allow a display of multiple variables' results in a clear and easily understandable visual way. Concurrently with the diagnosis, suggestions will be presented in text to each company. These recommendations will be specific APM & LPM tools and techniques that businesses can adopt to enhance the efficiency of their PD project.

The proposed assessment instrument is expected to be used in 2 different ways. Firstly, for the interviewer to understand if and how companies are taking advantage of the benefits of lean and agile PD project management methodologies. Secondly, by providing companies with a critical view of their development practices, the suggested tool encourages firms to improve less developed areas of their working procedures. In fact, the continuous improvement principle promoted by the assessment tool is facilitated by the set of specific APM & LPM tools and techniques proposed for each business.

3.3.1 Detailed guideline questionnaire

The full guideline questionnaire is composed of 23 different questions, divided into 2 different parts. The first part, as previously mentioned, comprises questions about the structure, development procedures and objectives of the company. The more detailed second part involves specific inquiries based on the benefits of APM and LPM tools and techniques. Each query may or may not have follow-up questions, which are aimed at obtaining in-depth insights about certain aspects of the company's working procedures. Tables 8 and 9 present the general and specific parts of the fully detailed proposed questionnaire, respectively. For all questions and respective follow-ups an explanation about their objective is presented. For the specific queries of the questionnaire, the associated APM/LPM practical tools and techniques, which presence, or future viability the questions try to assess, are also displayed.

Table 8 – General part of the proposed guideline questionnaire.

Questions	Explanation
Can you describe the company you work on? <i>How is it structured?</i>	Understand the field of activity of the company, what it strives to accomplish and its workforce structure.
What are the firm's main objectives?	Acknowledge the core objectives and purposes of the corporation.
How does the company develop its products?	Understand the general structure and steps of the development cycle.

Table 9 – Specific part of the proposed guideline questionnaire.

Questions	Explanation	APM/LPM tools
What do people do when they are faced with situations hard to deal with? <i>Can you describe it? Are the obstacles documented?</i>	Understand the company's strategies to tackle problems and setbacks. Assess the extent of the documentation in that regard.	Inspection at the source, cross checking, CAD system, daily meetings, A3 problem solving report, 5 whys.
Are company members capable of predicting hazardous situations? <i>How? Do they know what the most dangerous situations are and how they can arise? Are risks documented?</i>	Ascertain the existence of a collective strategy to prevent major failures and mistakes. See if risks and issues are properly documented.	Redundancy of parts, risk assessment matrix.
Do you or the company control and track the progress of a given activity? <i>Can you show me how it is done? How frequent is that control done?</i>	Understand if there is a strategy to identify the status of tasks. Figure out if there are intermediate deadlines and if they are being met or not.	Status boards, physical task board, time boxing, burndown chart, constant omnidirectional communication, frequent value delivery, daily meetings, chief engineer, time boxing.
Are all individuals informed about the most important activities, events, and deadlines of the entire development cycle? <i>How?</i>	Discover if there is a planning strategy and if it is communicated across the company.	Milestone table, chief engineer.
Can you explain me the role of each team member in a few words? <i>Do you all have a common understanding of the product?</i>	Find out if people have concrete tasks, are collaborative and strive to assist others.	Cross-functional/self-organized interdisciplinary teams, chief engineer, concept paper.

(To be continued)

(Continued)

Questions	Explanation	APM/LPM tools
Can the company ensure that a new member knows exactly what to do? <i>How?</i>	Assess if more experienced employees pass down knowledge to new hires and how that is accomplished.	Mentoring employees, rigorous application selection process.
Do company members frequently come across unfamiliar situations or aspects that they do not know how to deal with? <i>Why does that happen?</i>	Determine if people know how to do an activity without making mistakes and if they do why that occurs.	Engineering checklists, computerized know how databases, constant planning, daily meetings.
Is there a strategy to understand where the competition is falling short? Which one?	Determine if the firm stays updated regarding the technology and methods used by business rivals.	Competitor teardown.
Do you know what people that closely work with you need to do their activities? <i>What about people from different backgrounds, sub-teams, or departments? How? Do you realize how your actions affect other people's jobs?</i>	Understand if there is a collaborative working approach. Assess if employees have a holistic knowledge about the PD project.	Process standardization, product development value stream mapping, cross functional/self-organized interdisciplinary teams, chief engineer, review period, daily meetings.
Do people with distinct expertise understand the strengths and weaknesses of the product to be developed? <i>How is that accomplished? Do you know what the most important product features are?</i>	Assess if there is a common vision and understanding about the product to be developed and the many steps necessary to bring it to the market.	Test to failure, trade-off curves, digital mockups, simple product design, user stories, decision matrices, chief engineer, product backlog, CAD, and CAE systems, team room, daily meetings.
Do company members know the issues, improvement points and strengths of a recently finished activity? <i>How? Are these aspects documented?</i>	Determine if employees strive for continuously improving their actions. See if good practices and successes are documented.	Retrospective sessions.
Does the company have frequent suppliers? <i>If so, how can the company ensure that is always familiar with the practices of suppliers and vice-versa? Can the company guarantee a constant satisfaction with the suppliers' service? How does the firm know about new technological developments made available by suppliers?</i>	Understand if the company has regular suppliers. Assess the extent of the relationship between the company and its suppliers.	Guest engineers, rigorous supplier selection process, alternate external stakeholder representation, on-site external stakeholders, supplier technology demonstrations.
Does the company have specific product users and clients? <i>If so, are you familiar with what they expect and vice-versa? How? How do you interact with each other and exchange feedback and ideas?</i>	Understand if the corporation's products are aimed at a specific group of people. Assess the relationship between the company and its clients.	Alternate external stakeholder representation, on-site external stakeholders, user stories.
Does it take a long time to get someone's input on something? <i>Why?</i>	Assess the extent to which communication among company members is effective.	Employee colocation.

(To be continued)

(Continued)

Questions	Explanation	APM/LPM tools
Does the company regularly introduce innovation during the development activities? <i>How is that accomplished?</i>	Assess if the corporation attempts to constantly renew and perfect their processes. Understand if all employees are involved.	Set-based concurrent engineering.
Can successes and good practices be replicated from previous projects? <i>How?</i>	Evaluate if useful information and knowledge are maintained across distinct PD projects.	Design standardization.
What is the company's approach regarding product specifications? <i>Are product requirements changed or added during the development activities? What does the company do to include such changes?</i>	See if the company constantly tests, documents, and fulfills the product requirements. Understand if they are fixed or flexible. Assess the company's capability to adapt and cope with changing product specs.	Product backlog, concept paper.
Can you tell me a bit more about the hiring process of the company?	Understand if employees' full potential is taken advantage of. Determine if the working environment optimizes the talent and potential of each person.	Cross functional/self-organized interdisciplinary teams, rigorous application selection process.
Do you lose a lot of time finding things in the workplace? <i>Why?</i>	Assess the existence of a method to prevent employee distractions and wastes of time when doing a particular task on the workplace.	Optimal working area.
Do actions and decisions take a long time to be made and finalized? <i>Why? Can you provide an example?</i>	Understand if the company can ensure that documents, final decisions, and approvals are quickly made. Assess the time management of the firm.	Self-organized interdisciplinary teams, time boxing, chief engineer.

After acknowledging the reasons behind each main question and the lean and agile tools and techniques associated to them, it is now possible to develop a simplified version of the reference questionnaire. Table B1 of Appendix B presents this version, in which each question and the respective follow-ups are presented in an easily understandable way.

The inquiries of the questionnaire are supposed to be asked in a sequential manner. Rephrasing must be done if the respondent does not fully comprehend a particular question. Repliers must answer the queries to best of their knowledge. The interviewer must always direct the answerer to the specific proposed questions and avoid lengthy dialogues about detailed and particular information about the company and/or its development processes. Nonetheless, and as previously mentioned, the partakers of the interview are allowed to discuss each one of the suggested set of questions. The evaluator must, however, constantly control the duration time of the questionnaire throughout the reply process. It is important to guarantee that the maximum duration of 1 hour is not exceeded.

4. Case studies

In this chapter, the results of the assessment method will be presented for each one of the studied low maturity technical organizations. The case studies will be 3 non-profit student-led organizations that develop innovative products and a service provision business that also functions as a startup generator. As mentioned in the introduction of this thesis, the firms are all based in the city of Enschede, located in the region of Twente, in The Netherlands.

The student-led companies are all based in the same building: The Future Factory. This building, whose exterior view is shown in Figure C1 (Appendix C), is located in the vicinity of the University of Twente. It houses 5 companies (Figure 5) composed of former and/or future students from the UT and/or the Saxion University of Applied Sciences (SUAS). They use renewable energy sources, efficient storages, or innovative technology to work towards a better future. Even though all the businesses have exclusive working spaces, there are some common areas within the building, as shown in Figures C2 to C5 (Appendix C). The firms Green Team Twente, Drone Team Twente, and Electric Superbike Twente will be studied under the scope of the present dissertation.

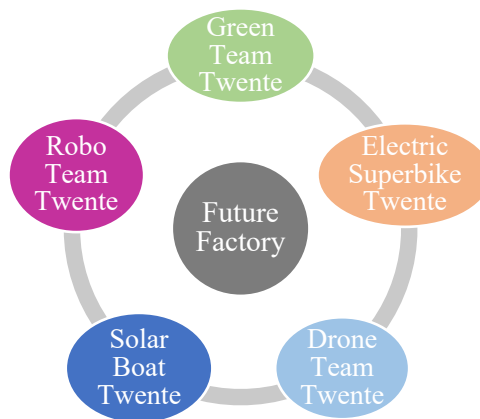


Figure 5 – Student-led organizations based in the Future Factory.

The startup incubator, Game Lab Oost, is based in a distinct location and has very different working procedures. The collected information from all 4 corporations is introduced in a structured textual way together with some general and historical data about each company. This option was taken to facilitate the reading and consequent understanding of the development practices being implemented by the analyzed corporations.

4.1 Green Team Twente

Green Team Twente (GTT) is a company composed of former and/or future students from the University of Twente and Saxion University of Applied Sciences that design, build and race one of the world's most fuel-efficient hydrogen cars (The Fuel of the Future, 2022). GTT was established in the academic year of 2011/2012 as an initiative of W.S.G. Isaac Newton, the student association of the mechanical engineering educational program at the UT. Since its creation, the main objective of the company has been showcasing the world that hydrogen is a viable alternative to the pollutant fossil fuels (Previous Years, 2022).

Every year, employees, who can work part-time or full-time in the corporation, are replaced and new personnel takes over. In 2011, the team solely comprised mechanical engineering students (Figure 6 – left). However, year teams have been multidisciplinary since September

2012. Mechanical, electrical, and chemical engineering, as well as advanced technology are some of the backgrounds commonly found amongst the GTT workforce. With this approach, the firm intended to introduce innovation on multiple aspects of the vehicle and simultaneously offer students from different fields the opportunity to participate in an innovative, sustainable project in which they can put their newly gained knowledge into practice (Previous Years, 2022).

On a yearly basis, a new model of the vehicle is developed and ultimately raced in national and international events held at the end of the academic year. The first vehicle ever developed by GTT is shown in Figure 6 (right). Throughout the years, the most important specific vehicle level specs have been maintained, which are its fuel efficiency and weight. From one year to the next, innovative elements are introduced but certain aspects of previous vehicle models are preserved. For example, in the academic year of 2016/2017, the developed chassis was based on the preceding year's model, as it can be seen in Figure 7. However, in the same academic year, the team introduced a new body design, along with a fully integrated dashboard on the steering wheel, and an electronically managed clutch system (Previous Years, 2022).



Figure 6 – 2011/2012 GTT team (left) and the car developed by them (right) (Previous Years, 2022).

In 2018/2019, the team redesigned the drive train and electrical components of the car and significantly improved its cooling system. In the following year, more ergonomic and compact interior components were designed. A screen showing data for an improved real-time driving experience was inclusively introduced for the first time. In 2021, mechanical components were optimized to make them simpler and lighter. Besides, a new cell fuel was added, electronic systems were upgraded, and the latest software was installed (Previous Years, 2022).

Over the course of the company's existence, changes have also been made in aspects not directly related to the vehicle. For example, in 2017/2018 the company's logo and color were changed to a more sustainability related theme (Figure 8 – right). Extra emphasis was put on practically educating people on hydrogen from 2018/2019 onwards. Teams started making educational videos and going to schools to give guest lectures. In 2020/2021, an exhibit about GTT was held at a local museum and company members made a documentary about hydrogen for the first time (Previous Years, 2022).



Figure 7 – Similarities between the chassis of the 2015 (left) and 2016 (right) car models (Previous Years, 2022).

Currently, in the academic year of 2021/2022, 27 people work in GTT (Figure 8 – left). These individuals are divided into 3 different sub-teams: management, communication, and technical. There are 2 sub-groups within the technical sub-team, which are the hydroelectric and mechanics, each one being led by a different chief.



Figure 8 – GTT team of the academic year 2021/2022 together with the previous year's car model (left), and the firm's logo prior to and since 2017 (right, top and bottom, respectively) (Previous Years, 2022; Heemskerk, 2022).

The semi-structured interview was conducted with a member of the management sub-team. It was found that all GTT employees work full-time from 9 am to 5 pm, even though there is the possibility of working part-time. These people are former and/or future students of UT and SUAS who have decided to take a gap year or participate in an internship period. Despite sharing the building and some rooms with other student-led companies, GTT possesses some exclusive working spaces (Figure D1, Appendix D). The employment contract at the GTT lasts 1 year, after which all employees are replaced by new members. The company's functional structure is shown in Figure 9. A detailed explanation about each working function is provided in Table D1 (Appendix D). The management sub-team is responsible for overseeing everything and combining the knowledge from everyone so that the car can succeed. The communication sub-team is accountable for publicizing the company and raising awareness amongst the public. The technical sub-team is in charge of the technical aspects of the car.

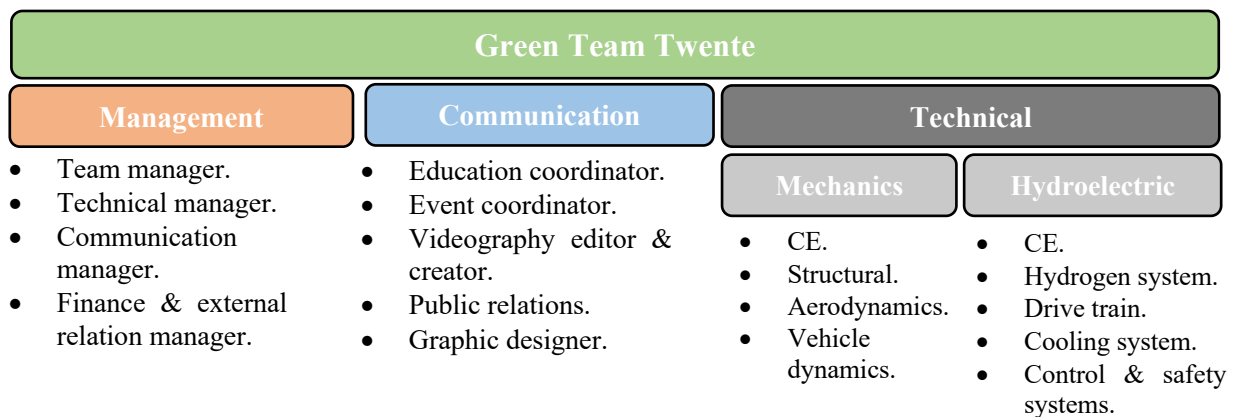


Figure 9 – Functional structure of GTT, which has 3 sub-teams.

GTT hosts and participates in several recruitment events throughout the year. Examples of this are the open days at the company's premises and the career fairs held at the UT and SUAS. Through these activities, GTT intends to bring candidates together and provide them an opportunity to learn more about the firm. Jobseekers can apply for multiple functions. For that they need a curriculum vitae (CV) and a motivation letter, in which they are required to mention, amongst other aspects, what they would like to learn whilst working in GTT and what function(s) they have more interest on. The company in turn, analyses the documents, and selects candidates having into account not only their expertise and wishes but also the extent to which they would be aligned with the company's needs and principles.

The company has a culture of encouraging employees to perform complex and important activities collectively. Members of GTT always want to learn as much as possible. They feel safe asking more experienced and knowledgeable employees for their feedback and opinion on some aspect of the PD project. Even though personnel have less free as the year progresses and the race gets closer, knowledge and ideas are always openly shared between everyone. In fact, the proximity of GTT working spaces allows people to move around with ease. For example, representatives of the management sub-team frequently walk around at the company to assist/inspect other sub-teams. Former GTT employees, who have resumed or started their studies at the UT or SUAS and are not physically present to share their knowledge, continue to support the present development project. They are frequently contacted when current company members need advice, help, and recommendations. This approach is more frequently done by members of the technical sub-team, who sometimes reveal difficulties in implementing the theoretical knowledge into practice. In addition, the student-led organization maintains a close contact with a set of different partner companies that assist when problems arise.

GTT possesses an online encyclopedia (Wikipedia), in which information is provided about how different development activities and car components are done and work, respectively. Every page presents insights about distinct vehicle parts or development stages. Complicated and particularly complex aspects are highlighted. An overview of the Wikipedia used by GTT is presented in Figure D2 (Appendix D). In fact, for the most critical vehicle components, GTT has developed a rather complex risk analysis. Here, not only the severity and probability of occurrence of the risks are presented, but also an explanation about how they can arise. Both online documents are made available for all members of staff, who can easily access and update them. These documents, who are maintained from one year to the other, ensure that newly hired employees know how things get done at GTT.

Once per week, all company members, regardless of their internal function, gather in a meeting that lasts approximately 1 hour. Here, through face-to-face communication, aspects related to the progress of the development activities are discussed. Difficulties are tackled, assignments are clarified, and adjustments are made. In these events, which do not have a fixed location, but are held in meeting rooms (Figures C3 to C5, Appendix C) people acknowledge how their actions affect other employees' jobs and contribute to the final fully developed car. The GTT management sub-team conducted regular evaluations of the work done by the technical sub-team at the beginning of the academic year of 2021/2022. These assessments were aimed at detecting improvement points, and strengths of recently finished activities. However, with the year's progression these assessments stopped being performed, since the time availability of GTT members significantly decreases as the end-of-year race gets closer.

A technical plan is collectively developed at the beginning of the year, including all the major tasks of the development cycle and their respective duration. This document, exhibited in Figure D3 (Appendix D) is posted on one of the GTT exclusive working rooms.

White boards are used by GTT to inform their employees about the most important deadlines of the development cycle. One of the white boards used by GTT is shown in Figure D4 (Appendix D). They are put up in the company's exclusive working areas. Since employees from different sub-teams frequently move around the firm's premises, they all have access to information presented in the boards. Both the management and technical sub-teams use online boards of the Trello application to keep track of their assigned activities. For each task completed, in progress and to be completed information is provided, such as the necessary inputs from other employees. The technical sub-team also uses sticky notes with the same purpose. At the beginning of the 1 year working period, online boards and sticky notes were constantly updated by employees as they were used as important working guidelines.

Nonetheless, as company members become more experienced and knowledgeable about their duties, online boards, and sticky notes lose preponderance. The online boards and sticky notes used by GTT are presented in Figures D5 and D6 (Appendix D), respectively.

GTT has partnerships with several companies that supply materials, parts, knowledge, and financial resources. A list of the GTT partners is shown in Table D2 (Appendix D). Through regular face-to-face meetings both GTT and the sponsors stay up to date to each other's practices and needs. When a sponsor is interested in supporting GTT, the company performs a thorough analyses of its procedures and background to assess if the cooperation is indeed viable and advantageous.

The management's sub-team member asserts that even though GTT documents the overall best practices and successes in guidelines, these are often forgotten or misused by new team members. A way more efficient approach is sharing such information in person to the next year's team members. This normally takes place in the transition period, i.e., the months (July and August) between the race and the beginning of the next academic year.

GTT is present on social media platforms such as Instagram, LinkedIn, and Facebook. The purpose is threefold. First, and most importantly to raise awareness about the potential and advantages of hydrogen in the automotive industry. Secondly, to promote the company, its members, partners, and activities. And lastly, to analyze companies that design, build and race similar vehicles. An example is the Forze Hydrogen Racing (FHR), a company based in the Delft University of Technology (DUT), in The Netherlands. The rivalry between FHR and GTT is healthy. Its leaders frequently communicate through social media to exchange information and insights.

Regarding vehicle requirements, at the beginning of the academic year the complete team gathers and develops a list of broad goals that include, amongst other aspects, the speed, acceleration, and efficiency intended for the current year's car. The requirements are constantly tested. If the team eventually considers the initially objectives as unfeasible or confusing, they are promptly updated. However, according to the management's sub-team member, requirements are more important when the car is fully completed. They are also more strictly followed by the technical sub-team. The most important aspect is achieving a working vehicle, which must be properly understood by the tech sub-team.

GTT holds bi-annual in person meetings with a supervisor board, composed of professors from the UT and SUAS. While the first gathering is aimed at obtaining policy approval, the second one intends to assess whether the budget targets were met. Nonetheless, due to the extremely little time availability of these faculty members, meetings ought to be scheduled 8 weeks in advance.

Overall, all members want the success of the car in the events held at the end of the academic year. No one is easily distracted when performing a working activity. Things and materials are not that quickly found and accessed by all GTT members. To prevent the burnout of employees the company has established fixed lunch and break times across all sub-teams.

4.2 Drone Team Twente

Drone Team Twente (DTT), which logo is shown in Figure 10 (left, top) is a company composed of former and/or future UT students that design and build innovative drones for humanitarian aid. Since its creation, in 2018, the main objectives of DTT have been (We are DroneTeam Twente, 2021; Our Mission, 2021):

- 1) Educating and inspiring people about drones and their applications.
- 2) Innovating and accelerating the drone industry to make a positive impact.

Every year, employees, who can work part-time or full-time in the corporation, are replaced and new personnel takes over. Over the course of its existence, DTT has always had multidisciplinary working teams. Mechanical, electrical, and industrial design engineering, as well as creative and advanced technology are some of the backgrounds found amongst the 2021/2022 DTT team, which is shown in Figure 10 (left, bottom). With this approach, the firm intended to introduce innovation on multiple aspects of the drone and simultaneously offer students from different fields the opportunity to participate in an innovative, sustainable project in which they can put their newly gained knowledge into practice (We are DroneTeam Twente, 2021; Our Mission, 2021). Over the years, DTT personnel has always been divided into different sub-teams. Nonetheless, the names of the sub-teams vary on a yearly basis. For the academic year 2021/2022 it was collectively decided to partition DTT members into 3 distinct sub-teams: board, technical team, and marketing & communication (MarCom). Within each sub-team there are specific working functions. The company's functional structure is shown in Figure 11. A detailed explanation about each working function is provided in Table E1 (Appendix E). The board is responsible for overseeing everything and combining the knowledge from everyone so that the drone can succeed. The MarCom sub-team is accountable for publicizing the company and raising awareness amongst the public as well as maintaining documentation for the following teams. The technical sub-team is in charge of the technical aspects of the drone.



Figure 10 – DTT logo (left, top), the 2021/2022 team (left, bottom), and the drone developed by them (right) (Vreeman, 2022; “Thunderbird,” 2021; We are DroneTeam Twente, 2021).

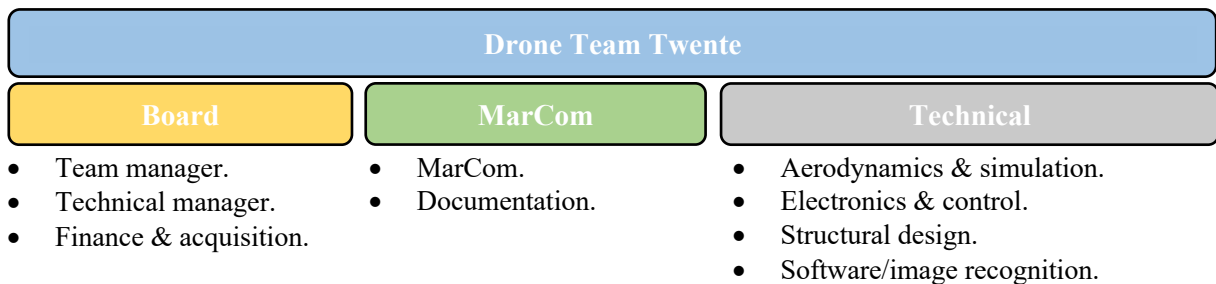


Figure 11 – Functional structure of DTT, which has 3 sub-teams.

On a yearly basis, the team develops a new model of the drone as part of the Institution of Mechanical Engineers (iMechE) unmanned aerial system (UAS) challenge. Starting each October, student teams, such as DTT, undertake a full design and build cycle of an unmanned aerial vehicle (UAV), commonly known as a drone, having into account specifications defined by the iMechE UAS prestigious challenge. These requirements are maintained throughout the year but can vary from year to year. Examples of drone specifications set by the competitive event over the years are shown in Figure 12. A final fly-off event including all participating teams takes place in June of the following year. The drone developed by the 2021/2022 DTT team is shown in Figure 10 (right).

According to the DTT team manager, a lot of setbacks and difficulties emerge throughout the year that no one truly knows how to predict or to deem as a potentially hazardous occurrence. Problems specially arise at 2 different moments. First, at the beginning of the academic year, when team members do not have a lot of experience and practical knowledge, which also results in more time being lost during decision making. Then, throughout the actual design and testing of the drone components. Here, the development risks, roughly estimated at the beginning of the project come to light.

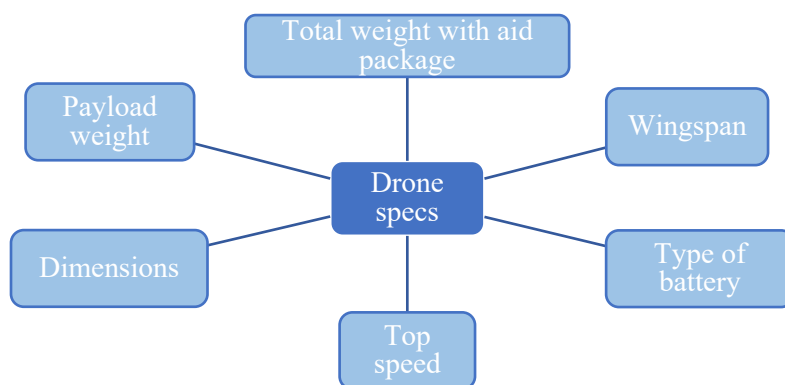


Figure 12 – Some of the drone requirements set by the yearly iMechE UAS competition.

When difficult aspects arise, employees are encouraged to access the Google Drive database maintained by the company over the years which contains a series of guidelines, indications, and recommendations for each functional position. An overview of the DTT know how database is shown in Figure E1 (Appendix E). A general view of the database's specific files used by the team manager and structural designer are shown in Figures E2 and E3 (Appendix E), respectively. Alternatively, DTT members can conduct an online search to obtain further knowledge on a given matter. Sometimes, former members of staff show up in DTT exclusive working spaces, such as the ones depicted in Figures E4 and E5 (Appendix E) to help and provide insights. When physically absent from the workplace, they assist current team members through social media platforms. DTT greatly empowers their employees to communicate with each other when facing situations hard to deal with. The team manager inclusively states that everyone within DTT is extremely open about what they think a problem is. For example, very structured collective brainstorm sessions are performed on a weekly basis. During these events, ideas and solutions are gathered from all team members to solve a specific problem. Nevertheless, DTT only truly analyzes the root causes of problems if the same issue keeps happening repeatedly.

At the beginning of the academic year 2021/2022, the team collectively developed a plan, containing all major tasks and respective duration necessary to accomplish a fully functional drone capable of satisfying the established requirements. Team members opted by representing all development tasks on a yearly scale. Even though this document (Figure E6, Appendix E) has been put up on one of the walls of a DTT exclusive working space, therefore being easily

accessible to all employees, it has not been updated since its creation, due to lack of time. In fact, DTT initially planned to develop 5 drone prototypes, but has only produced 3, since the team underestimated the time necessary for each prototype.

DTT personnel regularly uses the Miro online platform for the purposes shown in Figure 13.

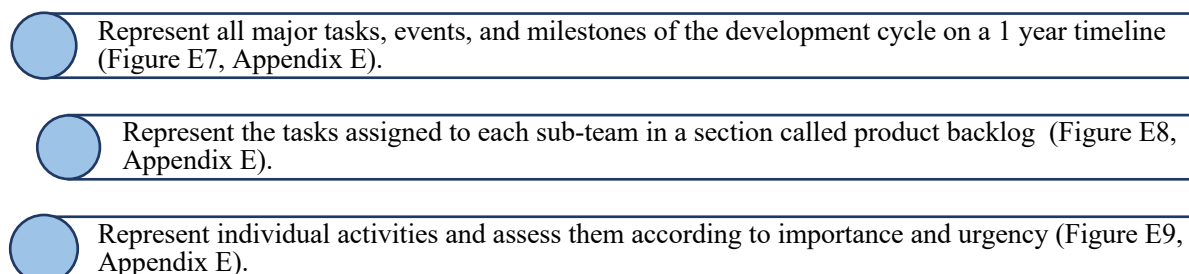
- 
- Represent all major tasks, events, and milestones of the development cycle on a 1 year timeline (Figure E7, Appendix E).
 - Represent the tasks assigned to each sub-team in a section called product backlog (Figure E8, Appendix E).
 - Represent individual activities and assess them according to importance and urgency (Figure E9, Appendix E).

Figure 13 – DTT usage of Miro platform.

According to the team manager, the DTT Miro platform is widely available to all employees, who can, at any given time, access and update its content. This person also considered the product backlog to be rather confusing and misleading. Besides Miro, DTT conducts general meetings every 2 weeks to make all employees acquainted with their tasks and with the status of the development project. These events, which do not have fixed times or durations, can occur either at a specific location within the exclusive DTT working space (Figure E10, Appendix E) or at meeting rooms shared by all Future Factory's based companies (Figures C3 to C5, Appendix C). According to the team manager, regular meetings help employees know what inputs (information, materials) other team members require for a successful completion of their tasks. As the year progresses, people become more experienced and knowledgeable about the development process and the different needs from everyone. Increasingly less time is lost in the trade-offs and in finding objects and materials in the workplace.

After each major activity of the development cycle, such as design reviews, where drone designs are presented to the public, the team gathers and discusses the strengths and possible improvement points of the recently finished task. In addition, DTT employees individually reflect on what could have been done better following the completion of an assignment. Each employee possesses an individual document, to which a page is added every week, containing information such as: challenges faced, important activities, and error prevention. Individual documents are updated throughout the year and maintained from one year to the next.

Every year the DTT team is forced to design and build a totally different drone. Even though drone shapes, looks and functionalities vary on a yearly basis, some development processes can be maintained, such as the manufacturing methods. In fact, for the past 2 years DTT has been producing several drone parts through 3D printing with polylactic acid (PLA). For that, the company uses a set of 3D printers installed in its exclusive working spaces (Figure E11, Appendix E). Some drone components are also ordered online. DTT has established partnerships with an array of companies, which supply financial resources, drone parts, and credit in their physical or online stores. A comprehensive list of the sponsors of DTT is shown in Table E2 (Appendix E).

Towards the halfway point of the academic year, DTT starts advertising work positions for the following year. This can be done online and or via the participation in business days held at local universities. Either way, candidates are always welcomed to learn more about DTT by visiting their facilities and establishing face-to-face conversations with current team members.

Job applicants need a CV and a motivation letter, in which they are required to mention, amongst other aspects, what they would like to learn whilst working in DTT and what function they have more interest on. The company in turn, analyses the documents, and selects candidates having into account not only their expertise and wishes but also the extent to which they would be aligned with the company's needs and principles.

DTT intends to have some days in the transition period (July and August) between the fly-off and the beginning of the following academic year, to inform new hires about the company's procedures. Face-to-face conversations will be held to exchange ideas and explanations will be given to new members on how to access the DTT documentation and the know how database. As a matter of fact, in the team manager's opinion, one of the biggest problems of previous years' transition periods was the new members' blatant unfamiliarity with the existing documentation and database, which caused major delays and wastes of time.

DTT is present on social media platforms such as Instagram, LinkedIn, and Facebook. The main purpose is analyzing the drones and development strategies of the other teams that participate in the iMechUAS Challenge to determine if DTT can achieve more affordable drone solutions.

4.3 Electric Superbike Twente

Electric Superbike Twente (EST) (Figure 14 - left), is a company composed of former and/or future students from the UT and SUAS that design, build and race a fully electric motorcycle. Since its inception in 2017, EST main objective has been to educate the world about the sustainability of electric mobility. The company's sub-target is achieving MotoGP lap times in the national and international events in which participates at the end of each academic year.

Every year, employees, who can work part-time or full-time in the corporation, are replaced and new personnel takes over. Over the course of its existence, EST has always had multidisciplinary working teams. Some of the academic backgrounds and expertise of the 2021/2022 EST workforce are shown in Figure 14 (right). With this approach, the firm intended to introduce innovation on multiple aspects of the racing motorcycle and simultaneously offer students from different fields the opportunity to participate in an innovative, sustainable project in which they can put their newly gained knowledge into practice.

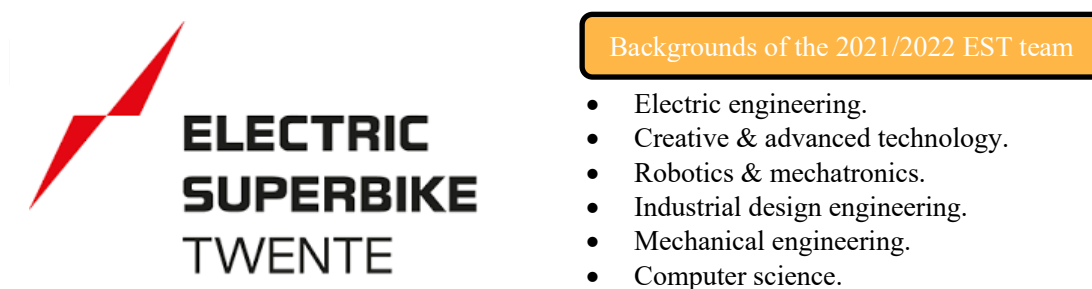


Figure 14 – EST logo (left) and a few of the educational backgrounds of the 2021/2022 team (right) (“K3D partner,” n.d.; Team 2021/2022, 2019).

Over the years, EST personnel has been divided into different sub-teams. The names of the sub-teams are essentially maintained from one year to the other. In fact, the sub-teams ‘management’, ‘powertrain’, and ‘chassis’ have always existed since the company's establishment. In 2019 the firm created a fourth sub-division, ‘marketing’, which was replaced for the broader communications sub-team in the following academic year. Within each sub-team there are specific working functions. The company's functional structure since 2020/2021 is shown in Figure 15. A detailed explanation about each working function is provided in Table

F1 (Appendix F). The management sub-team facilitates the work of all the other sub-teams. Although involving subjects such as team spirit, communication, planning and contact with external parties, the key managerial task is to steer the team away from potential pitfalls. The communications sub-team focuses on the contact to the outside world. They tell EST story to companies and other interested parties. The powertrain sub-team is accountable for delivering brute power to the superbike's rear wheel. These individuals focus on the electronic components of the vehicle. The chassis sub-team is in turn responsible for all the mechanic components in the superbikes. This includes structural parts like the mainframe, but also moving components like the electric motor, transmission, and wheels (Join Now, 2019).

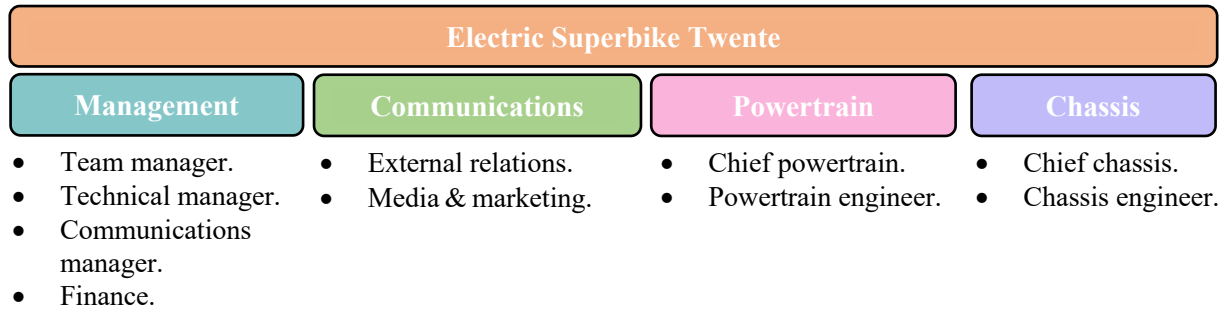


Figure 15 – Functional structure of EST, which has 4 sub-teams.

The interview was conducted with a member of the chassis sub-team. According to this person, a totally new racing motorcycle was designed and built in each one of the first 4 years of EST existence. Major components such as the engine, chassis and transmission were developed from scratch on a yearly basis. The 2021/2022 group, shown in Figure 16 (left), opted, however, to optimize the motorbikes developed by the 2 previous teams instead of producing a brand-new vehicle. With this approach, the team intended to increase the longevity of the 2 former motorcycle models, both also depicted in Figure 16 (left). Among other aspects, the current EST team has improved the cooling system and the power output of both motorbikes. The model built in 2020/2021 and displayed in the bottom right corner of Figure 16 (left) has inclusively received a battery upgrade (Huijbregts, 2022).



EST motorcycles' main specs

- Top speed.
- Acceleration.
- Power of the electric motor.
- Battery capacity.
- Total weight of the vehicle.
- Size of disk brakes.

Figure 16 – 2021/2022 EST team and the motorcycles developed in the 2 previous academic years (left) and the most important specs of EST motorbikes (right) (“Newsletter,” 2021; Delta-XE, 2019).

The team sets a series of broad requirements for the motorcycle at the beginning of each year. Such requisites, shown in Figure 16 (right), are essentially maintained for the entire duration of the annual working period. While the 2020/2021 team calculated the specs, the following year personnel preferred to make estimations. The initially defined specifications are subjected to small changes and adjustments, as they keep being continuously tested throughout the development process.

The components of the motorcycle can be divided into 2 main groups: the electrical system and the chassis. The former comprises parts such as the electric motor, battery pack, motor controller, and the battery management system. The chassis includes the frame, body work,

brakes, suspension, wheels, tires, etc (Delta-XE, 2019). Either way, each motorcycle component except for the battery pack has not only a particular group of detailed specs, but also a specific supplier. EST partners (Table F2, Appendix F) are mostly companies that provide not merely motorcycle parts, but also financial resources and knowledge. The battery pack was acquired with money raised in a crowdfunding campaign. This initiative encouraged people to be directly involved in the motorcycle development, by acquiring 1 or more of the 576 battery cells that make up the motorcycle's battery pack (Kentaa, n.d.).

The member of the chassis sub-team affirms that every Monday the team gathers, in an event called team scrum, to discuss problems and bottlenecks from the previous working week. These meetings do not have a fixed location and can occur either at the Future Factory's meeting rooms (Figures C3 to C5, Appendix C) or at the EST exclusive working spaces (Figures F1 and F2, Appendix F). During these collective activities, ideas and feedback are exchanged between different sub-teams and everyone is assigned their weekly tasks, thus becoming acquainted with what they ought to do. Besides the weekly team meetings, EST has implemented daily scrums within each sub-team with the same purpose. These everyday events and the sub-teams' chiefs, whose one of the roles is precisely aligning their subordinates, make employees aware of each other's needs. In addition, the member of the chassis sub-team asserted that a plan of action is collectively developed during sit down meetings held before each component/vehicle level test with the goal of preventing and solving problems that arose during previous tests. Overall, difficulties frequently come up throughout the project for 2 main reasons. Firstly, because the current team members do not have a lot of hands-on experience in optimizing electric racing motorcycles. Secondly, because none of the EST previous teams have opted by a vehicle optimization approach, which hampers an efficient knowledge transfer.

During the first 2 months of the academic year, EST utilized physical sticky notes (Figure F3, Appendix F) to inform all members of staff about the status of development activities. The post-its contained a brief description of the tasks and their assignees. A white board (Figure F4, Appendix F) was also made use of to present the major milestones and activities of the development project on a weekly basis. However, as time progressed, EST began shifting its attention towards digital means of managing the project. Physical sticky notes have become obsolete and white boards are currently seldomly used. Instead, the usage of the ClickUp online application became widespread since December 2021. EST takes advantage of this digital app for the array of purposes shown in Figure 17.

EST personnel has full access to the enterprise's content in the ClickUp app, which makes them acknowledgeable with other workers' tasks. They can easily change and update any given aspect. In addition to the individual reflection that each employee performs via the online platform, the interviewee further claims that collective reflections are done via 2 distinct ways: meetings established after each component/motorcycle level test and occasional retrospectives. Either way, the objective is always analyzing a recently completed activity, to identify the issues and problems that emerged during its execution.

It was revealed that each EST sub-team has a series of documents, containing information and best practices from previous years, that help employees during task execution. The company is currently working on aggregating all documents in a Wikipedia, a digital know how database widely accessible to all staff members. The member of the chassis sub-team also affirmed that the EST exclusive workspaces are organized monthly.

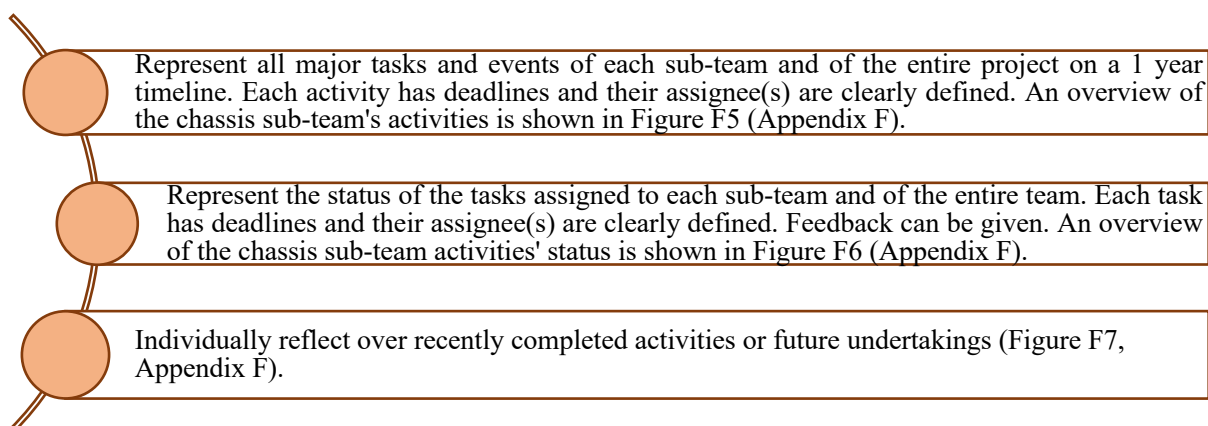


Figure 17 – EST usage of ClickUp digital application.

Decisions within the EST team are normally very quickly made. However, as per the member of the chassis sub-team a situation occurred in the recent past to which managers took too long to act. The incident in cause involved an employee who did not have the necessary expertise to properly know how things get done in the company, and therefore was causing disruptions in the normal operating procedures. Once every month, the EST supervisory board, composed of the current team manager and the external relations' employees from the previous team, analyzes the company's medium/long-term strategy and planning. Feedback is given as promptly as possible.

Towards the halfway point of the academic year, EST starts advertising work positions for the following year. This can be done online and via the participation in business days held at the UT. Regardless, candidates are always welcomed to learn more about EST by visiting their facilities and establishing face-to-face conversations with current team members. They can also learn more about the firm by taking part in the annual motorcycle reveals. Job applicants need a CV and a motivation letter, in which they are required to mention, amongst other aspects, what they would like to learn whilst working in EST and what function they have more interest on. The company in turn, analyses the documents, and selects candidates having into account not only their expertise and wishes but also the extent to which they would be aligned with the company's needs and principles.

It was remarked that the 2020/2021 team did not have enough time to finish the motorcycle, which happened for 2 distinct reasons. First due to the COVID-19 pandemic, which directly affected some individuals, and therefore delayed the development cycle. Second, because new team members lost a great deal of time understanding what exactly they were supposed to do to develop an efficient electric racing motorcycle. The actual development of the vehicle started very late and, consequently, the motorcycle was not ready by the end of the academic year. Nonetheless, the following team did not make the same mistake since they benefited from the help of an expert – an assistance professor in the Engineering Management department at the UT. This individual, with relevant background in product design and product development, provided planning tools and software which allowed the 2021/2022 EST team to start the optimization activities very early on.

To the chassis sub-team member's knowledge there is only 1 company based in the EU that produces electric racing motorcycles roughly similar to the ones developed by EST. The rival corporation, established in Finland, has a totally different team structure and organization, but identical technical aspects. In fact, the 2 firms frequently communicate about technical aspects of the electric racing motorcycles.

4.4 Game Lab Oost

Game Lab Oost (GLO) (Figure 18 - left) is a company composed of individuals with different backgrounds and educational levels that work together to develop applied/instruction games for businesses and industries, such as the healthcare and welfare. The workforce consists of professional experts from the field of game development and students from local universities currently doing their internship in the same subject area. At GLO, personnel have distinct functions, as shown in Table 10. A comprehensive description about each work function is presented in Table G1 (Appendix G). The development team is replaced every semester (“Game Lab East,” 2022). GLO, together with many other companies, are based in a building located in Enschede’s city center (Figure G1, Appendix G). Even though several common spaces are shared, such as the ones shown in Figures G2 to G4 (Appendix G), each firm has their private working space. GLO exclusive area is depicted in Figure G5 (Appendix G).



Figure 18 – The GLO logo (left) and the 3 stages of the company’s development cycle (right) (Boehmers, 2022).

According to GLO, which was founded in 2018, the implementation of relevant games in corporations’ activities results in a significant advantage over the competition. GLO is a viable option for clients to have serious games developed affordably. Besides, the gaming focused company offers students a learning environment and an opportunity for them to start a company based on the games developed for clients. Experts also benefit from GLO by having a chance to further develop game concepts. By combining the knowledge and expertise from students, clients, and game development experts, GLO ensures that innovation is introduced from the initial game idea to the final playable product.

Table 10 – Work functions at GLO (“Vacatures,” 2022).

GLO functions	
○	Game designer.
○	Game artist.
○	Project manager.
○	Programmer.
○	Applied psychologist.
○	Marketing & communication (MarCom).
○	User interaction (UI) and user experience (UX) designer.
○	Sound designer.
○	Game concept artist.
○	Game animator.

Overall, GLO has 3 main objectives. First and most importantly, develop the game industry in the east of The Netherlands, since there are very few gaming development focused companies in the region. Then, provide attractive employment options for students from local universities. And finally, show students the benefits of gaming, which they can apply in their own firms.

GLO can start the development of a new game in 2 different ways. The first and more direct one is by being directly contacted by a client who presents a well-defined assignment. The indirect alternative is if the project manager and MarCom responsible people discover an evident benefit of developing a new game in a particular field (e.g., healthcare), after thoroughly researching the market. The second option requires an additional effort of GLO in finding a

serious client upon completion of the newly developed game. Nonetheless, the development cycle of GLO is composed of 3 distinct steps, as illustrated in Figure 18 (right). According to the interviewee, the project manager, every development step is composed of many working sprints, each lasting from 1 to 2 weeks.

At first, during the inspiration phase, which takes 2 weeks, the team collectively defines the general specifications of the game. This includes identifying the game's targeted audience, as well as the intended age range and academic level of players. On the first day of this step, a 1-page document is elaborated containing a representation of all the tasks that need to be done to accomplish the game. It shows the scope of work decomposed from general to specific matters. During inspiration a written contract is signed with the client. This documents states that although the final playable game will be property of the customer, its development process will be owned by GLO, which in turn can reuse it to create start-ups. Then, in ideation, a 4-week process, GLO members create several different rudimental design solutions for the game through sessions such as sketching and brainstorming. The aim is to come up with a large quantity of ideas that are scrutinized, refined, and eventually broken down into the best, most practical and innovative ones capable of fulfilling the initially defined requirements. These game design solutions are related to:

- ⇒ Features of the game, such as its plot (storyline, main events, and levels), backgrounds, environment, objects, and characters.
- ⇒ The specific way players interact with the game, which entails user friendly graphics, icons, buttons, menus, etc.
- ⇒ Sounds of the game, such as sound effects, music, voices, and the theme song.

Each design is thoroughly analyzed having into account, for example, the possible risks that may come to light during its implementation. As part of the design selection process, GLO compares some of its design solutions to similar examples developed by other companies or individuals (asset pack database). The purpose is to acquire insights about the designs' practical viability. Results and good practices from previous GLO projects are also shared and discussed amongst employees for the same reason. As a matter of fact, current members have access to the applications, documents, video recordings, and trailers from GLO past games. Materials from preceding projects are additionally taken advantage of during interactions with potential clients to showcase the company's capabilities. At the end of ideation, a brief presentation is made for the client about the main aspects of the game to be developed. Moreover, a design document containing the aspects mentioned in Table 11 is also published and made available to the client and all employees.

Table 11 – Content of the GLO design document.

Content of the GLO design document
○ Goal of the project. ○ Some game templates. ○ Main game features and how they will be accomplished. ○ Risks and problems that might arise during the development of the game and how to prevent and solve them, respectively. ○ Explanation of the software that will be used during implementation. ○ All the tasks and respective assignee(s) necessary to accomplish the game.

The last step of the development process, implementation, lasting 16 weeks, consists of practically generating the defined game design solutions. The game requirements proposed in the inspiration phase are constantly tested and updated if the tests' results prove to be unsatisfactory. Every 2 weeks GLO has a playable and consequently testable prototype of the final game. At this point, a collective reflection is made to see if the company is in the right

track to meet the specifications. Clients are always informed about the designs' feasibility and the project's compliance with budget and time constraints. Also, these working game prototypes can be handed over to certain teams who want to continue their development in a start-up. Therefore, GLO promotes the generation of start-ups. Towards the end of this development phase, GLO releases a proof of concept – the minimum game version that can prove that the final game is feasible and/or viable for the client. Face-to-face meetings with the client are regularly held throughout the development cycle. These events, which occur in meetings rooms like the ones shown in Figures G2 to G4 (Appendix G), have variable frequency: always at the end of each development stage, weekly during inspiration and ideation, and every 2 weeks in implementation. Their main purpose is maintaining the customer updated about the game development activities.

In addition, GLO has quick online meetings with the board – composed of a professor from the UT specialized in serious gaming and e-sports, a business developer, and the project manager – on a weekly basis. Aspects such as the development strategy of the company, its documentation, policies, and the compliance with the client's budget are discussed in these digital events. Major decisions are also made here. According to the company's project manager, board members are the individuals with more knowledge about the final game. Each one of GLO meetings is always scheduled at the same day and time.

In the process of developing a game, GLO personnel hardly requires any physical resources, since the company has a well-established digital culture. In fact, GLO builds and stores its software on GitHub – the largest and most advanced development platform in the world ("Where the," 2022). GitHub repository allows GLO developers to work in parallel with each other, regardless of their physical locations. It also functions as a backup tool since it automatically saves the most recent changes in the company's code. Firm members also use boards provided by the Trello and Jira digital applications to represent completed, ongoing, and future activities of the project. Each card contains a brief description of the activity and the name of its assignee(s). Jira is further used by GLO to represent the workflow in diagrams and to create project timelines. Jira's project roadmaps, that can be made for a particular activity or for the whole project, facilitate the understanding of how individual tasks interrelate and contribute to the game's development. Throughout the course of the interview, it was also discovered that GLO possesses a digital art bible, a document in which game artists establish the visual style of the game. The art bible, also known as design guide, is used to ensure the visual style of the project is maintained during the making of it, thus serving as a work reference. GLO information present in GitHub, Trello, Jira, and the design guide is easily accessible to all employees, who can update it at any given time.

Problems, such as bugs in the code/software, game design solutions that do not work as intended, overcomplicated ones, or solutions unable to meet the requirements frequently arise during the implementation development phase. When staff members, especially students who do not have practical experience in game development, encounter the aforementioned difficulties they are encouraged to solve them as early as possible. For that, GLO personnel communicate with other team members, mainly the professional experts and the project manager, who have previous substantial hands-on experience in the area. Usually, the team manager provides feedback at the end of each day. However, since this person works part-time at GLO, and therefore is not always physically available, text messages or social media apps are used to pass on information. In person appointments with the team manager can be made if serious difficulties come to light. Upon facing a difficulty, GLO members can also resort to Google or communicate with employees from the other companies based in the building, such as Tex Town Games (Figure G6, Appendix G), that have similar aspects in regard to the games' development process. Documents containing the difficulties faced, and a breakdown of game

features with their respective explanation are elaborated after each development step. They are updated throughout the project and maintained between projects and semesters. Their main goal is informing future employees about past mistakes. GLO is also working with a student whose research is focused on maintaining knowledge through documentation.

GLO has weekly or biweekly collective reflection meetings throughout the development process, during which team members analyze recently completed activities. A special emphasis is given to encountered setbacks, mainly what could have been done better to tackle them and how to prevent their occurrence in future undertakings. The team manager takes advantage of these reflection sessions to provide practical tips to the GLO students. Moments of reflection are particularly important earlier in the development process when employees are less savvy.

To the project manager's knowledge there is only 1 entity, an internal program of SUAS (Extended Reality (XR) Lab), that also develops applied games for industries. GLO members, including the project manager, are acquainted with the practices done at the rival business, since many of them have done a specialization and/or projects at XR Lab at some point in the past. Unlike GLO, XR Lab does not communicate directly with clients. GLO is always interacting with future clients. Prospective customers/applicants can at any time visit GLO premises to learn more about the firm. Job positions are opened every 3 months. To apply, game designers, artists, and programmers must present their portfolio, which is in turn thoroughly analyzed. After GLO selects the best candidates, conventional face-to-face job interviews are done on an individual basis.

5. Discussion

In this chapter, the collected data from the 4 case studies and the practical feasibility of the proposed assessment tool are going to be analyzed. Initially, each company will be evaluated having into account the extent to which they are reaping the 7 core benefits of APM & LPM tools and techniques. Results will be presented in radar charts, together with a textual explanation, for an easier and clearer understanding. Concurrently with the diagnosis, a set of recommended actions (i.e., practical lean and agile management tools) will be proposed for each company. Then, a reflection is going to be conducted on how the suggested diagnostic tool functioned in practice. Here, several aspects are going to be examined. Examples are the time duration of the assessment method, its capability to detect the presence of agile and lean project management tools in companies, the adequacy of the questions, and major setbacks encountered during the method's execution.

5.1 Diagnosis assessment and recommendations for Green Team Twente

Green Team Twente's diagnostic assessment results are presented in Figure 19.



Figure 19 – GTT diagnostic assessment results.

Problem identification and resolution. GTT has a good set of collective strategies to solve situations that employees do not know how to face or are uncertain how to deal with. Employees have a common understanding about hazards and critical/complex aspects of the car. There is a uniform knowledge about how to prevent the occurrence of risks. When facing a problem, GTT personnel can ask themselves 5 consecutive times why the issue happened, so that its cause is more quickly identified. Also, for an individual problem resolution, GTT can encourage its employees to document drawbacks and how they solved them in A3 online/physical reports. These documents must be maintained throughout the year and for following teams to facilitate the problem solving. GTT can also implement regular retrospective sessions/meetings, during which all employees reflect on the issues and problems faced during a recently completed task. GTT can also opt by having similar car parts from different suppliers to reduce the likelihood of failures.

Knowledge about the product. All GTT team members know about the hydrogen car they develop. However, while the technical sub-team has in-depth knowledge, the other sub-teams possess a broader understanding of the product. To level the employees' perception of the vehicle, 3D digital representations and/or physical/digital prototypes of the vehicle can be created and shown to everyone. Brief descriptions of the vehicle's features and requirements can also be posted in the workplace. Alternatively, GTT can compare car/car component designs having into account certain criteria and present the respective results to all employees. Another option is performing collective test to failure sessions of critical car parts.

Consistent and innovative product. GTT is a company with excellent capabilities in developing increasingly robust and innovative hydrogen cars over the years. The reuse of previous car model's parts has been firmly established and it is done successfully at GTT. For the inclusion of innovative details in the vehicles, GTT can perform collective sessions at the beginning of each year, where members with different backgrounds suggest and reflect on a multitude of car parts' designs, until a final set of best designs is eventually achieved.

Good relationship with external stakeholders. GTT has a very strong relationship with its suppliers. Very regular events have inclusively been established so that both parties can be aligned. Since hydrogen cars are still very recent, it is recommended that GTT maintains the car design as simple as possible, to ensure the public's clear understanding. In fact, GTT pays a great deal of attention in informing the public about hydrogen in the automotive industry. GTT has been following its rivals' practices and cars in a seemingly superficial way. For a more comprehensive understanding, GTT can obtain car parts from the competition, subject them to tests and compare the tests' results to the ones from equivalent GTT car components.

Knowledge about the project. Everyone at GTT is properly acquainted with the major activities and deadlines of the car's development process. Employees competently keep track of their assigned tasks. However, to monitor the work more efficiently, personnel can graphically represent the work left to do versus time. The horizontal axis of the chart shows the time (e.g., days) and the vertical axis shows the amount of work remaining. An estimation line should be plotted prior to initiating an activity. Throughout the activity's execution, individuals can easily visualize if they are on the right track. GTT only sporadically collectively controls the process. To better manage it, GTT can implement daily 15-minute stand-up meetings within each sub-team or, ideally, with the whole team. These events should have a fixed location and can occur at the beginning or at the end of each working day. The meeting's agenda should focus on issues encountered, reflection on lessons learned, and assignments' clarification.

Knowledge sharing amongst employees. GTT employees constantly exchange knowledge and information with each other. The communication is easy and effective between them. To optimize the knowledge transfer between members, GTT can implement regular review periods, during which employees present their work to other members. Workers are encouraged to document practices and information so that new members are informed about them. Nevertheless, the GTT process of informing recently hired employees is still inefficient. A lot of information is lost and/or misused during the employee transition period. To improve this, GTT can define fixed dates during July and August to comprehensively instruct new hires about GTT practices and documents, so no time is lost at the beginning of the new academic year.

Task execution know how. GTT has a strict hiring process that ensures that new members are theoretically competent. No special attention is paid to the applicants' practical experience. The company has some strategies which guarantee that employees know why and how to do tasks. A fair amount of time is still lost in accessing materials at the workplace. GTT can have monthly cleaning sessions of the worksite, to ensure that only the strictly necessary objects are at hand.

5.2 Diagnosis assessment and recommendations for Drone Team Twente

Drone Team Twente's diagnostic assessment results are presented in Figure 20.



Figure 20 – DTT diagnostic assessment results.

Problem identification and resolution. DTT possesses a significant set of individual and collective strategies to solve setbacks and issues that arise during the drone's development. However, they are not very efficient since problems keep happening over and over again. To solve this, DTT brainstorm sessions' focus must be shifted into analyzing what caused the problems and not on how to quickly fix them. The frequency of these sessions may also be shortened to a daily basis. For a better understanding of the causes of the problems, DTT can appoint/hire an expert whose one of the responsibilities is leading the collective resolution of complicated situations within the technical sub-team. Managers can also schedule walk arounds to oversee the tech team's job. To detect the root cause of drone's design inconsistencies, DTT can take advantage of the CAD system. DTT personnel is fairly incapable of predicting risks or setbacks. DTT is urged to develop a risk assessment matrix. This matrix should include the drone's risks, a brief description of how they can come about, and an indication of the risks' severity and probability of occurrence. To diminish the likelihood of failures, DTT can also acquire similar drone parts from distinct suppliers.

Knowledge about the product. There is a roughly uniform understanding about the drone amongst the DTT workforce. Locally produced drone components, drone prototypes, and collective design reviews are some of DTT approaches to accomplish a standardized product knowledge.

Consistent and innovative product. DTT has proven it can introduce innovative aspects in its drones. Still, during the process of designing drone parts, all team members should equally contribute with design ideas and insights that are analyzed and successively perfected. DTT drones' performance and reliability have been inconstant and unpredictable over the course of the firm's existence. Even though constrained by extremely strict requirements, DTT should strive to reuse some components and/or architectures from previous drone models.

Good relationship with external stakeholders. The communication between DTT and its partner companies still occurs ad-hoc. This may indicate that DTT is not fully satisfied and aligned with the practices of its suppliers. Given the significant number of partners, the best strategy would be to select them based on an optimal trade-off between price, delivery times, and the ability to meet the imposed drone's requirements. DTT has solid methods to inform the public about its drones. By testing and analyzing specific parts of drones from rival companies, DTT would enhance its understanding about other iMechUAS Challenge participants.

Knowledge about the project. DTT employees are properly informed about the major deadlines and events of the drone's development cycle. Individual and sub-teams' tasks are managed and tracked in a somewhat confusing way. To facilitate the work's monitoring, DTT can perform daily 15-minute meetings within each sub-team or, preferably, with the whole team at the beginning or at the end of each working day. Meetings ought to have a fixed time and location. The aim of these events should be clarifying assignments. To reduce the confusion around DTT product backlog, employees can represent their own and their sub-team's activities in a digital board with multiple columns. Each column represents the status of a task (e.g., completed, in progress, waiting for feedback, to be completed).

Knowledge sharing amongst employees. DTT employees easily and effectively exchange opinions and information with each other. Personnel is motivated to document practices and difficulties encountered so that future employees are informed about them. No strategy is defined to inform new hires about the practices and documents of DTT. The company can schedule a period after the fly-off to instruct future employees on a face-to-face basis.

Task execution know how. DTT has a hiring process that guarantees that new members are theoretically competent. No special attention is paid to the applicants' practical experience. The company has some strategies which guarantee that employees know why and how to do tasks.

5.3 Diagnosis assessment and recommendations for Electric Superbike Twente

Electric Super Bike's diagnostic assessment results are presented in Figure 21.



Figure 21 – EST diagnostic assessment results.

Problem identification and resolution. EST demonstrates outstanding collective capabilities to solve difficult to deal with situations. Nevertheless, individuals are still quite incapable of tackling problems by themselves. Upon facing an issue, employees can write about it (including the resolution) in a physical/digital document that must be maintained for the future. When the same problem arises, team members will know how to solve it if they access the document. The firm still reveals difficulties in roughly predicting hazardous occurrences. A risk matrix can be made including the motorcycle's risks, their brief description and a quantitative assessment of their severity and likelihood of occurrence. The document must be made available to everyone.

Knowledge about the product. The knowledge about the motorcycle is still not uniform at EST. Powertrain and chassis sub-teams know more about the product than the remaining sub-teams. However, EST has already some practices that are aimed at standardizing the product's understanding. Since the previous motorbike's models are currently being improved, EST can compare the performance of non-optimized and optimized components and present the results to all employees. This can be achieved by mapping 2 important parts' characteristics on a graph and then plotting curves to illustrate the performance of both components relatively to the 2 characteristics. Results can be put up on the walls of EST exclusive working spaces. Individuals from the powertrain and chassis sub-teams can also evaluate the robustness and performance of designs and components of the motorcycle by taking advantage of the CAE software. Collective sessions including people from all sub-teams should then be scheduled with the purpose of presenting and explaining the CAE simulations' results.

Consistent and innovative product. The consistency and strong points of EST motorbikes cannot be maintained over the years. The performance of the vehicle's parts has always been unpredictable. While optimizing parts (e.g., cooling system), the team should strive to maintain certain designs, architectures, and even parts to replicate successes from previous models.

Good relationship with external stakeholders. EST is clearly satisfied with the service provided by its partner companies. Each supplier has well-defined tasks within EST. Since electric racing motorcycles are extremely recent in the market, it is recommended that EST takes part in regular meetings with the suppliers, where the latest technology breakthroughs are presented and discussed. EST is properly aware of the technical aspects of the rival company's motorcycle. EST has a good strategy to involve and inform the public about its motorcycles.

Knowledge about the project. EST holds very regular collective sessions to track the activities' progress. All these gatherings ought to have fixed times and locations to increase their efficiency. EST online strategy to trace the workflow at all levels is extremely compelling and easily understandable. Individuals are constantly informed about recently completed tasks.

Knowledge sharing amongst employees. Current EST employees regularly and efficiently exchange information with each other. The staff is encouraged to register good practices and problems in documents that are maintained for future teams. Yet, EST new hires still lose a great deal of time at the beginning of the year being acquainted with what they have to do. Therefore, EST cannot ensure that the motorcycle will be ready by the end of the year. To improve this aspect, EST can schedule a fixed period subsequently to the race, during which former employees teach new ones on how things get done at EST, mainly how the company's documents and content in the ClickUp digital application are accessed and updated.

Task execution know how. EST possesses a hiring process that guarantees that new members are theoretically competent. More focus should be given to the applicant's practical hands-on experience. The company has a significant set of strategies that ensure employees know why and how to do tasks. No time is lost accessing materials and objects at the EST workplace.

5.4 Diagnosis assessment and recommendations for Game Lab Oost

Game Lab Oost's diagnostic assessment results are presented in Figure 22.



Figure 22 – GLO diagnostic assessment results.

Problem identification and resolution. GLO has excellent capabilities in dealing with the problems that come to light during the games' development. Difficult situations are solved as quickly and as effectively as possible. Current employees strive for informing future members about challenging situations they encountered and mistakes they made. To further improve its capacity to solve issues, GLO can encourage its more experienced members (project manager and professional experts) to regularly, for example on a weekly or biweekly basis, check the work currently being done by the students. The latter are more prone to make mistakes and/or not knowing how to solve complicated matters and thus would benefit from such supervision. GLO personnel is also properly informed about the risks that may arise throughout the development of the game. GLO has a well-defined risk prevention strategy. Employees are competent in roughly estimating how and why risks can appear.

Knowledge about the product. All GLO employees have a very good overall understanding of the games they develop. They are familiar with specific games' templates, features, software, and designs. Staff members are acquainted not only with the games' designs practical viability but also with how they relate to each other. Everyone knows the limitations of the initially defined game requirements. Personnel continuously perfect their vision of the final product. Nonetheless, the in-depth knowledge about the games is clearly not uniform amongst GLO staff. GLO can conduct general comprehensive evaluations of individual game designs, elements, and templates. These assessments can be achieved by mapping 2 relevant game's characteristics on a graph and then plotting curves to illustrate the performance of the designs, elements, and templates relatively to the pair of features. Descriptions of the changes requested by the client on games' elements and requirements should constantly be posted in the workplace or, in alternative, made digitally available to all employees, especially the less experienced students.

Consistent and innovative product. GLO possesses a set of solid strategies that ensure the introduction of innovation in aspects of the game, such as the game's objects, characters, icons, levels, and soundtrack. The company cannot still fully guarantee a predictable performance of the elements of its games. For that to happen, team members should try to reuse or adapt successful designs and practices from previous games produced by GLO or other companies.

Good relationship with external stakeholders. GLO has an extremely close relationship with its clients. The latter are constantly updated about the requested game features, elements, and designs and how they will be accomplished. Customers have a very clear perception of the final game. This understanding of the game keeps constantly being refined throughout the entire development project. To ensure that customers always understand the final playable game, GLO should try to keep the game's features, elements, and designs as simple as possible. GLO can also occasionally invite customers or their representatives to visit the company's facilities to observe how their game is being developed and exchange information with the personnel. GLO is fairly acquainted with the games developed by the competition.

Knowledge about the project. GLO partitions the development cycle of each game into well-defined and time boxed stages, which all employees are very familiar with. Staff members are informed about the goal of the project and the set of tasks necessary to bring the final game to fruition. Employees can efficiently keep track of their individual tasks and of the most important activities of the project. Everyone knows how individual tasks contribute to the success of the project. There is a uniform collective understanding about the strengths and weaknesses of recently completed tasks. To enhance the workforce's knowledge about a given GLO project, the company can implement daily 15-minute stand-up meetings involving all employees. The aim of these events is discussing issues encountered during that day's work and clarifying individual assignments and strategies. Online events with the same purpose can be held as an alternative. GLO can also better control the work done in each iteration and development stage by representing the work left to do (in hours) versus time (in days) on a graph. The firm should start by making an estimation and then plotting the real values to assess if it is in the right track.

Knowledge sharing amongst employees. GLO possesses a vast set of in-person collective activities in which ideas and information are exchanged. More experienced members are motivated in sharing their expertise with less knowledgeable staff members. Students feel encouraged in requesting help and assistance whenever necessary. The communication between all GLO members appears to be quite effective. GLO personnel is capable of frequently being in touch with the board. The company has a deep-rooted culture of promoting the dissemination of knowledge through an extensive array of documents and databases with shared access and contribution. GLO has a good strategy to guarantee that new members do not lose time being familiar with the firm's working procedures at the beginning of the employment period.

Task execution know how. GLO hiring process examines the practical experience of applicants. Current employees have a solid work reference to maintain the games' visual style. They know how game features will be accomplished. However, the personnel's knowledge about the code/software of games can still be improved. GLO can develop a computerized know how database in which information about coding best practices, recommendations and guidelines is presented to all employees. The goal is that team members know exactly how to do a coding task and why they do it. As an alternative, GLO can implement daily sessions at the beginning of each day where more experienced members provide insights about the code/software necessary to achieve intended game features.

5.5 Reflection about the proposed diagnosis assessment instrument

Generally, the proposed diagnosis assessment instrument worked satisfactory since it was capable of collecting the necessary information to assess the 4 companies on the 7 benefits of APM and LPM in a practical and quick way. Therefore, its core objective was accomplished. Out of the 4 interviews carried out, only one exceeded the pre-established time limit of 1 hour. In fact, the interviews with GTT, DTT, and EST lasted between 30 and 45 minutes. The interview held with the GLO project manager took approximately 1 hour and 15 minutes. This was due to the fact the interviewer was particularly unfamiliar both with the company and with game development terms and definitions. The time devoted for the development of the suggested assessment tool was a few dozens of hours. Financial resources were only spent during the application process, which was conducted during the employees' paid working hours. This means that the 4 companies ended up paying for the time their employees dedicated to the interviews.

The predefined order of the questions was successfully followed. However, occasionally the information provided in some of the initial questions proved to be sufficient to answer subsequent ones. A small number of questions required minor adjustments since the respondents were not totally sure about what was being asked. A more significant number of queries was inclusively deemed as extremely interesting and relevant by the interviewees. As intended, a small discussion was initiated after each main question. The discussion moment revolved around the follow-up questions. Most of them were successfully asked and answered. A great deal of information was collected in each one of the 4 semi-structured interviews. However, some of the answers were not totally satisfactory and/or complete. This resulted in the retrieved information having to be complemented by data obtained from the companies' websites. All the information was eventually presented in a compelling and structured way in chapter 4 of this thesis. As a matter of fact, a certain degree of knowledge about the companies is recommended prior to initiating the practical application of the proposed assessment tool. This previous understanding allows the questioner to better adapt the queries to the company, thus sticking to important information, and avoid lengthy discussions about irrelevant details.

Overall, it was clear that the repliers always tried to answer the questions to the best of their knowledge. In fact, the suggested diagnosis assessment tool functions particularly well when the respondents have not only a good understanding of the company they work for, but also the time availability and willingness to publicly disclose this information. All 4 respondents partially displayed these 3 characteristics. The interviewed member of GTT management team showed some reluctance in revealing more sensitive information. In addition, close-up photos of the hydrogen car were also not allowed. Both actions can be justified by the fact that the end-of-year race was due in only 1 week. All the other non-profit student-led organization did not oppose in any way to reveal information and allow photographs to be taken. The EST race and DTT fly-off were still 1-2 months away from taking place. GLO, being a service provider, i.e., a profitable organization, also did not allow photographs being taken of the firm's practices.

The proposed diagnostic method detected several APM and LPM tools and techniques being used by the 4 low maturity technical organizations. The detection capacity of the suggested method regarding LPM and APM tools/techniques is shown in Tables 12 and 13, respectively. In these tables, grey cells mean that the assessment method was not capable of detecting the presence of the respective tool/technique. Green cells indicate the detection of the corresponding tool/technique. The darker the green the closer the similarity with the tool/technique description presented in chapter 3. Some of the tools/techniques were not applicable to Game Lab Oost (GLO).

Table 12 – Capacity of the proposed assessment method to detect LPM tools/techniques in the 4 case study companies (Grey - no detection; Green (light to dark) - level of similarity with the definition).

	GTT	DTT	EST	GLO
3D digital mockups				Not applicable
5 whys				
A3 problem solving report				
CAD				Not applicable
CAE				Not applicable
Chief engineer				
Competitor teardown				
Computerized know how databases				
Concept paper				
Constant omnidirectional communication				
Cross checking				
Cross functional teams				
Daily wrap-up meetings				
Decision matrices				
Design standardization				
Engineering checklists				
Guest engineers				
Inspection at the source				
Mentoring employees				
Milestone table				
Process standardization				
Product development value stream mapping				
Redundancy of parts				
Rigorous application selection process				
Rigorous supplier selection process				Not applicable
Risk assessment matrix				
Set-based concurrent engineering				
Status boards				
Supplier technology demonstrations				
Team room				
Test to failure				
Trade-off curves				

Table 13 – Capacity of the proposed assessment method to detect APM tools/techniques in the 4 case study companies (Grey - no detection; Green (light to dark) - level of similarity with the definition).

	GTT	DTT	EST	GLO
Alternate external stakeholder representation				
Burndown chart				
Constant planning				
Daily stand-up meetings				
Employee colocation				
Frequent value delivery				
On-site external stakeholders				
Optimal working area				
Physical task board				
Product backlog				
Retrospective sessions				
Review period				
Self-organized interdisciplinary teams				
Simple product design				
Time boxing				
User stories				

6. Conclusions

The objective of the work presented in this thesis was to develop a diagnostic tool based on agile project management (APM) and lean project management (LPM). This tool allows small and medium-sized enterprises (SME) to understand the extent to which they are reaping the benefits of APM & LPM techniques, as well as to identify specific APM & LPM techniques which can be implemented to improve the SME practices. In order to fulfill this global objective, the following 5 sub-objectives were defined, thus creating a guideline for this thesis:

1. Investigate the definition of APM and respective techniques and tools.
2. Investigate the definition of LPM and respective techniques and tools.
3. Understand the state of the art of current APM and LPM diagnostic tools.
4. Propose an APM and LPM diagnostic tool.
5. Verify and validate the proposed diagnostic tool by applying it in 4 case studies.

The first sub-objective was answered by performing an extended literature study. It was concluded that APM is a methodology that allows companies to constantly adapt to changing customer and market requirements. An agile company frequently delivers value to its clients. APM encourages firms to continuously improve their product development process in order to meet the stakeholders' requests. Also included in this literature study was an overview of the 16 different practical APM techniques and tools. Each of these has a direct benefit.

The second sub-objective was fulfilled by performing an extended literature study. It was concluded that LPM is an approach which enables corporations to produce more innovative and valuable products by spending less resources (capital, materials, and time). LPM encourages the creation and dissemination of knowledge amongst the firm's personnel. The literature review also included an overview of the 30 different practical LPM techniques and tools, each having a direct benefit.

The third sub-objective was fulfilled through a comprehensive bibliographic review. A total of 12 different APM & LPM assessment methods were analyzed. It was observed that almost all the current evaluation methods directly assess the presence of either APM or LPM tools and techniques. However, these methods are unable to determine if companies are taking advantage of the benefits of APM & LPM tools and techniques. It was also concluded that some of the 12 assessment methods do not have an efficient time and cost trade-off. In addition, certain assessment tools possess unprecise ways of presenting the final evaluation results. It was further verified that most of the analyzed assessment methods are strict and broad, thus unsuitable for adaptation to the company being studied. It was found that only a small number of researchers have included direct observations of the company's practices in their assessment methods.

The fourth sub-objective was accomplished through the creation of a more practical and effective assessment method, thus differentiated from the existent ones. The proposed method was composed of 2 parts. The first one consisted of a mix of close and open-ended questions, but mainly the latter. The first few questions were aimed at understanding the company. The remaining queries focused on assessing if the firm is reaping the benefits of APM & LPM techniques and tools. A total of 7 core benefits were determined after narrowing down the somewhat redundant and similar benefits of all the 46 APM & LPM tools and techniques found and analyzed during the previously mentioned literature reviews. The second part of the suggested assessment tool, sometimes concurrent with the first, consisted of a moment to directly observe the practices being done by the firms. During this time, photographs were taken and working procedures were documented.

The last sub-objective was satisfied by applying the developed assessment method to 4 SME. It was concluded that all 4 low maturity technical organizations are already taking advantage of the 7 main benefits of APM & LPM tools and techniques. They do it by implementing specific lean and agile project management tools/techniques, adapting them, or doing similar practices. However, the level of fulfilment of these benefits varies within companies. It was discovered that all analyzed SME are presently doing a large number of APM & LPM tools and techniques, although the companies are generally not aware that such practices are indeed a part of lean and agile project management methodologies. For example, the GLO team manager was unaware that Scrum – which GLO clearly takes advantage of – is in fact based on APM tools and techniques. The case study companies can still improve in most benefits if they adopt the proposed recommendations, which are practical APM & LPM tools and techniques. It was found that there are certain improvements that companies can make that do not fall within the scope of the present thesis. As an example, GTT can shorten the time in advance with which meetings with its supervisory board are scheduled. Another example is for EST managers to make quicker and more regular decisions.

6.1 Recommendations and future work

One key aspect for future applications of the proposed assessment method is to include a validation stage. This can be done with brief 30-minute face-to-face discussions with the same company members that took part in the interviews. The goal is to understand if companies agree with the evaluation done and consider the proposed recommendations as useful and applicable. As it happens, the validation process for the 4 case studies considered is still ongoing. It is expected to be conducted throughout the months of July and August of 2022. In the future, the suggested assessment method can also be vetted by an APM/LPM expert prior to being practically applied. The aim should be refining the questions and its structure.

The present assessment method was applied to only 1 member of the company. Throughout this thesis, it became clear that the knowledge about the final product and its development process is still not uniform amongst company members with different working positions. Therefore, future studies can analyze the possibility of having a questionnaire with inquiries for different staff members. As an alternative, the same questions can be asked to individuals with distinct backgrounds and/or from contrasting sub-teams/departments. Both alternatives would result in the collection of much more information, which could in turn improve the capacity and detection range of the proposed assessment tool.

The proposed evaluation tool showed good performance, although it cannot be considered fully reliable due to insufficient testing. One of the key aspects would be to further test the method in more low technical maturity organizations, mainly technological start-ups, which were not analyzed in this research. In addition, for future works it is advisable to conduct a more comprehensive comparison between the coverage and capacity of the proposed and existing APM/LPM assessment methods. Finally, more work can be done in determining if the partition into the 7 core APM/LPM benefits was appropriately conducted and if no relevant advantages were left out.

References

- Abrahamsson, P., Warsta, J., Siponen, M.T., Ronkainen, J. (2003). New directions on agile methods: A comparative analysis. *Proceedings – International Conference on Software Engineering*, 244-254. <https://doi.org/10.1109/icse.2003.1201204>.
- Agile tools and techniques. (2019, January 18). Gov.UK: Service Manual. Retrieved from <https://www.gov.uk/service-manual/agile-delivery/agile-tools-techniques>.
- Ambler, S. (2002). *Agile Modeling: Effective Practices for Extreme Programming and the Unified Process*. Wiley, New York.
- Andrei, B.A., Casu-Pop, A.C., Gheorghe, S.C., Boianuiu, C.A. (2019). A Study on Using Waterfall and Agile Methods in Software Project Management. *Journal of Information Systems & Operations Management*, 13(1). Available at <http://www.rebe.rau.ro/RePEc/rau/jisomg/SU19/JISOM-SU19-A12.pdf>.
- Are you the next world champion? (2022). Green Team Twente. Retrieved from <https://www.greenteamtwente.nl/join/>.
- Aronsson, M. (2004). Education matters – but does entrepreneurship education? An interview with David Birch. *Academy of Management Learning & Education*, 3(3), 289-292.
- Balaji, S., Murugaiyan, M.S. (2012). Waterfall Vs V-Model Vs Agile: A Comparative Study on SDLC. *International Journal of Information Technology and Business Management*, 2(1), 26-30.
- Ballard, G., Howell, G.A. (2003). Lean project management. *Building Research & Information*, 31(2), 119-133. <https://doi.org/10.1080/09613210301997>.
- Bang, T.J. (2007). *An Agile Approach to Requirement Specification*. In: Concas, G., Damiani, E., Scotto, M., Succi, G. (eds). *Agile Processes in Software Engineering and Extreme Programming. XP 2007. Lecture Notes in Computer Science*, vol 4536. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-73101-6_35.
- Beck, K. (2000). *Extreme Programming Explained: Embrace Change*. Addison-Wesley.
- Beck, K., Andres, C. (2005). *Extreme Programming Explained: Embrace Change*. (2nd edition) Addison-Wesley Professional.
- Beck, K., Beedle, M., Bennekum, A.V., Cockburn, A., Cunningham, W., Fowler, M., Grenning, J., (...), Jeffries, R. (2001). *Manifesto for Agile Software Development*. Retrieved from <http://agilemanifesto.org/iso/en/manifesto.html>.
- Benjamin, C. (2022). Lean Manufacturing Diagnostic Assessment: Researcher's Perspective. *SEMS: Society for Engineering and Management Systems*. Retrieved from <https://www.iise.org/SEMS/details.aspx?id=39526>.
- Bjarnason, E., Wnuk, K., Regnell, B. (2011). *A case study on benefits and side-effects of agile practices in large-scale requirements engineering*. In *Agile RE*.
- Blessing, L., Chakrabarti, A. (2009). *DRM, a Design Research Methodology*. Springer.
- Boehm, B., Turner, R. (2003). *Balancing agility and discipline*. Addison-Wesley Professional, Boston.
- Boehmers, C. (2022). *Gamelab East Foundation*. HealthValley Netherlands. Retrieved from <https://www.healthvalley.nl/nl/netwerk/partners/stichting-gamelab-oost/>.
- Borba, J.C.R., Trabasso, L.G., Pessôa, M.V.P. (2019). Agile Management in Product Development. *Research-Technology Management*, 62(5), 63-67. <https://doi.org/10.1080/08956308.2019.1638488>.
- Braak, M. (2018). *Implementing lean product development to tech startups* [Master Thesis, Faculty of Engineering Technology, University of Twente].
- Campbell, B., Iver, R.M. (n.d.). *Agile Maturity Self-Assessment*. Available at <http://www.robbiemaciver.com/documents/presentations/A2010-Agile%20Maturity%20Self-Assessment.pdf>.
- Cao, L.C.L., Ramesh, B. (2008). Agile Requirements Engineering Practices: An Empirical Study. *IEEE Software*, 25(1), 60-67. <http://dx.doi.org/10.1109/MS.2008.1>.

- Carlson, D., Matuzic, P. (2010). *Practical agile requirements engineering*. In 13th Annual systems engineering conference.
- Carter, J. (2021). *New Product Development Process* [Definitive Guide]. TCGen. Available at <https://www.tcgen.com/downloads/New-Product-Development-Process-Definitive-Guide.pdf>.
- Casteren, W.V. (2017). *The Waterfall Model and the Agile Methodologies: A comparison by project characteristics – short*. <https://doi.org/10.13140/RG.2.2.10021.50403>.
- Chappell, E. (2020, June 11). *What is Waterfall Project Management? (Process, Pros, Cons)*. ClickUp blog. Retrieved from <https://clickup.com/blog/waterfall-project-management/>.
- Clark, D. (2021, 7 July). *Number of small and medium-sized enterprises (SMEs) in the European Union (EU27) from 2008 to 2021, by size*. Statista. Available at <https://www.statista.com/statistics/878412/number-of-smes-in-europe-by-size/>.
- Clayton, R.F. (2014). *Lean Diagnostic Tool*. ToAZ. Retrieved from <https://pdfcoffee.com/lean-diagnostic-tool-pdf-free.html>.
- Cohn, M. (2005). *Agile Estimating and Planning*. Prentice Hall PTR, New Jersey.
- Conforto, E., Amaral, D., Silva, S., Felippo, A. (2016). The agility construct on project management theory. *International Journal of Project Management*, 34(4), 660-674. <https://doi.org/10.1016/j.ijproman.2016.01.007>.
- Davis, B. (2012). *Agile Practices for Waterfall Projects: Shifting Processes for Competitive Advantage*. J. Ross Publishing.
- Debois, S. (2022, March 8). *10 Advantages and Disadvantages of Questionnaires*. SurveyAnyplace Blog. Retrieved from <https://surveyanyplace.com/blog/questionnaire-pros-and-cons/>.
- Deemer, P., Benefield, G., Larman, C., Vodde, B. (2012). *A Lightweight Guide to the Theory and Practice of Scrum: Version 2.0*. The Scrum Primer. Available at https://scrumprimer.org/scrumprimer20_small.pdf.
- Delta-XE. (2019). *Electric Superbike Twente*. Retrieved from <https://electric superbiketwente.nl/superbikes/delta-xe/>.
- Denning, S. (2021, June 3). *A Powerful Diagnostic Tool for Agile Enterprises*. Forbes. Retrieved from <https://www.forbes.com/sites/stevedenning/2021/01/03/a-powerful-diagnostic-tool-for-agile-enterprises/?sh=509a32d13813>.
- Elssamadisy, A. (2006). Getting Beyond “It Depends!”: Being Specific But Not Prescriptive About Agile. *Practice Adoption Agile Journal*.
- European Commission. (2019). *User guide to the SME Definition*. Available at <https://ec.europa.eu/docsroom/documents/42921>.
- Fowler, M., Beck, K., Brant, J., Opdyke, W., Roberts, D. (1999). *Refactoring: Improving the Design of Existing Code*. Addison Wesley, Reading, Massachusetts.
- Fraser, S., Mellon, B., Dunsmore, K., Lundh, E. (2001). XP requirement negotiation workshop. In *XP requirement negotiation workshop co-located with XP2001 – The second international conference on eXtreme programming and agile processes in software engineering*, Villasimius, Cagliari, Italy, 23rd May 2001, 26-31.
- Fumagali, L., Ierace, S., Dovere, E., Macchi, M., Cavalieri, S., Garetti, M. (2011). Agile diagnostic tool based on electrical signature analysis. *IFAC Proceedings Volumes*, 44(1), 14067-14072. <https://doi.org/10.3182/20110828-6-IT-1002.02873>.
- Game Lab East in a nutshell. (2022). Stichting Game Lab Oost. Retrieved from https://gamelaboost-nl.translate.goog/over-ons/?_x_tr_sl=nl&_x_tr_tl=en&_x_tr_hl=pt-PT&_x_tr_pto=sc.
- Güell, F. (2020, March 29). *Organizational maturity*. Agile Innovation. Retrieved from <https://www.fguell.com/en/organizational-maturity/>.
- Heemskerk, K. (2022). *Green Team Twente*. Euro Circuits. Retrieved from <https://www.eurocircuits.com/blog/green-team-twente/>.

- Highsmith, J.A. (2002). *Agile software development ecosystems*, 13. Addison-Wesley Professional.
- Highsmith, J., Fowler, M. (2001). The Agile Manifesto. *Software Development*, 9(8), 29-30.
- Hines, P., Francis, M., Found, P. (2006). Towards lean product lifecycle management: a framework for new product development. *Journal of Manufacturing Technology Management*, 17(7), 866-887.
- Hoda, R., Noble, J., Marshall, S. (2008). Agile project management. *New Zealand computer science research student conference*, 6, 218-221.
- Hoda, R., Noble, J., Marshall, S. (2011). The impact of inadequate customer collaboration on self-organizing agile teams. *Information and Software Technology*, 53(5), 521-534.
- Hoppmann, J. (2009). *The Lean innovation Roadmap - A Systematic Approach to Introducing Lean in Product Development Processes and Establishing a Learning Organization* [Diploma Thesis, Technical University of Braunschweig]. Available at https://dspace.mit.edu/bitstream/handle/1721.1/81770/TH_090601_Hoppmann.pdf?sequence=1&isAllowed=y.
- Huijbregts, J. (2022). *Student team Electric Superbike Twente shows engines for the coming racing season*. Retrieved from <https://tweakers.net/nieuws/195912/studententeam-electric-superbike-twente-toont-motoren-voor-komend-raceseizoen.html>.
- Hunt, J. (2006). *Agile software construction*. Springer, London.
- Jalali, S., Wohlin, C. (2011). Global software engineering and agile practices: a systematic review. *Journal of Software: Evolution and Process*, 24(6), 643-659. <https://doi.org/10.1002/smr.561>.
- Join Now. (2019). Electric Superbike Twente. Retrieved from <https://electricsuperbiketwente.nl/join-now/>.
- Join Us (...). (2021). Drone Team Twente. Retrieved from <https://electricsuperbiketwente.nl/join-now/>.
- Ju, X., Ferreira, F., Wang, M. (2020). Innovation, agile project management and firm performance in a public sector-dominated economy: Empirical evidence from high-tech small and medium-sized enterprises in China. *Socio-Economic Planning Sciences*, 72, 100779. <https://doi.org/10.1016/j.seps.2019.100779>.
- Jun, L., Qiuzhen, W., Lin, G. (2010). Application of agile requirement engineering in modest-sized information systems development. In *2010 second world congress on software engineering*, 1, 207-210.
- Jurado, M.C. (2012). *Visual Planning in Lean Product Development* [Masters thesis, KTH Royal Institute of Technology in Stockholm]. Available at <http://www.diva-portal.org/smash/get/diva2:600974/FULLTEXT01.pdf>.
- K3D partner Electric Superbike Twente. (n.d.). K3D Masters in 3D Metal Printing. Retrieved from <https://k3d.nl/nieuws-bericht/k3d-partner-electric-superbike-twente/>.
- Karlsson, C., Ahlstrom, P. (1996). The difficult path to Lean Product Development. *Product Innovation Management*, 13(4), 283-295.
- Kennedy, M. (2003). *Product development for the lean enterprise: why Toyota's system is four times more productive and how you can implement it*. Oaklea Press, Richmond.
- Kentaa. (n.d.). Electric Superbike Twente 2021. Retrieved from <https://www.steunutwente.nl/project/est-2021>.
- Kollmann, T., Stockmann, C., Hensellek, S., Kensbock, J. (2017). *European Startup Monitor 2016*. University Duisburg-Essen. Retrieved from https://duepublico2.uni-due.de/receive/duepublico_mods_00043790.
- Law, A., Charron, R. (2005). *Effects of agile practices on social factors*. ACM Press, St. Louis, Missouri.
- LeanMap. (2022). *Operational Assessment for Business Benchmarking*. LeanMap. Retrieved from <https://www.leanmap.com/consulting/operational-assessment/>.

- Lundh, E., Sandberg, M. (2002). Time constrained requirements engineering with extreme programming – An experience report. In *Proceedings of the International workshop on time constrained requirements engineering*.
- Lynn, R. (2022). *Agile and Lean Project Management*. Planview. Retrieved from <https://www.planview.com/resources/articles/lkdc-agile-lean-project-management/>.
- Magistretti, S., Trabucchi, D., Dell’Era, C., Buganza, T. (2019). A New Path Toward a Hybrid Model: Insights from PwC’s Italian Experience Centre. *Research-Technology Management*, 62(5), 30-37. <https://doi.org/10.1080/08956308.2019.1638223>.
- Marodin, G.A., Frank, A.G., Tortorella, G.L., Netland, T.H. (2018). Lean Product Development and Lean Manufacturing: Testing Moderation Effects. *International Journal of Production Economics*, 203, 301-310. <https://doi.org/10.1016/j.ijpe.2018.07.009>.
- Morgan, J.M, Liker, J.K. (2006). *The Toyota Product Development System: Integrating People, Process, and Technology*. (1st edition). Productivity Press New York.
- Newsletter September 2021. (2021). Electric Superbike Twente. Retrieved from <https://electricsuperbiketwente.nl/newsletter-september-2021/>.
- Newkirk, J.W., Martin, R.C. (2001). *Extreme Programming*. Practice Prentice Hall.
- Oliver, N., Dostaler, I., Dewberry, E. (2004). New product development benchmarks: the Japanese, North American an UK consumer electronics industries. *The Journal of High Technology Management Research*, 15, 249-265.
- Our Mission. (2021). DroneTeam Twente. Retrieved from <https://droneteamtwente.nl/2021-2022-team/>.
- Our Partners. (2022). Green Team Twente. Retrieved from <https://www.greenteamtwente.nl/partners/>.
- Paetsch, F., Eberlein, A., Maurer, F. (2003). Requirements engineering and agile software development. In *Proceedings of twelfth IEEE international workshops on enabling technologies: Infrastructure for collaborative enterprises (WETICE)*, 308-313.
- Partners. (2019). Electric Superbike Twente. Retrieved from <https://electricsuperbiketwente.nl/partners/>.
- Partners in (...). (2021). Drone Team Twente. Retrieved from <https://droneteamtwente.nl/our-partners/>.
- Pessôa, M. V. P. and Trabasso, L. G. (2017). *The lean product design and development journey*. Springer.
- Pfahl, D., Langtangen, H.P., Hannay, J.E. (2012). What do We Know about Scientific Software Development’s Agile Practices? *Computing in Science and Engineering*, 14(2). 24-37. <https://doi.org/10.1109/MCSE.2011.113>.
- Pichler, M., Rumetshofer, H., Wahler, W. (2006). Agile Requirements Engineering for a Social Insurance for Occupational Risks Organization: A Case Study. In *14th IEEE International Conference on Requirements Engineering*, 251-256.
- Previous Years. (2022). Green Team Twente. Retrieved from <https://www.greenteamtwente.nl/history/>.
- Pukinskis, A. (2005). *5 stumbling blocks for new corporate agile projects*. The agile blog.
- Radeka, K. (2013). *The Mastery of Innovation A Field Guide to Lean Product Development*. CRC Press.
- Ramesh, B., Cao, L., & Baskerville, R. (2010). Agile requirements engineering practices and challenges: an empirical study. *Information Systems Journal*, 20(5), 449-480. <https://doi.org/10.1111/j.1365-2575.2007.00259.x>.
- Sacco, J. (2022). *How Agile are you? A 50 Point Test*. Finite Recruitment. Retrieved from <https://www.finite.com.au/blog/2019/08/how-agile-are-you/>.
- Saldierna, C., Lino, M. (2010). *The Design Research Methodology as a Framework for the Development of a Tool for Engineering Design Education*.
- Schumacher, D. (2009, March 30). *Borland Agile Assessment*. From the Agile Transformation Trenches: Where the rubber meets the road in an enterprise adopting Agile practices.

- Retrieved from https://borland.typepad.com/agile_transformation/2009/03/borland-agile-assessment-2009.html.
- Schwaber, K., Beedle, M. (2002). *Agile Software Development with SUM*. Prentice Hall, Englewood Cliffs.
- Scott, M., Bruce, R. (1987). Five stages of growth in small business. *Long Range Planning*, 20(3), 45-52. [https://doi.org/10.1016/0024-6301\(87\)90071-9](https://doi.org/10.1016/0024-6301(87)90071-9).
- Sensei, L. (2021). *Lean Agile Diagnostic Assessment*. Lean Sensei International. Retrieved from <https://www.leanagilesensei.com/lean-agile-assessments>.
- Serrador, P., Pinto, J.K. (2015). Does Agile work? – A quantitative analysis of agile project success. *International Journal of Project Management*, 33(5), 1040-1051. <https://doi.org/10.1016/j.ijproman.2015.01.006>.
- Sidky, A. (2006). *The Agile Adoption Process Framework: Detailed Reference Document: Agile Practices and Concepts with Assessment Indicators*. Virginia Polytechnic Institute and State University. <https://doi.org/10.48550/arXiv.cs/0612092>.
- Sidky, A., Arthur, J., Bohner, S. (2007). A disciplined approach to adopting agile practices: the agile adoption framework. *Innovations in Systems and Software Engineering*, 3, 203-216. <https://doi.org/10.1007/s11334-007-0026-z>.
- Sillitti, A., Ceschi, M., Russo, B., Succi, G. (2005). Managing uncertainty in requirements: A survey in documentation-driven and agile companies. In *11th IEEE international software metrics symposium (METRICS'05)*, 10-17.
- Sladeczek, J. (2021). *What is the purpose of Agile diagnostics?* Agileknowhow.com. Retrieved from <https://agileknowhow.com/2017/02/02/what-is-the-purpose-of-agile-diagnostics/>.
- Sobek, D.K., Liker, J., Ward, A.C. (1998). Another look at how Toyota integrates product development. *Harvard Business Review*, 76(4), 36-49.
- Stavru, S. (2014). A critical examination of recent industrial surveys on agile method usage. *Journal of Systems and Software*, 94, 87-97. <https://doi.org/10.1016/j.jss.2014.03.041>.
- Team 2021/2022. (2019). *Electric Superbike Twente*. Retrieved from <https://electricsuperbiketwente.nl/team/>.
- Thabit, T.H., Solaimanzadah, A., Al-bood, M.T. (2017). The Effectiveness of COSO Framework to Evaluate Internal Control System: The Case of Kurdistan Companies. *Cihan International Journal of Social Science*, 1(1), 44.
- The 10th annual State of Agile Report*. (2016). VersionOne: Agile Made Easier. Available at <http://www.agile247.pl/wp-content/uploads/2016/04/VersionOne-10th-Annual-State-of-Agile-Report.pdf>.
- The Agile Journey: A Scrum overview*. (2021, June 23). Pm-partners. Retrieved from <https://www.pm-partners.com.au/the-agile-journey-a-scrum-overview/>.
- The Fuel of the Future*. (2022). Green Team Twente. Retrieved from <https://www.greenteamtwente.nl/>.
- Thesing, T., Feldmann, C., Burchardt, M. (2021). Agile versus Waterfall Project Management: Decision Model for Selecting the Appropriate Approach to a Project. *Procedia Computer Science*, 181, 746-756. <https://doi.org/10.1016/j.procs.2021.01.227>.
- Thunderbird: Our 2022 iMechE UAS Challenge drone*. (2021). DroneTeam Twente. Retrieved from <https://droneteamtwente.nl/2022-thunderbird/>.
- TXM. (2021). *Using a Lean Diagnostic Tool*. TXM Lean Solutions. Retrieved from <https://txm.com/using-a-lean-diagnostic-tool/>.
- Ulrich, K.T., Eppinger, S.D. (2004). *Product Design and Development*. (3rd edition). McGraw-Hill/Irwin.
- Vacatures: Stages en afstudeerstages in serious games*. (2022). Gamelab: Stichting Gamelab Oost. Retrieved from <https://gamelaboost.nl/vacatures/>.

- Vallon, R., Estácio, B.J.S., Prikladnicki, R., Grechenig, T. (2018). Systematic literature review on agile practices in global software development. *Information and Software Technology*, 96, 161-180. <https://doi.org/10.1016/j.infsof.2017.12.004>.
- Velthuisen, J.W., Kramer, G., Yildirim, B., Schmidl, D.R. (2018). *Europe Monitor: Innovation and Digital Transformation: How do European SMEs perform?* Pwc. Available at <https://www.pwc.nl/nl/assets/documents/pwc-europe-monitor-innovation-sme.pdf>.
- Vreeman, J.C. (2022). *Drone Team Twente Reveals New Aid Drone: Thunderbird*. University of Twente. Retrieved from <https://www.utwente.nl/en/news/2022/5/634498/droneteam-twente-reveals-new-aid-drone-thunderbird>.
- Wake, W.C. (2001). *Extreme Programming Explored*. Addison-Wesley Professional.
- Ward, A. (2007). *Lean product and process development*. Lean Institute, USA.
- Ward, A., Liker, J.K., Cristiano, J., Sobek, D.K. (1995). The second Toyota paradox: how delaying decisions can make better cars faster. *Long Range Planning*, 4, 129.
- Ward, A.C., Sobek, D.K. (2014). *Lean Product and Process Development*. (2nd ed.). Lean Enterprise Institute, Inc.
- Waters, K. (n.d.). *How Agile Are You? (Take This 42 Point Test)*. 101 ways. Retrieved from <https://www.101ways.com/how-agile-are-you-take-this-42-point-test/>.
- We are DroneTeam Twente*. (2021). DroneTeam Twente. Retrieved from <https://droneteamtente.nl/>.
- Where the world builds software*. (2022). GitHub. Retrieved from <https://github.com/>.
- Williams, L. (2010). Agile Software Development Methodologies and Practices. *Advances in Computers*, 80 (C), 1-44. [https://doi.org/10.1016/S0065-2458\(10\)80001-4](https://doi.org/10.1016/S0065-2458(10)80001-4).
- Womack, J.P., Jones, D.T., Ross, D. (1994). The Machine that Changed the World. *The International Journal of Human Factors in Manufacturing*, 4(3), 341-343.
- Zerfass, A., Dühring, L. Berger, K., Brockhaus, J. (2018). *Fast and flexible. Corporate communication in agile organizations (Communication Insights, Issue 5)*. Leipzig, Germany: Academic Society for Management & Communication. Available online at www.academic-society.net.
- Žužek, T., Gosar, Ž., Kušar, J., Berlec, T. (2020). Adopting agile project management practices in non-software SMEs: A case study of a slovenian medium-sized manufacturing company. *Sustainability*, 12(21), 1-17. <https://doi.org/10.3390/su12219245>.
- Žužek, T., Gosar, Ž., Kušar, J., Berlec, T. (2021). A new product development model for smes: Introducing agility to the plan-driven concurrent product development approach. *Sustainability (Switzerland)*, 13(21), art.no.12159. <https://doi.org/10.3390/su132112159>.

Appendix A - APM/LPM assessment tools found in the literature

Table A1 – Description of the APM/LPM assessment tools found in the literature.

APM/LPM diagnostic tool	Description
42 Point Test	Set of 42 statements that make a full assessment of a team's alignment with agile principles and methods. Each sentence must be answered with 0 or 1 points. According to the researcher, each team member should be subjected to the questionnaire. The results for each team member are summed and the average score represents the score for the team.
Agility Maturity Self-Assessment	Set of 6 questions, each one assessing one different category (teams, leadership, project management, communication/promotion, business value, and risk management) of the company. Each question must be answered on a scale from 1 to 7, with 1-point increments. The results for each component are presented upon answering. The final agility result for the firm is obtained after summing the points of each one of the questions.
Borland Agile Assessment	Questionnaire composed of 12 questions answered on a 5-point agree/disagree scale. It is applied to the company's internal participants. 3 categories are evaluated – organizational structure, teams, and projects. Results are reported in aggregate. A diagnostic profile is created which helps the firm identifying areas for improvement in their agile project management.
Lean Agile Diagnostic Assessment	On-site or remote lean & agile assessment and review of the organization. This diagnostic tool is based on employees' interviews and site data collection. It is focused on the entire firm, but the evaluation is done by segments or areas of the company. The entire process is conducted by a team of experts and takes 3-4 days. At the end of the assessment, results are presented in a final report for each assessed segment, as well as a score for the entire enterprise. Here, the tool also proposes and guides the company to a future state that includes the best APM and LPM practices from leading companies.
Lean Diagnosis Tool	Questionnaire given to managers and accountants of different companies to determine the degree of leanness of the respective firms. It assesses 10 different components, such as leadership, organization & human resources (HR), culture, quality, operational basics, lean plan layout, supply chain, safety & environment, financial systems, and innovation. Results are represented on a spider diagram that shows the percentage of each component.
Lean Diagnostic Tool	Questionnaire composed of 56 items, unevenly divided into 8 different categories (leadership, customer focus, empowerment, communications, core processes, plant & equipment, supporting processes, and supporting infrastructure) aimed at measuring the extent to which lean is being implemented in the company. Each question has a scale from 1 to 5 points, with 1-point increments. The first level of the scale (1 point) corresponds to 0%. From there, every point accounts for 25%. Results are represented on a spider diagram that shows the percentage of each category.
Lean Diagnostic Tool (a)	Audit conducted by a team of experts to understand the level of implementation and improvement of 10 different lean components (leadership, organization & HR, culture, quality, operational basics, lean plant layout, supply chain, safety & environment, financial systems, and innovation). Each component is assessed on a scale from 0 to 10, with 0.1 increments. Results are represented on a spider diagram showing the final score of each component and an overall total representing the firm's lean score. This tool will also assist in planning the steps required to achieve a future improved state.
PPP Worksheet	Set of 20 questions, unequally divided into 3 segments (principles, processes, practices), that help firms diagnose their current state in relation to traditional and agile management approaches. Each question has a scale from 1 to 5 points, with 1-point increments. This tool can be applied either to the entire organization or to any part of that organization, such as a team or a department. At the end of the assessment, the evaluation is done through observation of the completed questionnaire.

(To be continued)

(Continued)

APM/LPM diagnostic tool	Description
The Agile Adoption Process Framework	Comprehensive diagnostic tool to assess the companies' agility in PM. It involves not only direct observation of work procedures and historical data, but also interviews with managers, developers, and clients. Over 300 questions are presented. Each question has 5 different satisfaction levels. Each specific APM practice proposed by the author is assessed according to categories, that can be organization, process, people, project management, tools, environment, and culture. Percentage results are compiled in tables.
The Operation Excellence Assessment (OEA)	Comprehensive LPM diagnostic tool that includes a thorough observation of the workplace and questionnaires applied to all team members. This assessment is conducted by a team of experts over the course of 5 days. Many different areas of the firm are evaluated. Some examples are leadership, management, readiness, teamwork, training, service, solving, efficiency, quality, maintenance, inventory, technology, and standards. One of the outcomes is a detailed diagnostics report that covers key observations, reference results, and an executive summary. The other outcome is a spider diagram, displaying the obtained points for each evaluated area. This expensive diagnostic tool properly identifies and clarifies current capabilities, performance levels, strengths, and weaknesses of the company. It also provides a detailed improvement plan.
The 50 Point Test	Set of 50 questions presented to every team member aimed at determining the level of agility of the corporation. The replies are simply a yes or no. Once each team member has completed the 50-point test, an average calculation is performed to obtain the total score for the company. According to the author, if the company scores less than 40 points, it should strive to update their processes and culture as quickly as possible.
Tool for assessing "leanness"	Tool to rate small companies in 12 different areas (voice of the customer, 5S (sort, set in order, shine, standardize, sustain), cellular manufacturing continuous improvement, integrated quality, pull system, quick changeovers, lean supply chain, maintenance, value stream and visual controls). The ratings are obtained through observation and interviews.

Appendix B - Simplified version of the guideline questionnaire

Table B1 – Simplified version of the guideline questionnaire.

#	Questions
1	Can you describe the company you work on? • <i>How is it structured?</i>
2	What are the firm's main objectives?
3	How does the company develop its products?
4	What do people do when they are faced with situations hard to deal with? • <i>Can you describe it?</i> • <i>Are the obstacles documented?</i>
5	Are company members capable of predicting hazardous situations? • <i>How?</i> • <i>Do they know what the most dangerous situations are and how they can arise?</i> • <i>Are risks documented?</i>
6	Do you or the company control and track the progress of a given activity? • <i>Can you show me how it is done?</i> • <i>How frequent is that control done?</i>
7	Are individuals informed about the most important activities, events, and deadlines of the entire development cycle? • <i>How?</i>
8	Can you explain me the role of each team member in a few words? • <i>Do you all have a common understanding of the product?</i>
9	Can the company ensure that a new member knows exactly what to do? • <i>How?</i>
10	Do company members frequently come across unfamiliar situations or aspects that they do not know how to deal with? • <i>Why?</i>
11	Is there a strategy to understand where the competition is falling short? • <i>Which one?</i>
12	Do you know what people that closely work with you need to do their activities? • <i>What about people from different backgrounds, sub-teams or departments?</i> • <i>How?</i> • <i>Do you realize how your actions affect other people's jobs?</i>
13	Do people with distinct expertise understand the strengths and weaknesses of the product to be developed? • <i>How is that accomplished?</i> • <i>Do you know what the most important product features are?</i>
14	Do company members know the issues, improvement points and strengths of a recently finished activity? • <i>How?</i> • <i>Are these aspects documented?</i>
15	Does the company have frequent suppliers? • <i>How can the company ensure that is always familiar with the practices of suppliers and vice-versa?</i> • <i>Can the company guarantee a constant satisfaction with the suppliers' service?</i> • <i>How does the firm know about new technological developments made available by suppliers?</i>

(To be continued)

(Continued)

#	Questions
16	Does the company have specific product users and clients? • <i>If so, are you familiar with what they expect and vice-versa?</i> • <i>How?</i> • <i>How do you interact with each other and exchange feedback and ideas?</i>
17	Does it take a long time to get someone's feedback on something? • <i>Why?</i>
18	Does the company regularly introduce innovation during the development activities? • <i>How is that accomplished?</i>
19	Can successes and good practices be replicated from previous projects? • <i>How?</i>
20	What is the company's approach regarding product specifications? • <i>Are product requirements changed or added during the development activities?</i> • <i>What does the company do to include such changes?</i>
21	Can you tell me a bit more about the hiring process of the company?
22	Do you lose a lot of time finding things in the workplace? • <i>Why?</i>
23	Do actions and decisions take a long time to be made and finalized? • <i>Why?</i> • <i>Can you provide us an example?</i>

Appendix C - Future Factory



Figure C1 – Exterior view of the Future Factory.



Figure C2 – One of the workspaces shared by the 5 companies based in the Future Factory.



Figure C3 – Meeting room used by the firms established in the Future Factory.



Figure C4 – Meeting room used by the firms established in the Future Factory.



Figure C5 – Meeting room used by the firms established in the Future Factory.

Appendix D - Green Team Twente



Figure D1 – One of the exclusive working spaces of GTT.

Logged in as: Wouter Groote Veldman (wgrooteveldman) [Update Profile](#) [Admin](#) [Log Out](#)

Green Team Twente Wiki

[Search](#) [Recent Changes](#) [Media Manager](#) [Sitemap](#)

[Trace](#) [Index](#)

Table of Contents

- How to Green Team Twente?
- Broad subjects
- How to document your project using this DokuWiki?
 - How to write proper documentation?
 - Documentation for subsystems (capstack, frame etc)
 - Subteam process documentation
 - How to use this wiki?
 - New pages & namespaces
- Old wiki

How to Green Team Twente?

Welcome to the Green Team wiki! Here you can find and/or document anything that can be of use long-term for your current, but also for the future teams. See this wiki as the Green Team Twente handbook, and as such try to update it regularly with things you have learned whilst doing a project.

Try to keep the info in this wiki in english.

Broad subjects

Category	Description
General information	Information about the stichting
ICT	Everything having to do with ICT
Subteams	Subteam specific knowledge
	Management
	Finance
	Communication
	Hydro-Electric
	Mechanics
	Simulation & Strategy
Events	Events we participate in
Contact info	Current/old teams' contact info, board info and email aliases
Braindump	Ideas and information that does not (yet) belong somewhere
Testing	Information concerning the testing of the car
Software	Information concerning the software

Looking for a complete list with all the pages? [Show all wiki pages](#)

How to document your project using this DokuWiki?

How to write proper documentation?

[Documentation for subsystems \(capstack, frame etc\)](#)

- Explain how the system works

Figure D2 – Overview of the Wikipedia used by GTT.

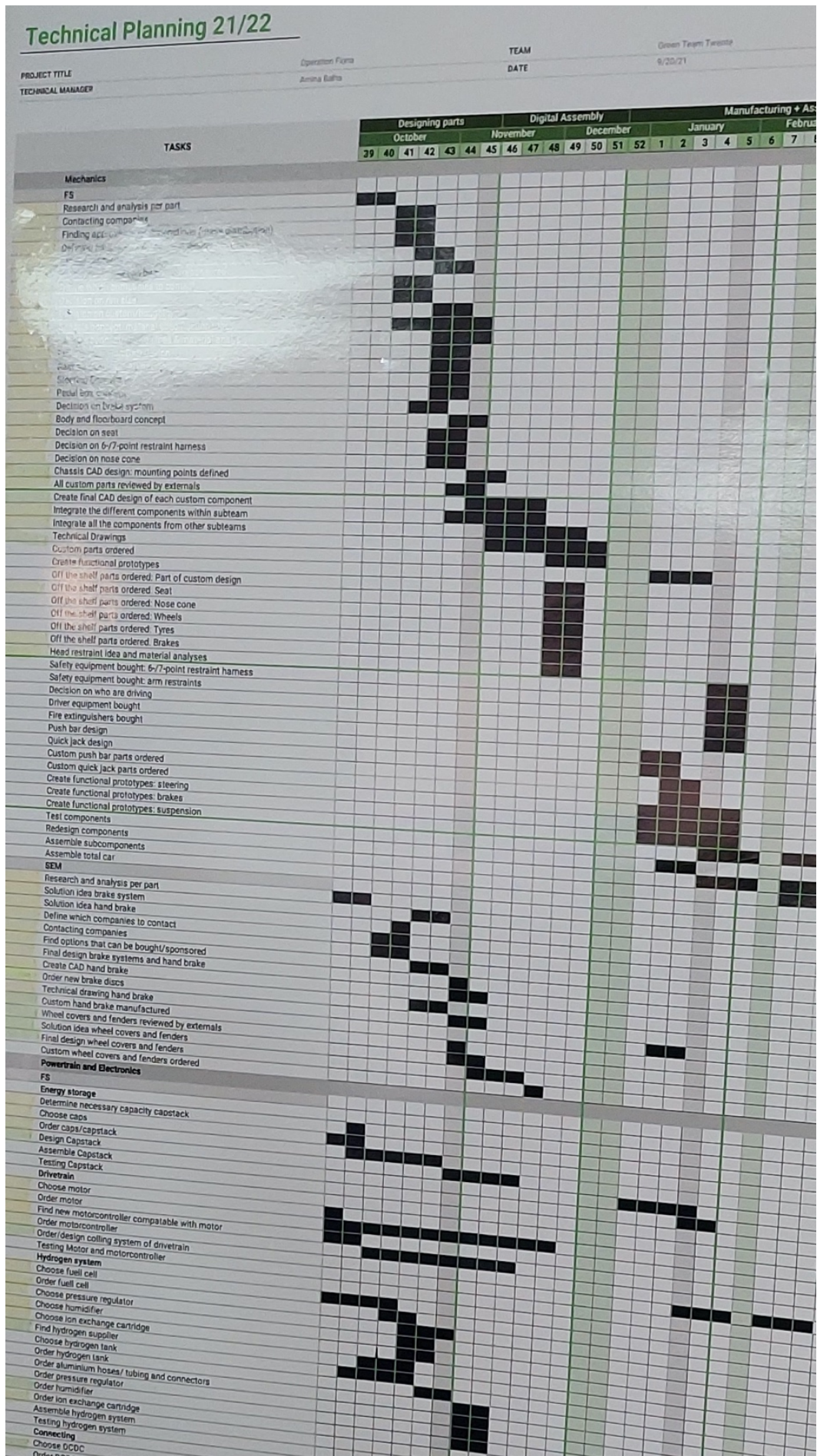


Figure D3 – Partially completed technical plan of GTT.

Deadlines Technical Team ♥			
Date	What ?	Who ?	
☒ 20 th May	Testing day @ Oldenzaal	A, Sv, Fa, G, B	
☒ 25 th May	Testing day @ Oldenzaal	Idv, A, Fa	
☐ 31 st May	SEM	Everyone!	
☒ 3 rd June	FSG: DSS + EDR	Everyone!	
☐ 10 th June	Documentation Up-to-date	Everyone!	
☐ 24 th June	Car Reveal: Total car assembled	Everyone!	+ (FSG deadline)
☐ 10 th July	FSN: Car driving on battery	Everyone!	
☐ 14 th Aug	FSG: Driving on Capstack (+hydro...)	Everyone!	

Figure D4 – One of the white boards used by GTT to display information.

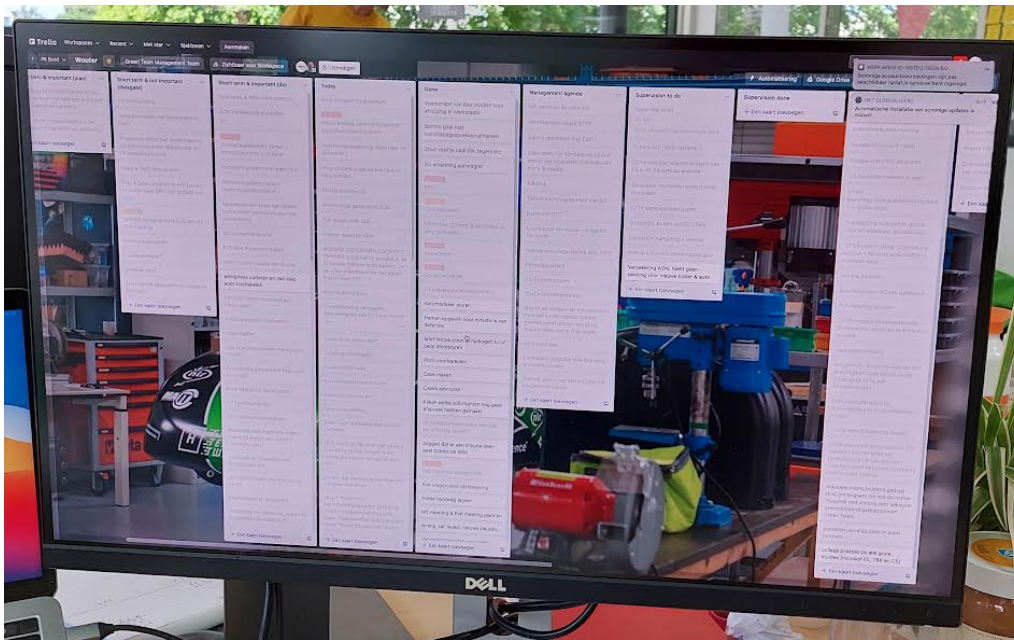


Figure D5 – Online boards utilized by GTT management and technical sub-teams to track the progress of activities.



Figure D6 – Sticky notes utilized by GTT technical sub-team to track the progress of activities.

Table D1 – Explanation about each working function of GTT (“Are you the,” 2022).

Sub-teams & sub-groups		Function	Description
Management		Team manager	Responsible for the entire project. Ensures that the overall goals are set and will be achieved. Has a clear overview of everything. People look for him in case of problems. Contact person for the race organization, press, and stakeholders.
		Technical manager	Responsible for the car. Ensures that the defined goals are achieved. Helps in approaching partners that can help with materials, parts, or knowledge. Predicts technical problems. Takes care of the overall integration of the technical team.
		Communication manager	Responsible for the media and branding of GTT. Contact person for the press. Arranges logistics for the company to attend external events. Ensures optimal cooperation within the communication team. Makes sure goals are set and achieved.
		Finance & external relation manager	Maintains existing relationships with partners. Looks for new contacts to expand the company’s network. Understands why a company trusts GTT. Manages the money provided by partners. Creates a budget, account and an estimation about the financial risks of decisions to be made. Approves big purchases.
Communication		Education coordinator	Responsible for raising awareness about hydrogen. Creates educational series, workshops, and other educational events for highschoolers, for example.
		Event coordinator	Responsible for the GTT events, such as the design and car presentation, in which speakers, decoration, and invitations must be arranged.
		Videography editor & creator	Responsible for taking pictures and videos during activities of the GTT and editing them afterwards.
		Public relations	Concerned with keeping the public up to date with GTT and events about hydrogen. Updates the social media, website, and writes a monthly newsletter.
		Graphic designer	Responsible for the visual appearance of the team. Makes sure that everything that is printed or sent to the public fits the company’s visual identity.
Tech	Mechanics	CE	Responsible for all mechanical and aerodynamic components of the car, its integration, the car performance, and the car concept. Keeps an overview, helps where/when necessary and ensures that the communication between the sub-group’s members runs smoothly.
		Structural	Responsible for the braking system and the mounting of all technical components, for which it is important to look at the division of all components requirements. Improves components’ designs on weight, stability, and reliability by making calculations and simulations.
		Aerodynamics	Responsible for the body and the aerodynamic features. Designs these by doing CFD simulations.
		Vehicle dynamics	Accountable for the car’s maneuverability and behavior on the road. Uses different types of simulations, finite element method (FEM), and motion analyses to find the best set up for the car.
	Hydroelectric	CE	Responsible for all the power, safety, and communication systems within the car. Keeps an overview, helps where/when necessary and ensures that the communication between the sub-group’s members runs smoothly.
		Hydrogen system	Responsible for all parts that are needed for the generation of electricity out of hydrogen and oxygen. This process starts at the hydrogen tank and ends at the fuel cell stack, with many parts in between. This person analyses the integration of such components and keeps testing them to find flaws. Designs are constantly improved.

(To be continued)

(Continued)

Sub-teams & sub-groups		Function	Description
Tech	Hydroelectric	Drive train	Improves and optimizes all parts that are needed for the transformation of electricity into kinetic energy. Examples are the fuel cell where electrical power is generated, the battery where energy is stored, and the motor and its controller, powered using the stored energy. The focus is on delivering as much power to the motor as possible while considering the system's efficiency and size.
		Cooling system	Responsible for preventing components' overheating. Performs tests on the cooling system. By considering the heat each components dissipates and by closely monitoring the temperatures, flows, and pressures of the cooling liquid, flaws will be found in components' designs.
		Control & safety systems	Accountable for the control and safety of the car. Strives to achieve an optimal driver/car interface. Works on the steering wheel, cockpit, safety sensors, and wireless connection to the outside.

Table D2 – List of all GTT partner companies (Our Partners, 2022).

Partners of GTT
AFMI.
AMK.
Altium.
Axtron.
Batenburg Techniek.
Benchmark.
BetterBe.
Bronkhorst.
Deloitte.
Dynteq.
EKPO.
Euro Circuits.
Fischer.
Heisterkamp.
HES Energy Systems.
HyCC.
IFM.
Jeveka.
Kleizen.
Lubribond.
MakerPoint.
MANN + HUMMEL.
Mazda Kolenaar Autobedrijven.
New Cosmos.
Oversluizen Thermal Engineering.
Pentair.
Pressure tech.
Principia.
Rosen.
Royal Netherlands Aerospace Centre.
Salomon's Metalen, Saxion Hogenschool.
Sintecs.
Skeleton.
SKF.
STMicroelectronics.
Swagelok.
Target.
TKH.
Trimm.
Twence.
VDL Energy Systems.
University of Twente.
Wissink, XIP.

Appendix E - Drone Team Twente

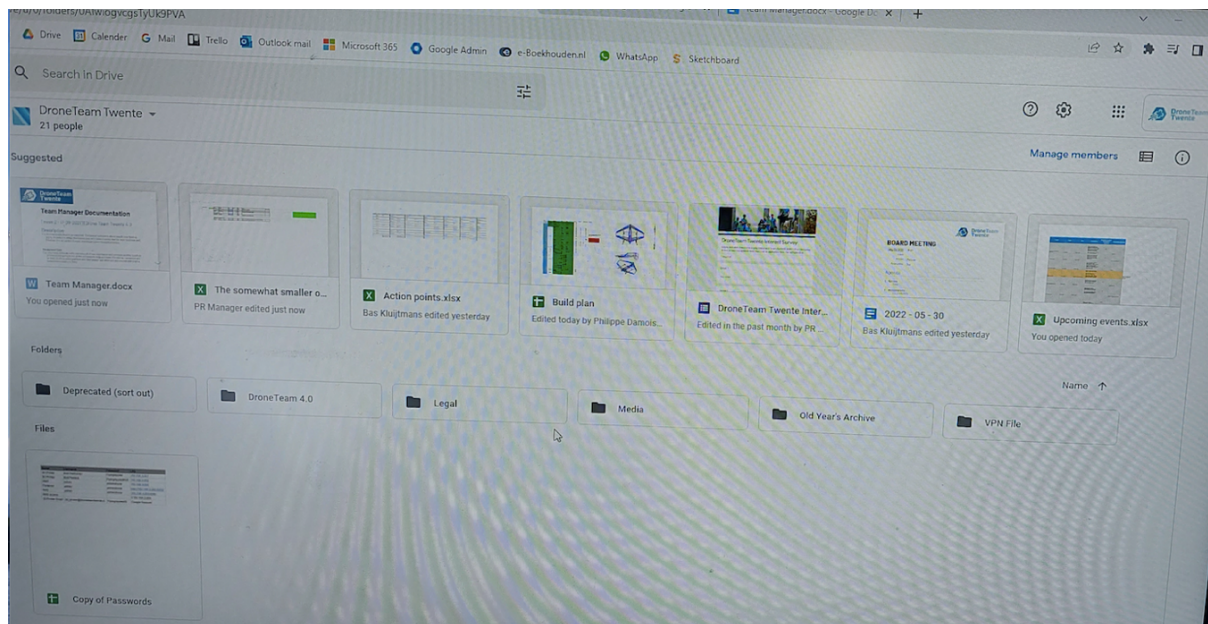


Figure E1 – Overview of the Google Drive database used by DTT.

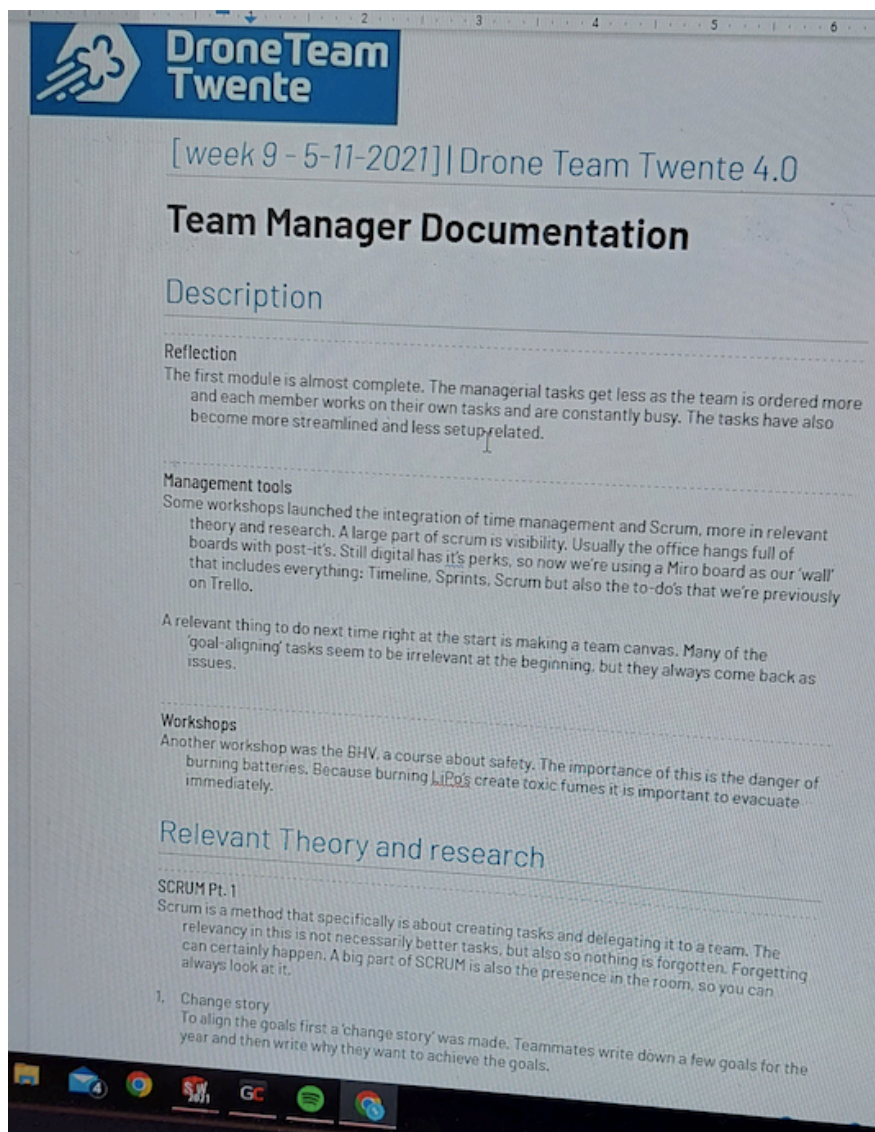


Figure E2 – File of the DTT Google Drive database dedicated to the team manager.

The image shows a screenshot of a Google Drive file template for 'Drone Team Twente'. The template is titled 'Template: Drone Team Twente 4.0 | [insert week]' and 'Structural Design Documentation'. It contains four main sections, each with a title and a description:

- Description**: This section is reserved for a description on the situation, if an encountered issue is being logged then describe the issue and influencing factors. In the case of theory and research, log the intended use of the research material within the drone team.
- Stepwise solution**: This section is to be used in the case of a problem encountered, to better explain how it was mitigated and how it can be avoided in the future. If the log is unrelated to an issue, remove this section for more space.
- Relevant Theory and research**: This component is to provide a detailed explanation on your findings, including relevant links or sources. When logging a problem, use this section to provide research needed to arrive at the solution.
- Conclusion**: Additional thoughts or applications of the logged material.

The template is displayed on a screen with a Windows taskbar visible at the bottom.

Figure E3 – File of the DTT Google Drive database dedicated to the structural designer.



Figure E4 – One of the exclusive working spaces of DTT.

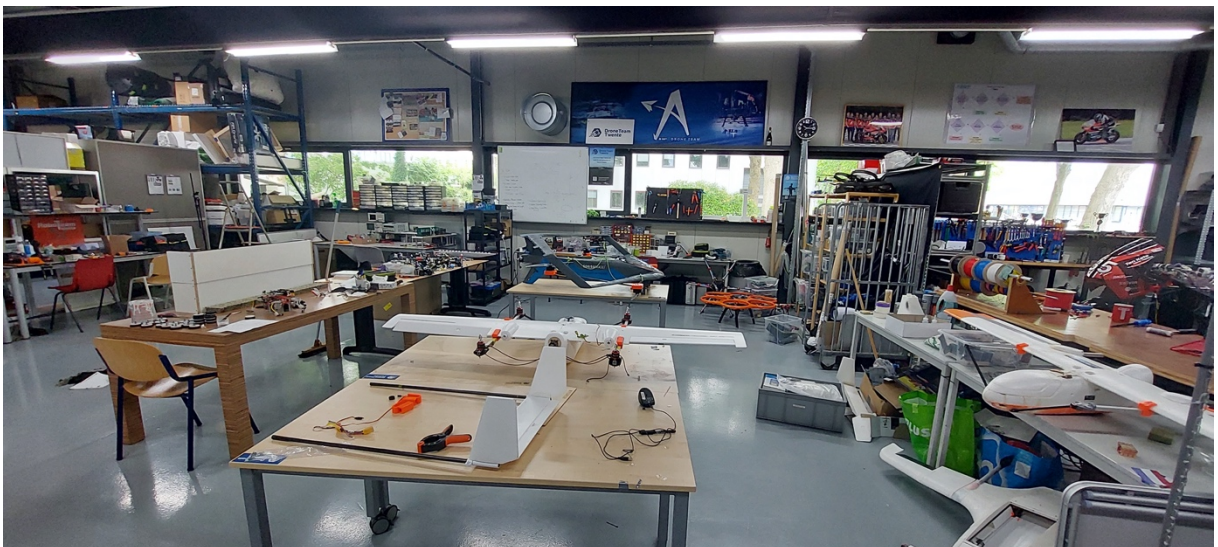


Figure E5 – One of the exclusive working spaces of DTT.

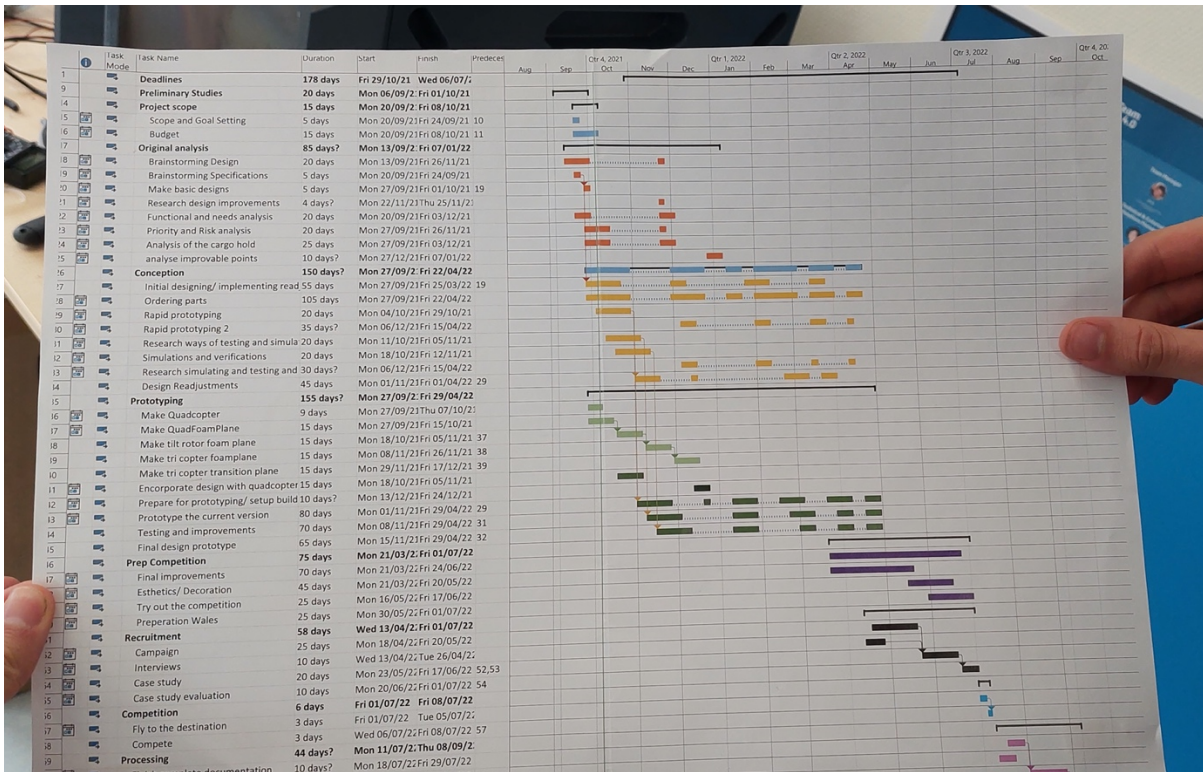


Figure E6 – Plan developed by DTT at the beginning of the development cycle.

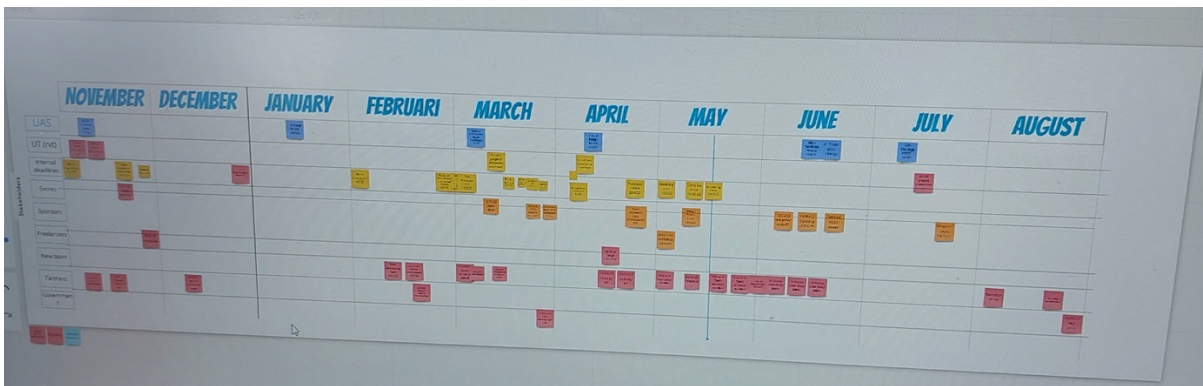


Figure E7 – Major tasks, events, and milestones of the DTT development cycle.

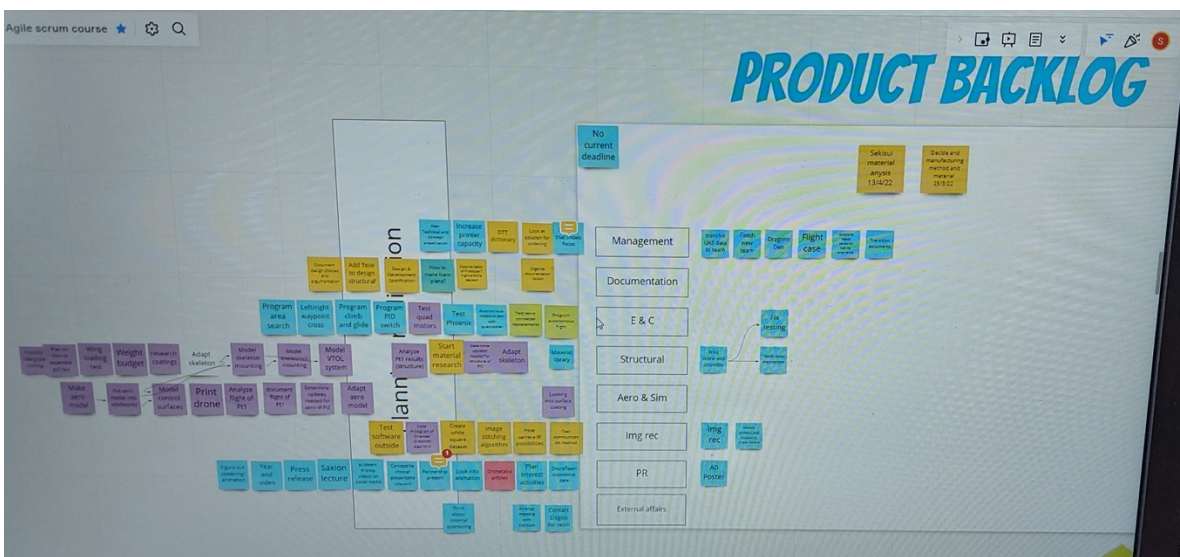


Figure E8 – Tasks assigned to each DTT sub-team.

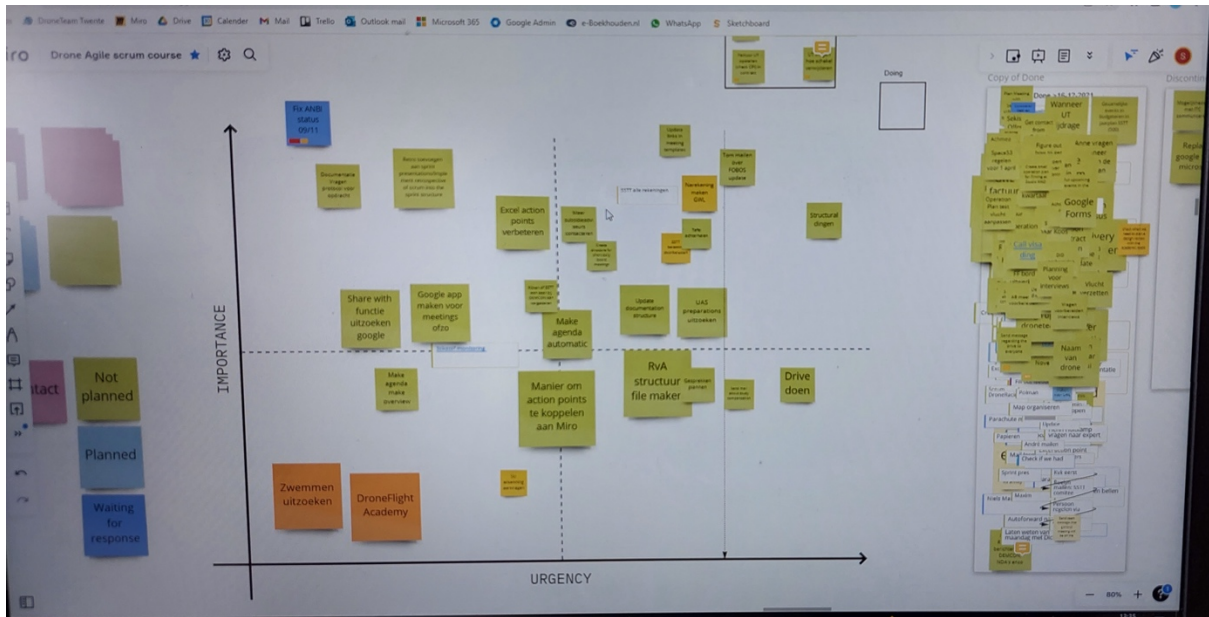


Figure E9 – Representation and evaluation of individual tasks at DTT.

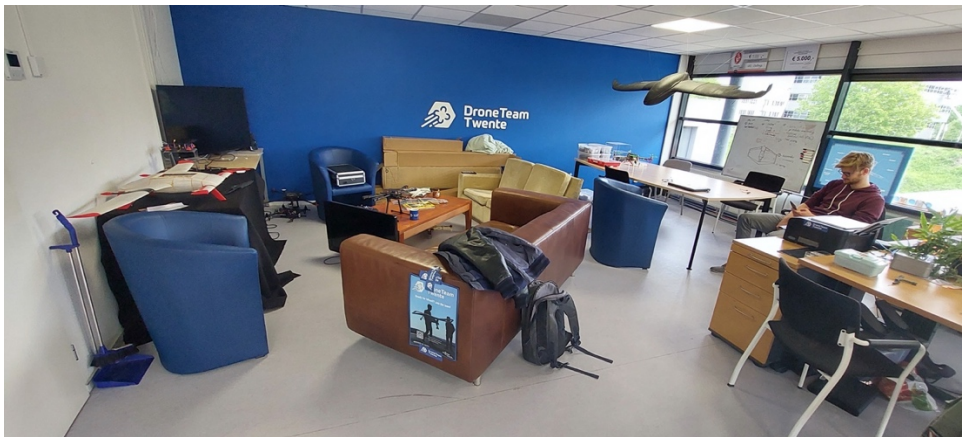


Figure E10 – Area where DTT conducts semiweekly meetings.

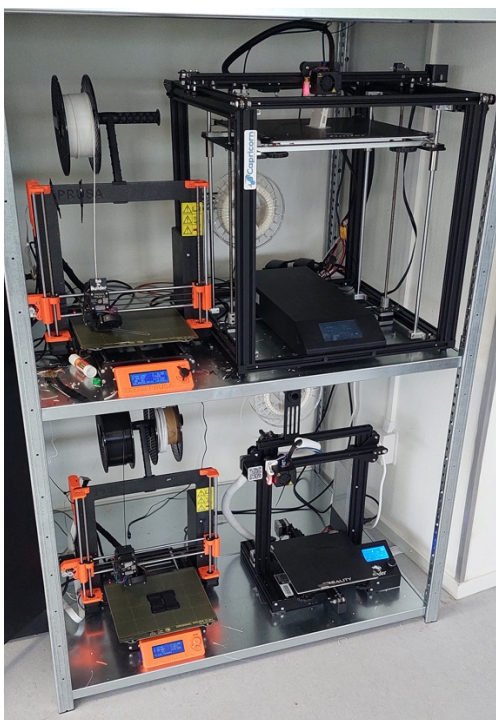


Figure E11 – Some of the 3D printers used by DTT.

Table E1 – Explanation about each working function of DTT (“Join us,” 2021).

Sub-teams	Function	Description
Board	Team manager	Responsible for the project. Has a general idea of all activities. Works closely with all the other members. Supports everyone to make sure goals are accomplished. Speaks to the press.
	Technical manager	Oversees the technical sub-team to make sure they can deliver a working drone by the end of the year. Keeps track of all parts and deliverables.
	Finance & acquisition	Keeps track of the money and spendings. Responsible for the acquisition of new partners. Communicates with current partners.
MarCom	MarCom	Responsible for showcasing what the company is doing in news, on social media, and on the firm’s website. Makes the graphic design and branding of the drone and the team itself. Organizes events such as the drone reveal and the unmanned aerial system (UAS) challenge.
	Documentation	Ensures that the team’s progress is documented and recorded to prevent the repetition of the same mistakes.
Technical	Aerodynamics & simulation	Determines the optimal wing design by doing CFD simulations and wind tunnel tests. Responsible for an optimal outer shape of the drone to ensure enough lift with as little drag as possible on the aircraft.
	Electronics & control	Designs the electronics that make the drone fly, while being as efficient with power as possible. Programs the flight controller to ensure that all sensors, motors, and control surfaces are properly integrated, and the drone keeps flying.
	Structural design	Responsible for designing a lightweight internal frame of the drone. Makes sure the unmanned aerial vehicle (UAV) can handle the loads it is subjected to. Designs the mounts, selects the materials, and tests the frame to see if it can withstand all forces during flight.
	Software/image recognition	Ensures that the drone can fly autonomously and recognize its ground target, while being as efficient with processing power as possible.

Table E2 – List of all DTT partner companies (“Partners in,” 2021).

Partners of DTT
ColorFabb. De Letterconcurrent. DESIGNLAB. DRONEBEELD. DroneFlight Academy. Flahsforge. Fokker. MARPLE. Nijdeken, Papen Metaal Techniek. Royal NLR. RS Components. Saxion University of Applied Sciences. Sekisui Kasei. SIMNET. Space 53. TINY GIANTS. TORVOL. University of Twente. UPFRONT. Würth.

Appendix F - Electric Superbike Twente



Figure F1 – One of EST exclusive working spaces.



Figure F2 – One of EST exclusive working spaces.



Figure F3 – Sticky notes used by EST until November 2021.

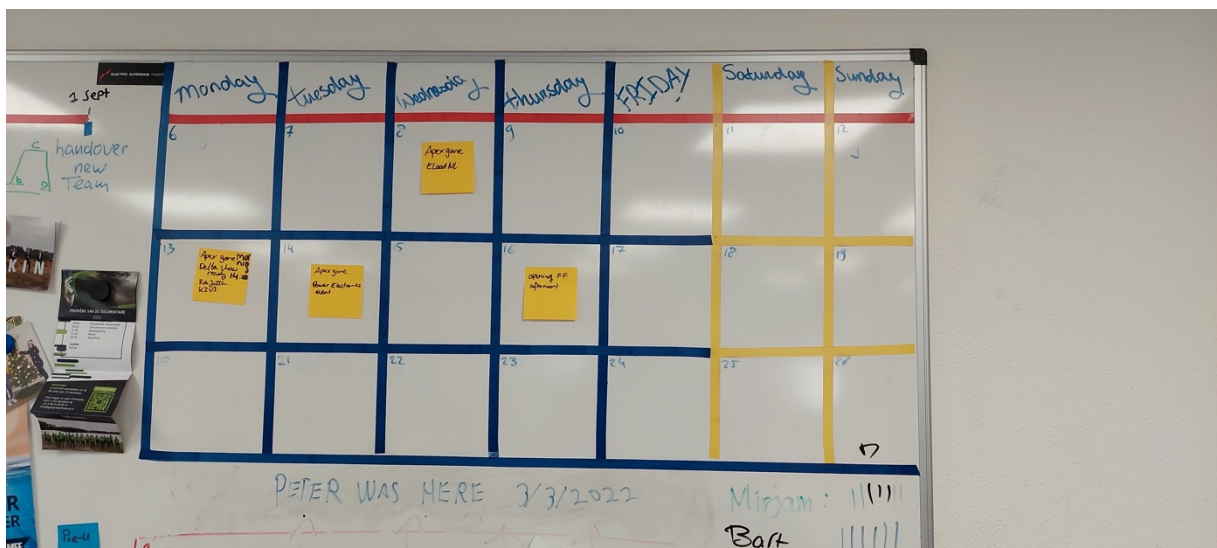


Figure F4 – White board used by EST to convey general information about the development process.

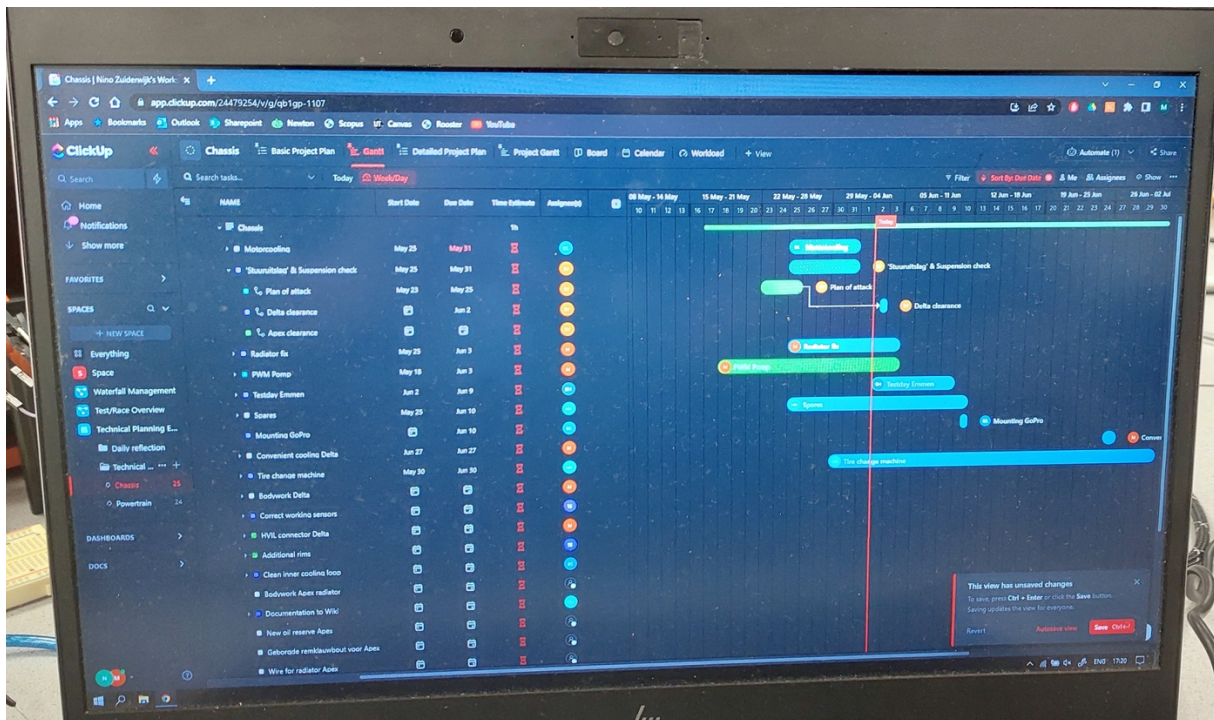


Figure F5 – Major tasks, events, and milestones of the EST chassis sub-team.

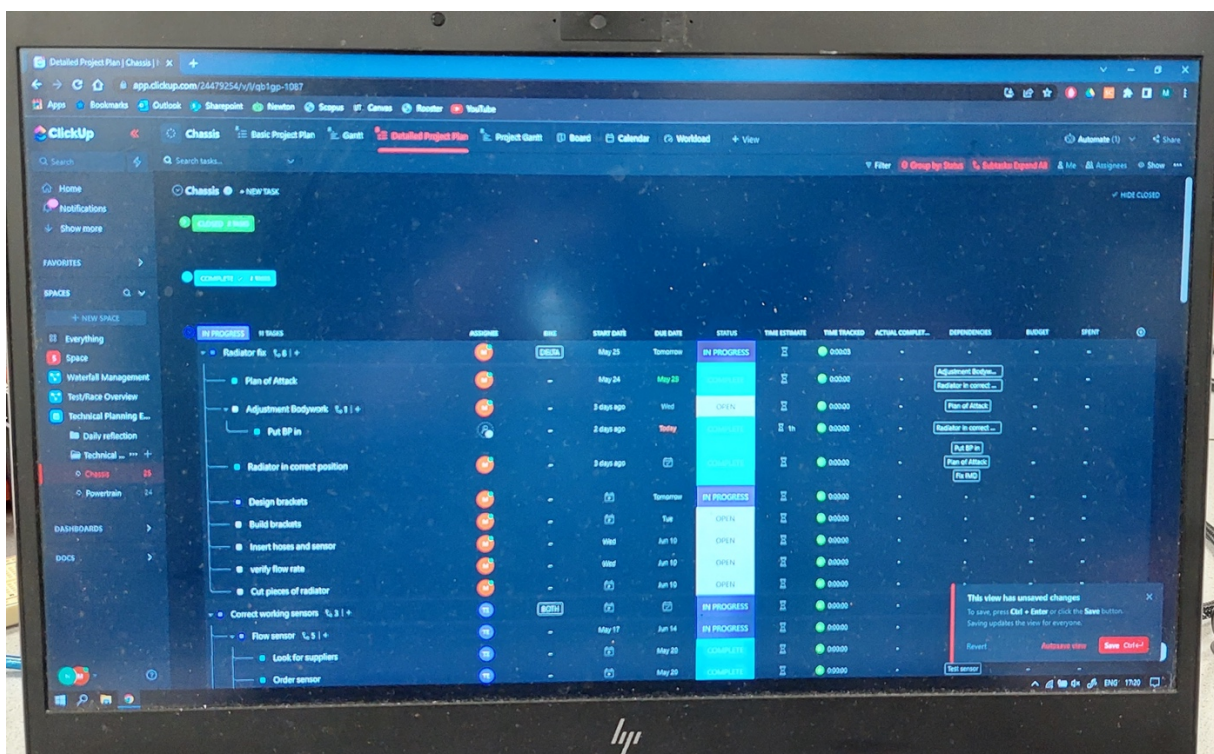


Figure F6 – Status of the activities assigned to the EST chassis sub-team.

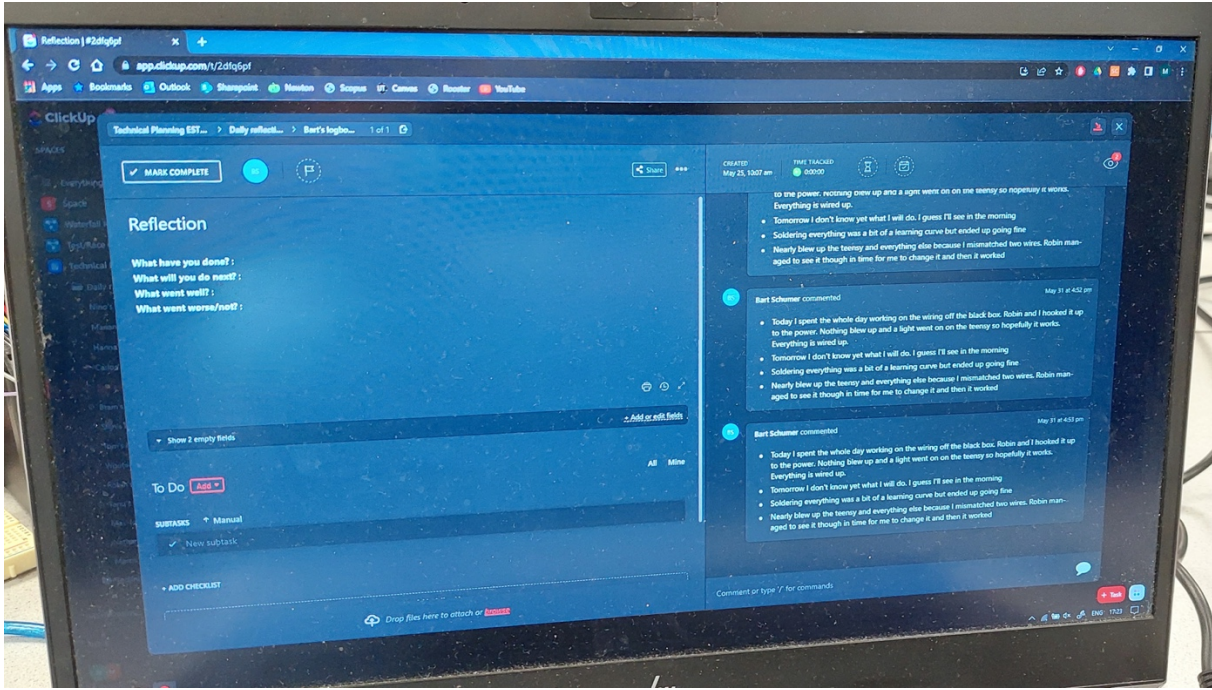


Figure F7 – Individual reflection done by EST team members through ClickUp digital app.

Table F1 – Explanation about each working function of EST (Join Now, 2019).

Sub-teams	Function	Description
Management	Team manager	Has an oversight of the entire team and its progress. Balances the interest of team members, partners, and other parties. Helps in making the plan and steering the team in the right direction. Contact person for the press and partners.
	Technical manager	Responsible for combining the various disciplines within the technical team and facilitating everything that is necessary to fulfill the goals. In charge of the technical development of the motorbike. Creates a comfortable and save environment where everyone can work together in the best way possible.
	Communications manager	Responsible for all the contact to the external world. Manages the communications team and helps them whenever needed.
	Finance	Manages the budgets and oversees major cash flows in the team.
Communications	Events	Responsible for organizing events such as the technical presentation, superbike reveal, partner day, and new team days.
	External relations	Keeps in touch with and expands the firm's portfolio of partners.
	Media & marketing	Manages the image of EST on and offline. This includes promotional material, like flyers, posters, banners, but also graphic design for the superbike, social media, and merchandise. Manages and regularly updates the company's website.
Powertrain	Chief powertrain	Responsible for the motorbike's electronics. Makes sure the right people are working on the right things at the right time. Involved in crucial decisions regarding electronics. Contact point within the sub-team and is the liaison with partners and other sub-teams.
	Powertrain engineer	Makes the superbike come to life. Ensures that the electrochemical energy stored in the battery results in a spinning rear wheel. Builds and orchestrates the brains of the bike, together with the many onboard safety features.
Chassis	Chief chassis	Responsible for the motorbike's mechanical components. Makes sure the right people are working on the right things at the right time. Is involved in crucial decisions. Contact point within the sub-team and acts as liaison with partners and other sub-teams.
	Chassis engineer	Designs and builds mechanical components of the motorbike having into optimal values of cost, space, and weight.

Table F2 – List of all EST partners (Partners, 2019).

Partners of EST
3D4MAKERS.COM. Aalberts. AERONAMIC. AFAM. AFMI. CAD2M. COMODO. De Letterconcurrent. DISTRELEC. DUPLEXX. ETC. Eurofins. EV Experience. F-500 Encapsulator Technology. GelKoh GmbH. HANKAMP GEARS. HELUKABEL. IACT Intech. JAKO. Kemari. KVASER. Laadlift.nl Mertens Riding School. MOTIK. MOTOPORT. Munsterhuis Autoverhuur B.V. PCV Group. PowerField. Prodrive Technologies. Provincie Overijssel. Red Drop Design. Roc van Twente. SAXION. Sebastiaan Bors. SIEMENS. SKF. StefTec Education. TAMESON. TEAM. Ten Kate Racing Products. TT Circuit Assen. University of Twente. Urenco. VDL ETG Almelo. VMI GROUP. Würth Elektronik. Xelvin. YER. ZEROONE.

Appendix G - Game Lab Oost



Figure G1 – Building where GLO is based in.



Figure G2 – Workspace shared by all companies based in the GLO building.



Figure G3 – Workspace shared by all companies based in the GLO building.



Figure G4 – Workspace shared by all companies based in the GLO building.

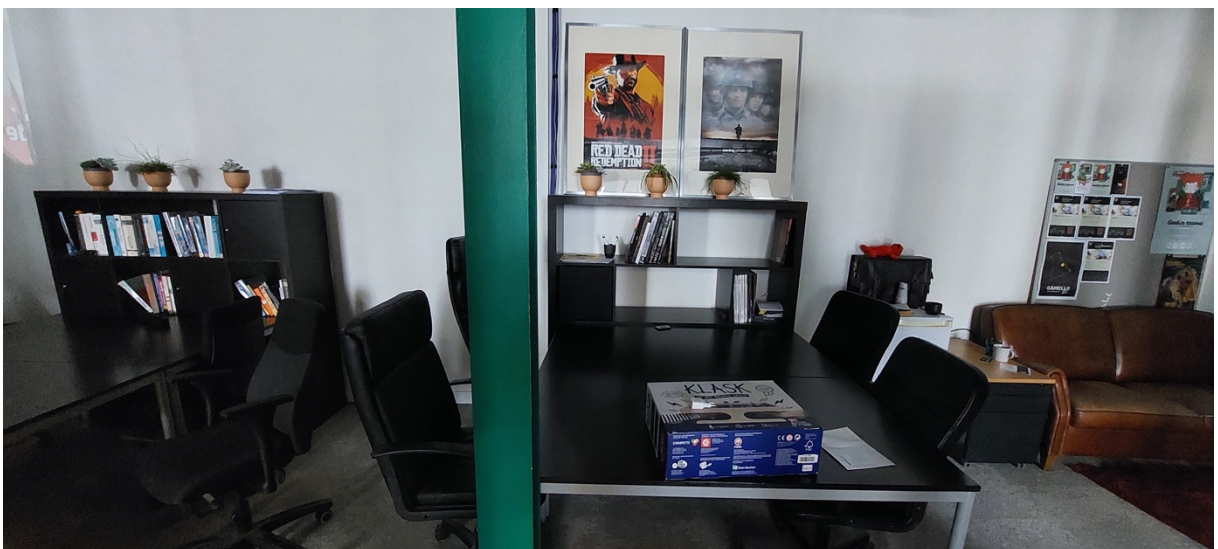


Figure G5 – GLO exclusive working space.



Figure G6 – Tex Town Games' exclusive working space.

Table G1 – Explanation about each working function of GLO (“Vacatures,” 2022).

GLO functions	Description
Game designer	Responsible for developing the set of rules that govern and guide the player’s actions, as well as the game’s response to such actions. In charge of specifying how the game will work for the people who play it.
Game artist	Creates 2D and 3D art for the visual elements of the game, such as characters, vehicles, props, scenery, background, objects, colors, textures, and clothing. This person is ultimately responsible for creating the look and feel for the game.
Project manager	Provides guidance to all company members. Oversees the development activities. Makes sure client expectations are met. Conducts market research and creates a business model based on that investigation.
Programmer	Accountable for writing and developing the software needed to create the games. Makes sure that the game design is fully implemented. Translates game concepts into clean and efficient code.
Applied psychologist	Conducts user research to analyze whether players experience games the way the company intended. This person selects people from the target audience, get them playing the game, and administers surveys or observe them to assess if the levels of excitement or anxiety are aligned with GLO targets.
Marketing & communication (MarCom)	Responsible for informing frequent or potential clients about GLO, its services, and members. Advertising, social media, and the company’s website are used and regularly updated to raise awareness amongst external stakeholders. MarCom members develop the project budget and aid in the market research.
User interaction (UI) and user experience (UX) designer	UI/UX designers are responsible for developing and optimizing the entire visual interface through which the user interacts with the game: buttons, menus, navigation, fonts, for example. These individuals create the look and feel of things like the heads-up display (HUD) showing the score, lives, and level of the game. They make sure that the menus and commands are clear. Ultimately, these designers are accountable for making sure the game is nice, and easy to use and to understand.
Sound designer	Responsible for collecting, editing, and creating sound effects, ambient effects and music for the game and the company’s social media.
Game concept artist	Responsible for the style and look of a game. They are the first to draw the environments, characters and objects present in the game. This person develops manual and digital sketches that are used to help game artists, programmers and designers understand how the game will look.
Game animator	In charge of making the objects created by the game artist move. The animator adds personality, emotion, and realism to the game. Due to the complexity of game animation, libraries of the movements are created, so that they can be reused in different characters and objects. The game animator takes full advantage of the GLO gaming technology and maximizes the opportunities for game play and interactivity.