UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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TRABAJO FIN DE MASTER EN INGENIERÍA INDUSTRIAL

Application of Agile approaches during the development of an hyperloop prototype

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1 Introduction

In this chapter the structure of the thesis will be depicted.

1.1 Starting point and problem definition

This thesis explores the product development process of a team of students at the Universitat Politècnica de València (Valencia, Spain) developing a prototype of Hyperloop, a disruptive mean of transport proposed by Elon Musk in 2012, based on eliminating the main two forces that limit movement: friction with the rail and air resistance, achieving speeds of up to 1000 km/h with zero fossil-fuel emissions. In a six-month period, the team has designed and implemented a full prototype to test in a 1,5 km-long track located in Los Angeles, USA, in a low-pressure environment. During this timeframe, the entire prototype development process will be described, with an important focus in trying to implement new product development methods for a more agile implementation.

Purdue Hyperloop and Hyperloop UPV are two teams of enthusiastic students engaged in an adventure with the aim of building the transport of the future. Thanks to their participation at previous Hyperloop competitions, both teams were able to meet each other and start talking about a meaningful collaboration with the aim of optimizing resources and combining the know-how of both universities.

Figure 1 From left to right: Purdue Hyperloop team and Hyperloop UPV team

The Purdue Hyperloop team is composed of 20 students from Purdue University (West Lafayette, Indiana, USA). The team took part at the Design Weekend, being one of the selected teams to participate at Pod Competition in January 2017, where they achieved the 7th place, receiving an award for performance and operations. Their advisor, Dr. Guillermo Paniagua, is Adjunct Professor in the Aeronautics and Aerospace department, and Professor of Mechanical Engineering at Purdue University. Doctor in Applied Sciences at the Université Libre de Bruxelles and expert in fluid dynamics and turbomachinery with a Diploma from the von Karman Institute (Belgium).

Hyperloop UPV is a team of 30 students from the Universitat Politècnica de València (Valencia, Spain). They were awarded "Top Design Concept" and "Propulsion/Compression Subsystem Technical Excellence Award" at SpaceX's Design Weekend, the first stage of the Hyperloop Pod Competition held in Texas on January 2016. The team counts with the help of Dr. Vicente Dolz, PhD. Mechanical Engineer, senior lecturer at UPV and researcher at the Center of Thermal Engines (CMT) in the fields of energy recovery from exhaust gases, turbomachinery processes, heat flow modelling and rankine cycles using organic fluids (ORC).

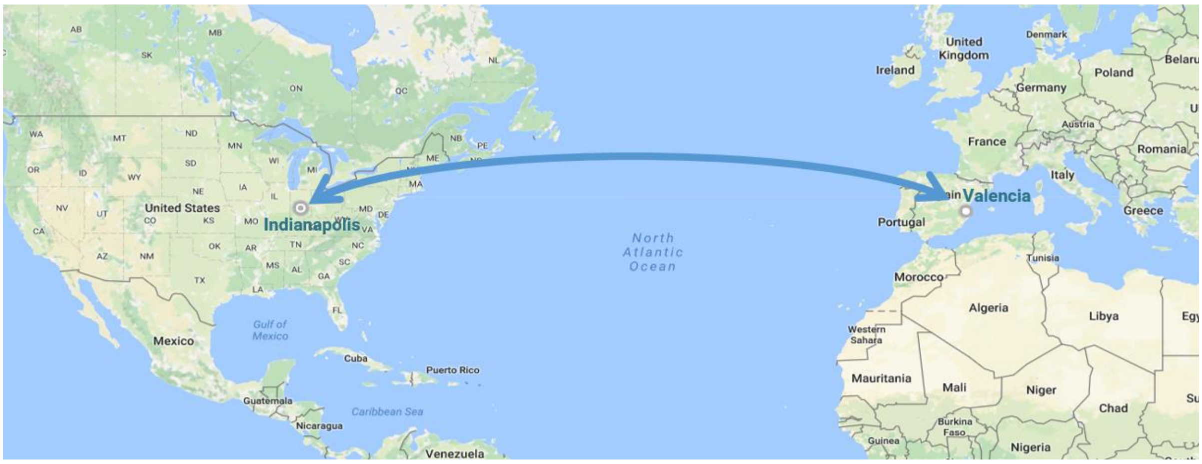

Figure 2 Geographical location of the teams (Vicén 2017)

Both teams decided to unite to participate in SpaceX's Hyperloop Pod Competition II. Originally belonging to countries that are separated by the Atlantic Ocean but joined together for a common purpose, under the name of Atlantic II, they turned what separates them into their identity.

Figure 3 Slogan of The Atlantic II (Vicén 2017)

It is also important to note that both teams have currently over a two years of experience working in the Hyperloop Project. They have raised supports among different companies and Institutions, helping to spread the Hyperloop idea around the world, and being able to achieve the resources needed to carry out research on the different subsystems to implement them in a real prototype.

Figure 4 First Purdue Hyperloop prototype, exhibited in January 2017 for Hyperloop Pod Competition 1 (Purdue Hyperloop 2017)

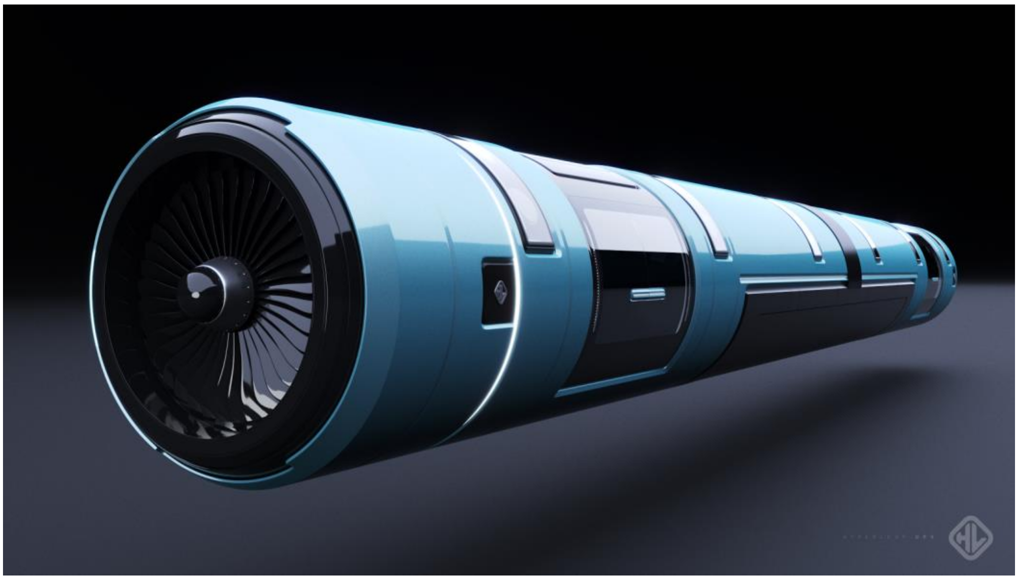

Figure 5 Hyperloop UPV's first concept design, awarded at Hyperloop Design Weekend, January 2016 (Hyperloop UPV 2016)

As an introduction, it should be mentioned how the Hyperloop competitions were born. After the initial concept proposed by Elon Musk in 2012 (Musk 2012) SpaceX decided to organize Hyperloop competitions to boost its development. The first Hyperloop competition was held in Texas A&M University, in January 2016. During this competition, named Design Weekend, teams were able to propose theoretical designs for the future Hyperloop or, on the other side, to propose concepts for prototypes to be built for the Test-track competition in Los Angeles. During this competition, several Universities qualified to build prototypes, and that way, SpaceX created the next competition, Hyperloop Pod Competition 1, which took place in

SpaceX Headquarters in Los Angeles, in January 2017. In this competition real prototypes were built and three teams were able to enter in the Hyperloop 1.5km-long Test Track to test their developments. The top speeds achieve during the competition were below 100km/h but the information obtained was useful to keep developing prototypes. Just after this competition, SpaceX announced Hyperloop Competition II, with a main focus: to achieve the maximum speed without crashing. This competition opened applications for new Universities and it is the one in which "the Atlantic II" took part, in August 2017.

Figure 6 Timeline of Hyperloop competitions (Vicén 2017)

Regarding the project planning, the SpaceX Pod Competition 2 was announced the 31st of August 2016. At that time teams from Hyperloop Pod Competition 1 were yet building their prototypes for their competition, being in January 2017. At that time, the Hyperloop UPV team was raising supports to build the first prototype, so when the competition was announced, the team quickly applied and started to follow a tough process of verification phases to bring the prototype to Los Angeles. As can be seen in the figure, the first report, called Preliminary Design Briefing (PDB), was handed in the 11th of November. This document was a first draft of the prototype, but as will be observed later, that design differed from the ultimate proposal. The second report, called the Final Design Package (FDP), was a more extensive document, with detailed information about all subsystems, simulations and providing proofs of fact. The third report was basically a Safety Briefing, including all safety measures that would allow teams to have the prototype ready for passing all tests. It is important to mention that SpaceX would not allow to enter the tube any team that had not passed all these three filters. To finalize with the verification process, teams would have to pass eight safety tests before entering the tube, which would be carried out from 20th to 26th of August at SpaceX Headquarters, and that would allow SpaceX to choose the three selected teams to participate at the competition on Sunday the 27th of August 2017.

Figure 7 Timeline of Hyperloop Pod Competition II (Vicén 2017)

The starting point of the Hyperloop UPV team.

The first Hyperloop UPV team was composed of five University students: David Pistoni, Daniel Orient, Angel Benedicto, Germán Torres, Juan Vicén and Vicente Dolz, the University advisor. This was the team that carried out the first analysis of the Hyperloop system in September 2015, that was awarded the Top Design Concept and Top Propulsion prizes in the Design Weekend back in January 2016.

After this competition, the media impact was high since the team was the only Spanish team awarded at the competition, and the first time such a competition had taken place. That allowed the team to be present at several talks and fairs, where they obtained the support of several companies to keep developing the research project. Suddenly, Germán found a job at an aerospace company called PLD Space.

At that time, Daniel also got an internship and Angel, David and Juan started planning their studies abroad, in US, Sweden and Germany, respectively. In July, Angel also departed to the States to start his Master at the University of Maryland. Just a month later, after the summer vacation, SpaceX announced the Hyperloop Pod Competition II.

Prior to departure to Sweden and Germany, David and Juan decided that they would help Daniel to lead the team from abroad. Despite being far away, in different parts of the world, the three team members decided to lead the next generation of students. leaving Daniel in charge of the technical direction onsite and David and Juan in charge of the team management and communications.

Just after departing, the three launched a recruiting campaign and in two days about three hundred members of the University, including students and professors, decided to apply to participate in the development process. After analyzing the information, the team decided to carry out an online test asking for more information and making some technical questions to prove the skills of the applicants, and then they chose 30 candidates. These 30 candidates were interviewed via online call and after the interview, the team was able to choose five technical leads. The initial structure was the following:

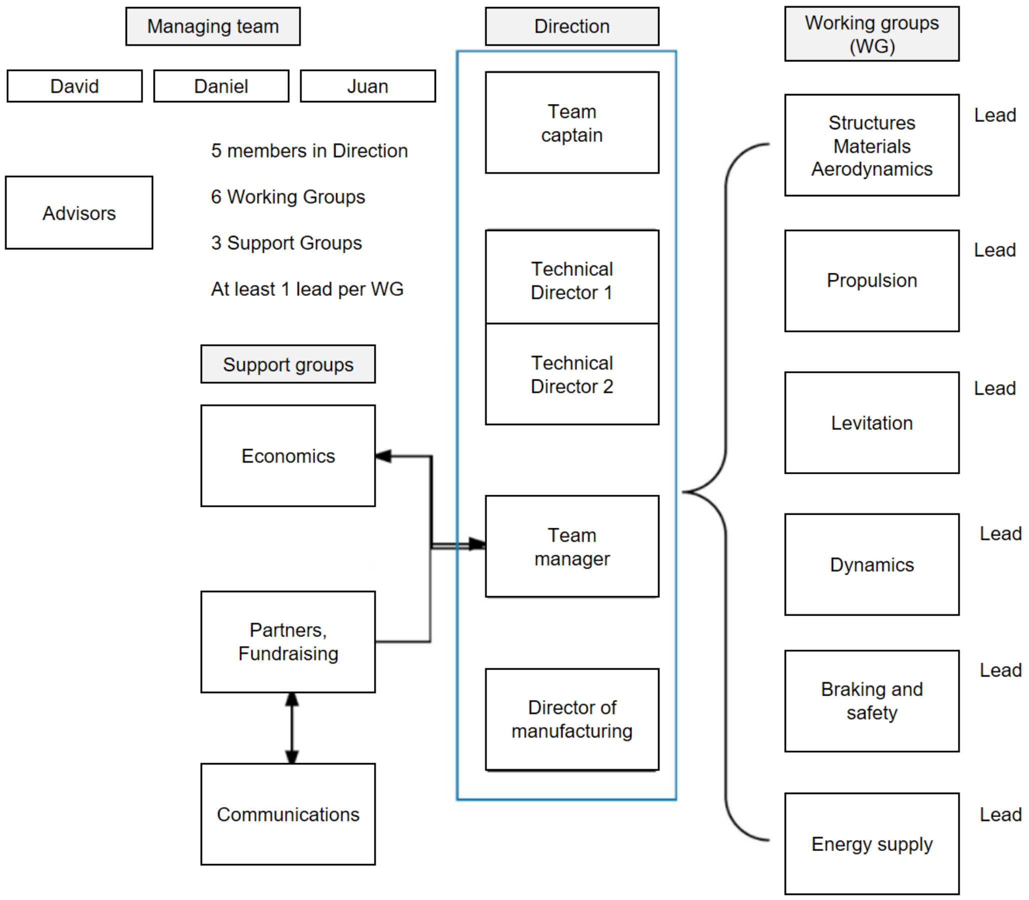

Figure 8 Initial structure of the Hyperloop UPV team (Vicén 2017)

As can be seen, the structure of the team was similar to that of an horizontal organization. For the day-to-day operation, there was one team lead per Working Group, two technical directors, a team captain, a team manager and finally a director of manufacturing. These eleven people were the core of the team, and were in charge of taking the technical decisions to keep the project going. Together with the technical direction team, three support groups were created, which were vital to ensure the funding needed to operate: these were Economics (in charge of managing the economic resources), Partners (in charge of approaching companies and signing partnership agreements) and Communications (in charge of ensuring the impact, visibility and reach needed). Also, critical decisions such as the entry/exit of new members, deadlines and definition of objectives, were taken always by the Managing Team, composed by the three main directors: Daniel, David, and Juan.

As some of the roles were very specific and no profiles matched the needed skills, the team had to appoint the students that most likely were to adapt to the situation. In the case of levitation, Daniel was appointed, so he had to be Technical director and at the same time, lead of a Working Group. Although challenging, in the end this proved to be the best solution. Also, the director of Manufacturing and the Structures Lead were the same, because at the first time no manufacturing was needed.

Regarding meetings, it must be stated that dealing with students makes the process a bit more difficult, because many factors limit the time availability of each student, such as the obligatory lessons and lab sessions, exams periods… that's why instead of having a strict weekly schedule, the managing team decided that each lead would be responsible for organizing the weekly meetings (at least once a week) with their co-workers and to ensure that deadlines were met. Leads met with the direction once a week, usually Friday afternoon at 4 p.m., time at which nobody usually has lessons. In the direction meeting each lead would report to the technical directors the weekly progress and speak about every concern to keep up with the work, discussing technical problems and reaching solutions. Directly after the Direction meeting, a General team meeting was carried out. In this meeting all team members of Hyperloop UPV were invited to attend, and after a first introduction by the Managing Team, then every Working Group had to talk about the progress, the main concerns, and the next steps to be taken. These meetings were really useful not only worked as a tool to keep the track of the project, but also to make the people connect with each other, because students usually don't have time to connect during the lessons and this meeting was an important point of connection for the whole team. A total of 35 General Meetings were performed during the time span of 9 months, from October to June.

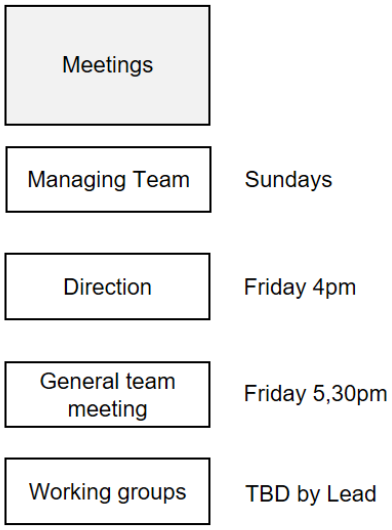

Figure 9 Meeting structure of the Hyperloop UPV team (Vicén 2017)

The starting point of the Purdue Hyperloop team.

The Purdue Hyperloop team was participating in the Hyperloop Pod Competition 1. The members of the team were busy creating a full prototype for that competition when the Hyperloop Pod Competition 2 was announced. From January 2016, the members of the team had already experienced an almost complete development process, but not all the members were aiming to join for the next competition, because some of them were graduating. At Purdue University, the structure of the team was different: instead of being a club of students, the team was managed by a Professor, in this case Professor Guillermo Paniagua, who offered an official practical course about Hyperloop in which students could enroll. In this approach, the professor was the manager of the team, because he was the one in charge of the economic and space management. The team had two parts: one more centered of the futuristic research of Hyperloop and other part aimed at the building process, which is the one that was in contact with the Hyperloop UPV team. The Build team was composed of about 10 people, and it had a Team Captain, called Aaron, who was also the point of contact with the Spanish team and who was in charge of both the technical and the management sides. Four working groups reported to him and to Professor Paniagua during the days of team meeting, which was carried out weekly on Tuesdays.

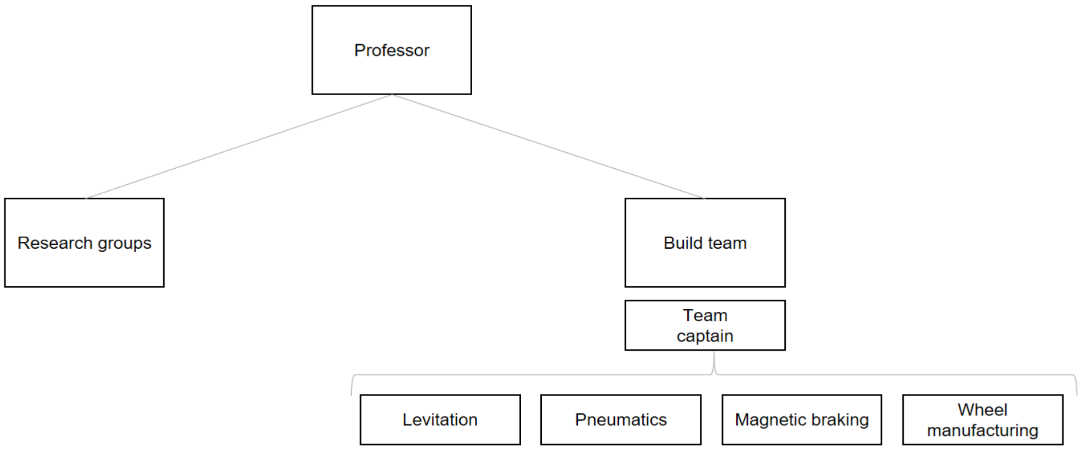

Figure 10 Team structure of the Purdue Hyperloop team (Vicén 2017)

Table 1 Description of the organization structure of both teams (Vicén 2017)

	Hyperloop UPV	Purdue Hyperloop
Budget management	Students	Professor
Space management	Students	Professor
Role assignment	Students	Professor/University
Decision making	Managing team (Students)	Professor
Fundraising	Students	Professor/University
Attendance	Free	Compulsory
Rewards	Practical experience	Credits (ECTS)

After the submission of the first report (each University did the submission separately), Professor Guillermo Paniagua contacted the Hyperloop UPV team to talk about a possible collaboration in order to bring a prototype together to California for summer. After several calls, both teams saw advantages:

On the one side, the Hyperloop UPV team didn't have experience manufacturing a Hyperloop prototype, and the resources and supports obtained at that time weren't enough to build everything in Valencia. But they did have experience in simulation and design, something that made them win in Design Weekend, as well as a robust team of about 30 people ready for working.

On the other side, the Purdue Hyperloop team was busy developing the first prototype and they didn't have time and people enough in the team to carry out the theoretical design and write the technical reports. But Purdue University had big facilities and workshops to do the manufacturing and assembly of the prototype, including the advantages of having the prototype already in the USA (customs usually delay the shipping process, especially if the items are hazardous materials, because then it has to be made by boat, and this process takes about one month).

Table 2 Decision-making chart for collaboration approval, December 2017 (Vicén 2017)

	Hyperloop UPV	Purdue Hyperloop
Location	Valencia, Spain	Indiana, USA
Team members	30	10 (build team)
Time availability	High	Low
Testing facilities	Limited	Sufficient
Workshop space	Small	Big
Funding	Medium	Medium/High
Manufacturing experience	No	Yes
Design experience	Yes	Yes
Shipping time to LA	30 days (boat)	3 days (ground transport)

Finally, the collaboration agreement was signed and both teams started to work together in December 2016: this was the beginning of The Atlantic II.

1.2 Motivation

The motivation of this work arises from the need to manage teams and develop products and technologies faster and more efficiently. Thanks to the lessons learned in March 2015 at "**Think.Make.Start. Hackathon**", a seminar organized by Dipl.-Ing. Annette Böhmer, Research Assistant at the Chair of Product Development at the Technical University of Munich (TUM) and the Unternehmertum (Center for Innovation and Business Creation at TUM), the author was able to understand the principles of product development in small teams with the Scrum methodology applied to hardware prototyping.

This Seminar led to a research work carried out by the author called **“Analysis and application of State-of-the-Art Product Development Methods”** under the mentoring of Mrs. Böhmer, in which several new Product Development methods were identified and explained to further apply them in the development of a prototype of an air-monitoring station called Hawa Dawa during a two-week period with a team of 5 university students.

After this experience, the author of this thesis entered a new challenge: in 2015, Elon Musk decided to organize a competition of students to develop a more ambitious product: the Hyperloop. In comparison with the first air-monitoring device, the new development process included several aspects which the author considered interesting to describe:

1. The **number of people involved**
   Whereas in the first project the number of people was 5, this new project involved more than 30 people, something more similar to a medium-sized startup or company.
2. The **time constraints**
   These were more similar to a professional project: 1-year timeframe in comparison with the 2 weeks in the case of the previous work.
3. The **complexity**

   Although the timeframe of the project was longer, the uncertainty levels remained high because the team was not formed by common employees, but by students who volunteered and had limited time to work on the prototype. The complexity of the project increased due to the fact that the prototype had to be shipped from Spain to USA, dealing with international players.
4. The **budget**

   The order of magnitude of the budget in the first project was of about 500€, with secured funding by the University, this new project was in the order of 50.000€ without secured funding by the University. That didn’t only mean having a person only in charge of the economic management, but having to raise funds to be able to develop the project.
5. The **Variety of Skills required to make the project a reality**

   While in the first project the only needed skills were programming, soldering and 3D printing, the new project involved new areas of work, such as dealing with CNC machines for manufacturing, working with composite materials, high voltages, pneumatic systems and magnetic materials. The technical skills needed to develop the project had more variety.

Table 3 Differences between the two projects (Vicén 2017)

	Hawa Dawa prototype	Hyperloop prototype
Number of people involved	5	+30
Timeframe	2 weeks	1 year
Complexity	Medium/Low	High
Budget	500€	50,000€
Technical skills	Programming, soldering, 3D printing	Programming, soldering, 3D printing, pneumatics, high voltages, magnetics, vacuum, composite manufacturing, CNC machining, welding..

The new project represented, as can be derived from the table, an opportunity to analyze new product development methods in a project with a high degree of technical skills involved, a high degree of complexity and at the same time a high degree of uncertainty due to the fact that all the work was carried out by volunteering students, resulting in a radical example of product development. In essence, the competition was a means to accelerate the development process and pass from an idea to a working prototype as fast as possible with real competitors (teams from other universities) boosting efficiency.

This, together with the desire of adding his grain of salt to the development of a new transportation method that is 100% electric and sustainable achieving 1000 km/h, was the motivation of the author to start this work.

About the author

Juan Vicén was the founder of a non-profit organization called Makers UPV at the age of 20, with the purpose of applying the knowledge acquired at the University in real life applications.

He, together with his team, raised a community of about 2000 students interested in technology competitions, knowledge-sharing workshops and do-it-yourself projects. Based at the Universitat Politecnica de Valencia (Spain), there he got his Bachelor Degree in Industrial Engineering in September 2015 and after his Bachelor, he obtained a Double-Degree Erasmus Scholarship to do his Master between Valencia and the Technical University of Munich (TUM).

At TUM he carried out his first research work at the Chair of Product Development with Advisor Dipl. Ing. Annette Böhmer, named “Analysis and application of State-of-the-Art

Product Development Methods". At the same time, the author got involved in a Seminar called "Think.Make.Start" aimed at applying new Agile methods to build real prototypes.

There he obtained and award with their team "Hawa Dawa" for their prototype of an air-quality measuring device, which has now become a startup and is commercializing its first product. After his experience in Germany, the author returned to Spain and founded a team to participate in the Hyperloop competition organized by Elon Musk's aerospace company, SpaceX.

There they got the Top Design Concept and Best Propulsion Subsystem awards thanks to their theoretical concept in January 2016. Their aim to bring the theoretical concept into life made them participate in the next competition, consisting in building a real prototype for August 2017.

During that time, the author was able to better understand the processes involved in real-scale product development, from the conceptualization phase until the final testing and validation, a fruitful experience that led the development of his second research work, which is the one that follows.

1.3 Objectives

The purpose of this thesis is to explore and apply new Product Development (PD) methods evaluating their performance in the solution of real problems, in this case the development of a Hyperloop prototype in a timeframe of one year.

The objective is not only to obtain a higher degree of understanding of the current product development methods, but also to serve as a reference for future technological developments made by students, research groups or companies, highlighting the lessons-learned during the process and providing basic recommendations that can help them carry out similar projects more efficiently.

Consequently, the aim of this thesis is to evaluate PD methods in a practical way (with a real project), as well as uncovering new ways of application and in order to make the process more efficient.

1.4 Structure of the work

This work will be structured in six chapters.

The first chapter will be an introduction chapter, in which the starting point will be described, the objectives as well as the motivation of the author in this field of study.

Next, the second chapter will include a description of the research methodology used for this work, including the research areas that the work covers and the definition of the data collection procedures.

After the detail of the methodology, the third chapter will be a research carried out to understand the State of the art in the mentioned research fields, this will include first definitions of new Product Development methods and explanations of the procedure models of product development, finalizing with a summary of the meaning of artifacts in procedure models of product development.

Once the State of the Art is known, the next step (fourth chapter) will be to start by understanding the application of the Agile Methods in Product Development, describing the existing approaches, classifying them and selecting the most appropriate ones to the implementation in the project depending on the characteristics and other important factors. A planning will be also provided to proceed with this implementation.

In chapter five, the results of the data collection will be shown, comparing the results from the real process (the realization of the Hyperloop prototype) and the literature. During the chapter, the several processes will be arranged in a chronological way and after that there will be a process of clustering and of analysis of interdependencies to demonstrate that the work was carried out the right way.

Finally, the sixth chapter will include recommendations for future works and some final words as a conclusion.

Figure 11 Structure of the thesis (Vicén 2017)

2 Research methodology

2.1 Explorative Research

The concept of Explorative Research comes originally from the field of Social Science, but it is also explored in other fields such as Market Research (Böhler, 2004, P. 37). It is used when there isn't any or a there is only a little scientific knowledge about particular objects of research, but at the same time there is a presumption of the presence of interesting elements (Stebbins, 2001, P. 6). The more important characteristics and prerequisites of Explorative Research are the flexibility in the search of data as well as the openness and creativity during the research process (Böhler, 2004, P. 37). Commonly used methods are interviews, talks with experts or literature research (Stebbins, 2001, P. 22; Böhler, 2004, P. 37).

As part of the explorative research, both qualitative and quantitative data can be collected (see figure below)

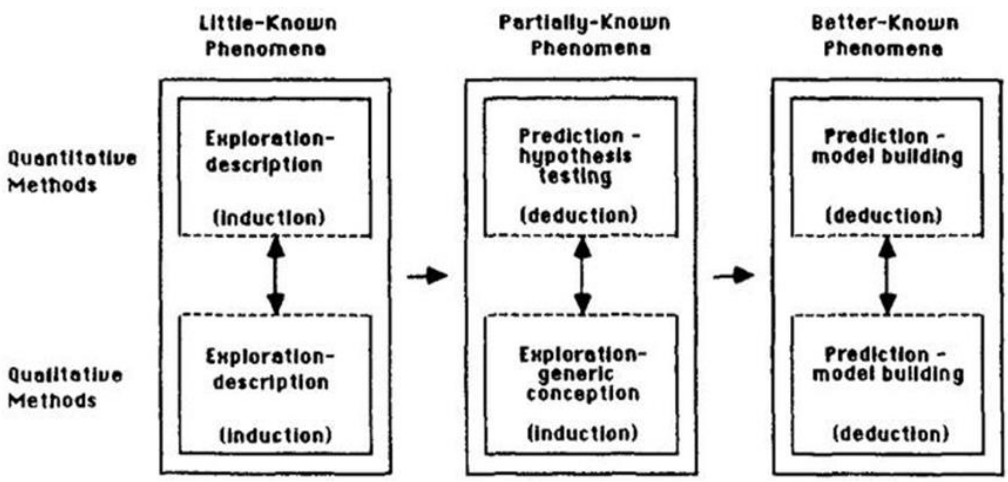

Figure 12 Relationship between qualitative and quantitative research methods (Shaffir & Stebbins, 1991, P. 6)

The explorative research starts at the left side of the picture. If there is more knowledge available, the research method moves to the right. For example, more understanding can lead to the testing of hypothesis or the development appropriate models. This means in practical terms that, based on an explorative research, generic and comprehensive concepts can be developed with increased technical progress (Stebbins, 2001, P. 6). It is important that the exploration takes places inductively. That means, that an effort should be made to go from the basic information gathered to the establishment of general statements, theories and concepts (Creswell, 2014, P. 66). In contrast, in the deductive method the researcher tests and verifies general theories, leading to deductions that are later reviewed (Creswell, 2014, P. 59).

As a summary, it should be stated that explorative research is used, when a research topic hasn't been scientifically investigated at all, and the research has been based mainly on predictions and controls instead of flexibility and creativity, and so the research related to Figure 1 advanced earlier has been subjected to heavy changes, so that the establishment of new principles is required (Stebbins, 2001, P. 9).

The final goal is the inductive establishment of new concepts or empirical generalization through the creation and union of new ideas. The most important criteria are the quality of the new ideas, which can be detailed and refined in further research (Stebbins, 2001, P. 9).

2.2 Research areas of this work

This work can be thematically located in the field of innovation processes. Innovations can pertain to the following dimensions:

1. Product or Service Innovation:

-Structural innovation (Organisation, Direction, Management)

-Social innovation (Human aspects of a company)

2. Market innovation (Business concept Innovation)

-Production system innovation (technical or physical field, such as production)

-Process innovation (Hauschildt & Salomo, 2007, P. 9-11; Wahren, 2004, P. 19f; Hübner, 2002, P. 10)

The focus of this work will be in the field of Product innovation. This field relates to all fundamental activities from the identification of possibilities of innovation, the development of prototypes, until the beginning of production (Gürtler & Lindemann, 2016, P. 488). For that purpose, all activities from ideation to the practical application to the introduction to market will be taken into account.

Another limitation is the concentration on development of physical products. Virtual products (such as smartphone Apps) or services are not considered as the main focus, although they can be seen as parts or complements of the physical product. The main focus of the research will be the use of Agile methods as well as analysis of the effects of methods and artefacts.

This field didn’t take too much attention until now, which is why this work will take it as a explorative research from now on.

2.3 Methodology and data collection for this work

First, and because there is not much theoretical knowledge available, a research on literature about innovation processes and Agile methods in physical product development will be carried out, The results of this findings will be summarised in order to outline the first ideas and concepts. These should represent a theoretically founded starting point to keep researching.

A first application and comparison of these ideas is the basis of the data collected, which will follow the same philosophy as the Seminar Think.Make.Start. of UnternehmerTUM, held in the Makerspace UnternehmerTUM located in Garching, Munich (Germany). This is a practice-oriented course from the Technical University of Munich (TUM), in which 50 students develop innovative products in interdisciplinary teams (UnternehmerTUM, 2015). The focus of this course is to put the Agile approaches and methods into practice and to concretise in iterative phases the product ideas in form of prototypes (e.g. through rapid prototyping). Moreover, students also build during the process a business model that matches with the product (Lehrstuhl für Produktentwicklung, 2016).

For the data collection, student teams are accompanied daily. On the one side, some can be documented systematically through several activities, such as the application of methods, the fabrication of artefacts or the use of prototypes. On the other side, the reasons and motivations of the participants are determined with open and spontaneous individual and group interviews.

In the following study, as the author attended the Think.Make.Start Seminar before (year 2015), a similar philosophy will be used, but adapted to the new project, which is longer in duration, team members, budget, and therefore, in complexity.

3 State of the Art

3.1 Definitions

Before covering the topic of the process models in product development, first of all explanations to several definitions will be introduced. This will be a consistent and uniform understanding, which will be the basis for the rest of the statements of this work.

3.1.1 Procedure models

Procedure models are basically a guide used by developers for the implementation and organization of processes (Lindemann, 2009, P. 33). A process is defined as the transformation from input data to output data (Lindemann, 2009, P. 16). They are a support in which the most important components of the planned method are structured. They are products, roles, activities and processes. This is depicted in the figure below:

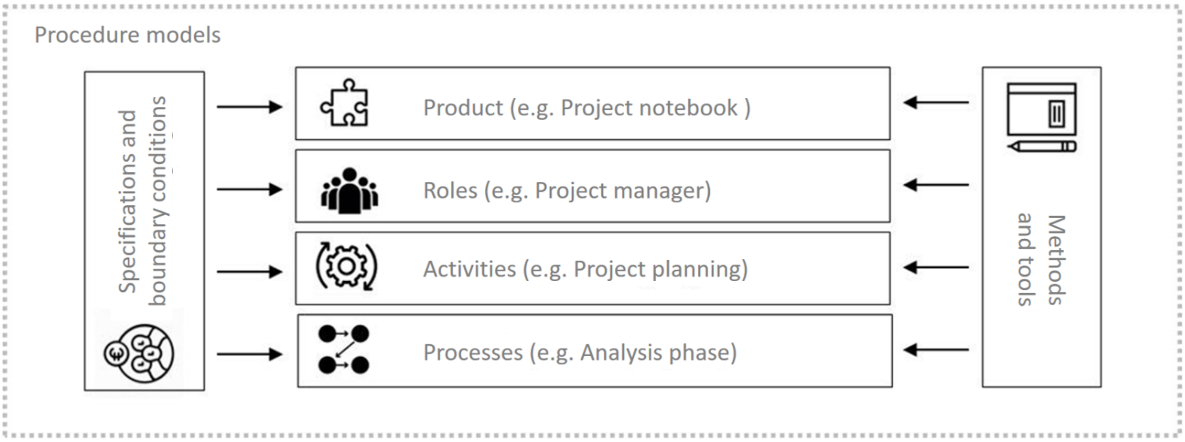

Figure 13 Parts of a procedure model (in conformity with Fischer et al., 1998, P. 17 & Hammerschall, 2008)

A procedure model defines who (Role model) is responsible at which time point (Timing model) for the creation of a defined element (Product model). Also, it is specified how the procedure should work (Activity model) (Hammerschall, 2008, P. 27; Broy & Kuhrmann, 2013, P. 87). As a whole, a procedure model specifies "who, how, what and when" someone has to do something. The developer should help with the implementation through the preparation of methods and tools. Specifications and boundary conditions should be also taken into account, which could be external standards (e.g. ISO Standards) as well as internal specifications (e.g. Compliance guidelines) (Hammerschall, 2008, P. 28).

A procedure model is used to obtain a standardised understanding and it allows to have a consistent method to implement projects (Meyer & Reher, 2016, P. 36; Hammerschall, 2008, P. 26). Together with a better planning, procedure models also offer the possibility to do a more critical reflection of past processes, being able to obtain a "learning effect" and to unveil the optimization potential (Lindemann, 2009, P. 33).

3.1.2 Methods

A method describes a systematic and reasoned path to achieve defined objectives. It is used to solve a specific problem or an assignment (Lindemann, 2009, P. 57; Fischer et al., 1998, P. 26). For that purpose, certain guidelines and rules should be defined and a proposal for the sequence of action steps that should be followed (Broy & Kuhrmann, 2013, P. 86). In other words, it is a prescriptive formalism that specifies each and every activity as well as its respective documentation. Thus, methods are characterized by an operational nature (Lindemann, 2009, P. 57). To establish methods, several tools are used (Fischer et al., 1998, P. 26), such as calculation programs or forms.

- Basic principle of the systematic thinking
- Basic principle of the problem decomposition
- Basic principle of „From the whole to details "
- Basic principle of „From the abstract to the concrete "
- Basic principle of the discursive approach
- Basic principle of the repeated reflection
- Basic principle of „Thinking in alternatives "
- Basic principle of the change in modality

Finally, it is important to note that the methods are differentiated by their formalization and their operative execution. A procedure model tells "who how what and when" does a job. The methods provide therefore support and answer the question "with whom and in which steps" the tasks should be carried out (Lindemann, 2009, P. 58). As it is explained in **Figure 2** several methods can be applicable inside a procedure model (Broy & Kuhrmann, 2013, P. 87).

3.1.3 Agile Approaches

In the business context, the concept of "Agile" started to be used after the publication of the „Manifesto for Agile Software Development" in Year 2001 (Beck et al., 2001), which draw much attention. These developers wanted to set against the extensive, complex and document intensive procedure models for a more efficient development (Hanser, 2010, P. 9). Specially, they were dealing with constantly increasing complexity and the obligation meet the needs of the frequent changes of requirements (Klein, 2016, P. 18).

On that basis, some definitions were created in the literature. Looking for similarities, the following description of the term "Agile" can be obtained, which in the context of this work could be of application:

Agility describes the skill of responding quickly and continuously to the variations of the situations in the market and its environment, which can be external or internal, expected or unexpected. The reaction implies the consideration of internal factors as well as the comprehension of all stakeholders and other environmental factors to be able to change in an effective and holistic way. The principal objective is to have a lean and flexible development (Hoffmann, 2008, P. 2).

3.1.4 Artefacts

The word "Artefact" comes from the Latin arte = with skill and factum = done. Depending on the context the term has different meanings. For example an artefact is in archeology an object whose form can be maintained due to the influence of the man, while in electronics it is an interfering signal.

In the business world, one can find the term in the field of software development. In the Unified Modeling Language (UML), an Artefact is an element that is formed as a consequence of the provision or the use of a software system during the development process. It is therefore a physical bunch of information, for example some data with source code or a table in a databank (Object Management Group, 2007, P. 213). Rumpe (2012, P. 12) defines Artefact, apart from the UML, as all the results of a software development that are described in a certain notation (e.g. the natural language or the programming language). These can also be middle products. Here a difference can be made between material (source code, drafts, documentation...) and immaterial (methods, knowledge, concepts) Artefacts (Fay et al., 2009, P. 81).

Apart from the software development, Brökel (2016, P. 21) describes an Artefact as an object in which one can save information. It is interesting to note that all objects in some form can represent an Artefact. For example, also a simple product such as a table could be an Artefact, because through reverse engineering it could generate some information. Gülke (2014, P. 49) includes in his definition the origin and application of the word Artefact. He explains the term as a virtual or physical object of a business, that can be modified or eliminated during a process.

While this definition of the term Artefact is very general, Klein (2016, P. 37) limited its meaning in the field of the building of machines and facilities. An Artefact represents here a component of the procedure model. Artefacts describe in a similar form as documentation, which parts of a project have to be developed and in which (intermediate) results will be divided. They therefore include, what has to be developed in a product.

An approach that will be used in this work, uses the term as a synonym or part of the product model (see Chapter 3.1.1).

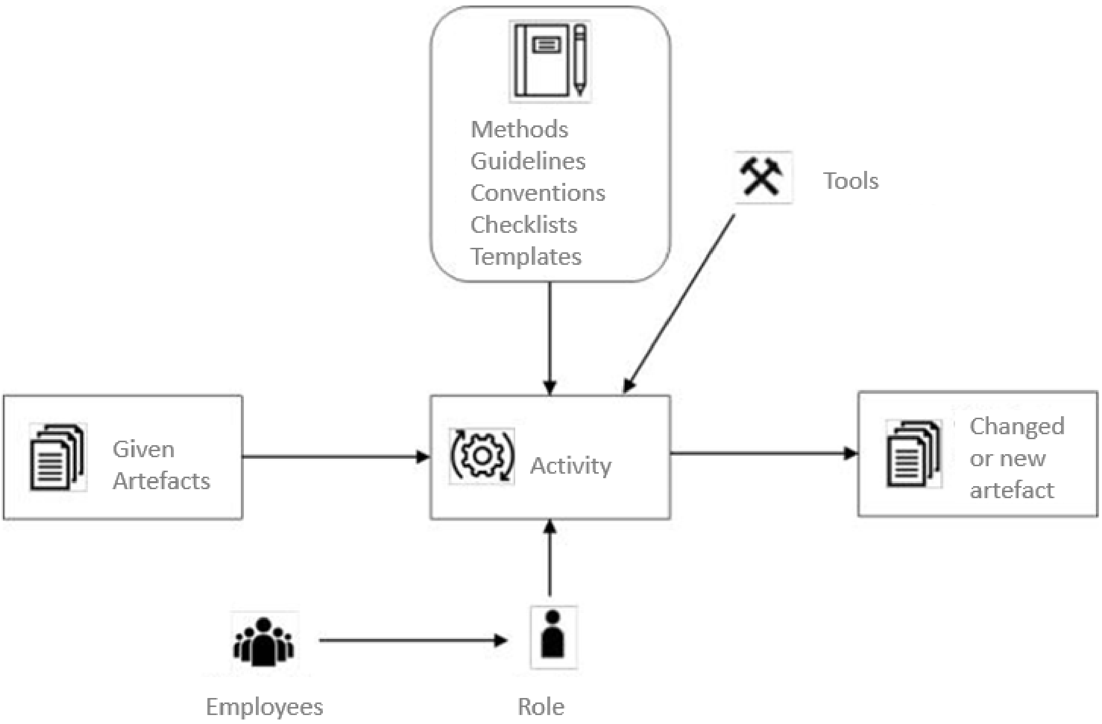

Figure 14 Dependency between Artefact and Activity (in conformity with Balzert, 2009, P. 443)

As can be seen in Figure 14, the artefacts of these fields are linked to an activity and an employee, that has an specific role (Broy & Kuhrmann, 2013, P. 87; Hahn et al., 2013, P. 75). The artefacts can be changed and the use of a given artefact can be the requirement for a new one. The use of methods such as requirements (e.g. guidelines) or boundary conditions (e.g. availability of tools) has an influence on the creation process (Balzert, 2009, P. 443).

To sum up, in this work the following definition can be derived (see figure below).

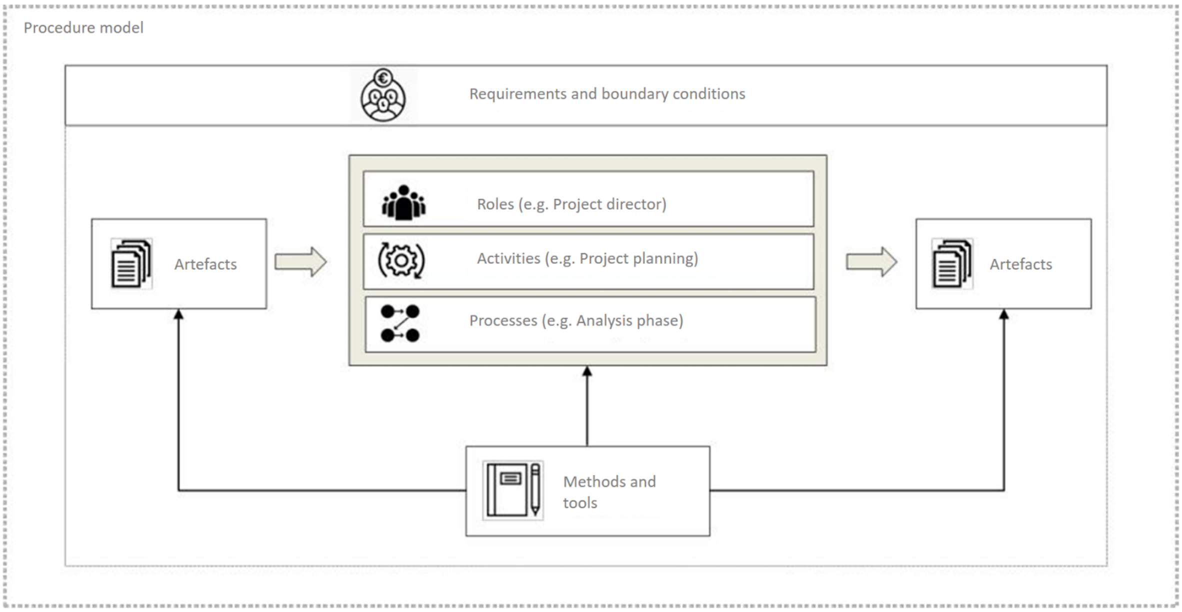

Figure 15 Parts of a procedure model with artefacts included

Artefacts contain all information that is needed and that comes up in the product development processes. They can be in physical/material or virtual/immaterial form. They are information carriers. Under the influence of methods and machines as well as requirements and boundary conditions, the artefacts will be generated/edited or eliminated inside a procedure model. It is also possible the release of the need of a new artefact to the use of an old one. They enter depending on the case of application (e.g. different time points of the product development) in the different component models (roles, activities and processes).

3.1.5 Increments

The term "Increment" is defined in the dictionary as an increase or addition of a magnitude. The application can be found usually in the field of mathematics.

Thanks to the popular Agile procedure model "Scrum", this term has now a broader application in the field of software development. An increment is defined as artefact. The particularity of the increment is that it is part of a "finished" part or product functionality (Klein, 2016 P. 86). It is therefore a potential useful function that can theoretically be ready for the clients with less effort (Maximini, 2013, P. 177).

3.2 Procedure models in Product Development

As only some understanding of the most important notions can be obtained, in the following sections it will follow a detailed research on procedure models in the product innovation and product development. For that reason, first different characteristic forms will be presented. Finally, relevant models for this work will be presented.

3.2.1 Characteristics of Procedure Models

Linear procedure models are usually known as sequential, classic of traditional (Hoffmann, 2008; Klein & Reinhart, 2016, P. 70). A well-known model, that is many times chosen as the typical example, is the Cascade model (Royce, 1987, P. 329).

These procedure models are characterised by a very extensive and complete planning at the beginning of the project (Hoffmann, 2008, P. 5). After the detailed analysis of requirements several phases need to be passed, in which defined tasks should be carried out and defined results should be achieved. The outputs of each phases serve again as an input for the next step. It is therefore a top-down approach (Gnatz, 2005, P. 20). The product will be first completely delivered at the end of the development (Klein, 2016, P. 47). The compliance of the sequential method is controlled and supervised by the project controlling staff (Hoffmann, 2008, P. 5). A schematic representation of the phases is detailed in figure 5a.

The biggest disadvantage of the classical model is its inflexibility against unexpected changes. Nowadays technologies are rapidly developed and the requirements of the clients and users have to be redesigned in small timeframes (Link, 2014, S. 74). In the linear model the sequence of phases is fixed and the changes are not possible, so no quick and effective modifications can be done (Gnatz, 2005, P. 20). It also happens that the costs of a classical development project are fixed early and later cannot be influenced, so later measures to change can be expensive and with severe consequences (Ehrlenspiel, 2009, P. 615f).

To be able to adapt to this increasing complexity in the product development, new procedure methods appeared later, which took into account the product design, the emerging costs and the possible risks in a lighter and more transparent way (Hoffmann, 2008, P. 6).

First the evolutionary or *iterative procedure models* were developed. One of the well-known methods was the one proposed by Barry W. Boehm called the Spiral model (Boehm, 1988, P. 63). From the iterative procedure model, the trend passed to the development of a general specification based in steps to an always more concrete division of tasks (Bodendorf, 1990, P. 75). The overall system was developed in several iterations. The planning consisted in short-term time horizons, and after every step modifications could be carried out thanks to experiences and learn effects (Gnatz, 2005, P. 21). Analogous to the linear models, here the model was top-down, although recesses and deviations from the standard approaches were allowed (see Figure 5b) (Balzert, 2009, P. 560). With the iterative methods the planning phase passed to the background and the results won attention. That was the reason why usually first prototypes were created (Goll & Hommel, 2015).

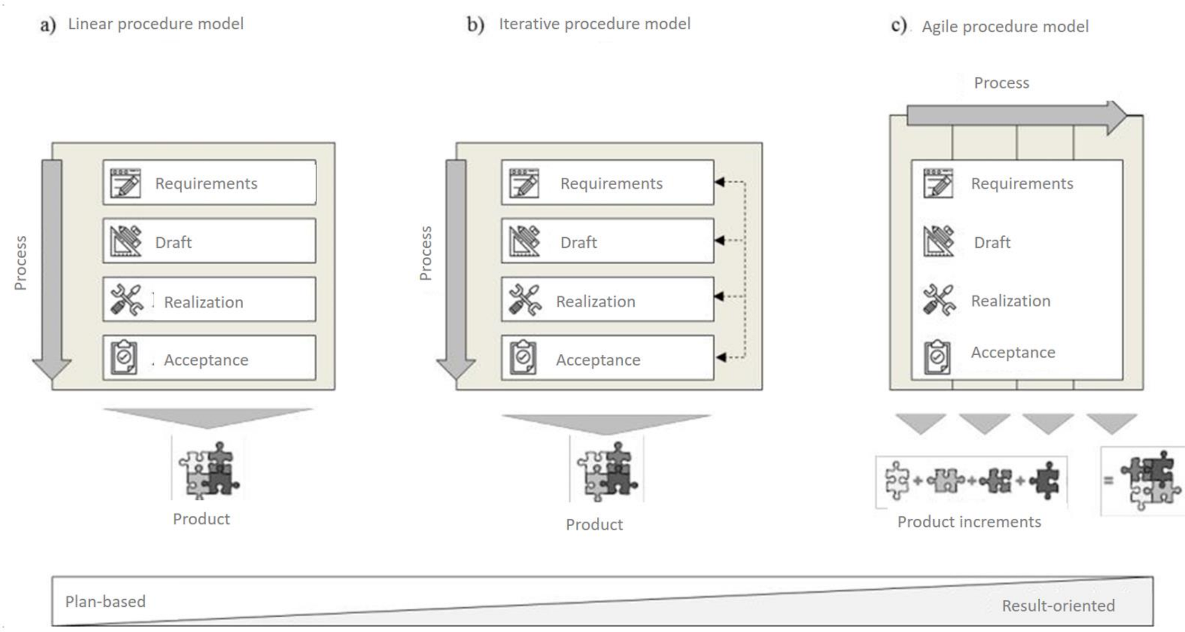

Figure 16 Characteristic forms of procedure models (in conformity with Klein & Reinhart, 2016, P. 70; Klein, 2016, P. 47; Gnatz, 2005, P. 19f)

In **Agile procedure methods** the planning is not the focus, but the highest value is given to the client and the results achieved (Goll & Hommel, 2015). As the planning in large time frames is not considered, at the early stage of development the requirements are only drafted (Gnatz, 2005, P. 23). The detail is later carried out during the project progression. The emphasis is put in Agile methods in the ability to adapt and the flexibility, accepting the unpredictability of the events (Link, 2014, P. 74). The sequence of different development phases is therefore not given, and instead behooves the estimation of the team (Klein, 2016, P. 47). In the Figure above, in the option c) it can be seen that the single steps can also run parallel to each other.

An important characteristic is the provision of potential deliverable product parts, the so-called product increments (Gurusamy et al., 2016, P. 36; Coldewey, 2002, P. 242). These approach implies that the requirements during the project progression of the series won't be fulfilled (Goll & Hommel, 2015).

Following the magical triangle of project management (Horsch, 2003, P. 21) , the plan-driven and result-oriented procedure models can be confronted with three criteria: budget, time frame and scope (number of product features) (Cooper, 2016, P. 22), represented in the figure below.

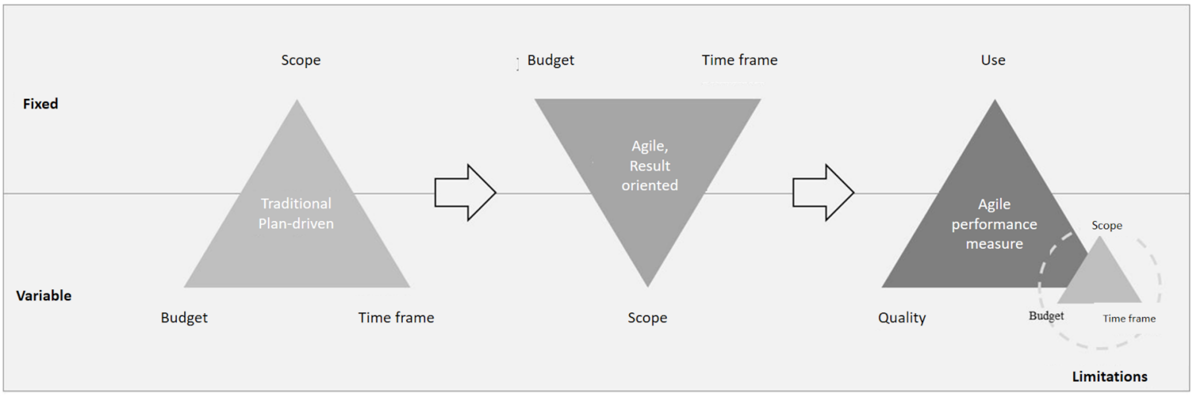

Figure 17 Fixed and variable parts in traditional and Agile procedure models (in conformity with Cooper, 2016, P. 23& Highsmith, 2010, P. 21)

In their respective representations are certain components fixed and variable. In traditional plan-driven procedure models the scope of the product is fixed at the beginning. The budget and the timeframe are variable. In Agile, result-oriented model, the scope of the product is variable, the number of product characteristics can change. The budget and the timeframe are on the other side fixed (Cooper, 2016, P. 22). Highsmith (2010) expanded this classification of success measures from projects. The magical triangle was modified, because the factors budgets, timeframe and scope were not appropriate for the success determination of Agile projects.

For example, the fixed compliance with the timeframe could not be considered as a result criterion, because Agile projects were based on change, flexibility, and adaptation (Highsmith, 2010, P. 19). Consequently, the "Agile triangle for the measurement of success" was developed and can be seen in Figure 6 (to the right). The only success criterion was the the customer use. The quality is a variable criterion that could be adapted with the expected user benefit. Furthermore, the traditional magical triangle was summarized in its overall limitations. Budget, scope, and time frame are only for the achievement of the client benefits and the varying quality criteria (Highsmith, 2010, P. 20). Also, the importance of prototyping is high and it must be planned using state-of-the-art rapid and virtual prototyping tools to accelerate the process (Liou, 2017).

In the following chapters well-known procedure models relevant for this work will be presented. Traditional methods will not be considered, because they are not appropriate for innovation processes (Morris et al., 2014, P.10).

3.2.2 Iterative Procedure Models

One of the most iterative methods is the VDI 2221 "Methodology for development and construction of technical systems and products". Furthermore, the Munich procedure model (MVM) will be also shortly studied due to its suitability for this work.

3.2.2.1 VDI 2221: Methodology for the development and construction of technical systems

The objective with the design of the guideline VDI 2221 is to provide a general method to develop and build technical systems. This method is generally applicable in different disciplines, because it is only specified the gross structure and there's no dependence on specific characteristics (Jänsch & Birkhofer, 2006, P. 49). For that purpose, the model has a broader application, with great use in the product development in engineering (Pahl et al., 2007, P. 21).

The model can be divided into four main phases. In engineering were the examples the clarification of the task, the conception of the system, the system design and finally the development. Furthermore, these phases are composed of seven steps, from which the result documentation emerges (Ehrlenspiel, 2009, P. 253). The model VDI 2221 is represented in the figure below:

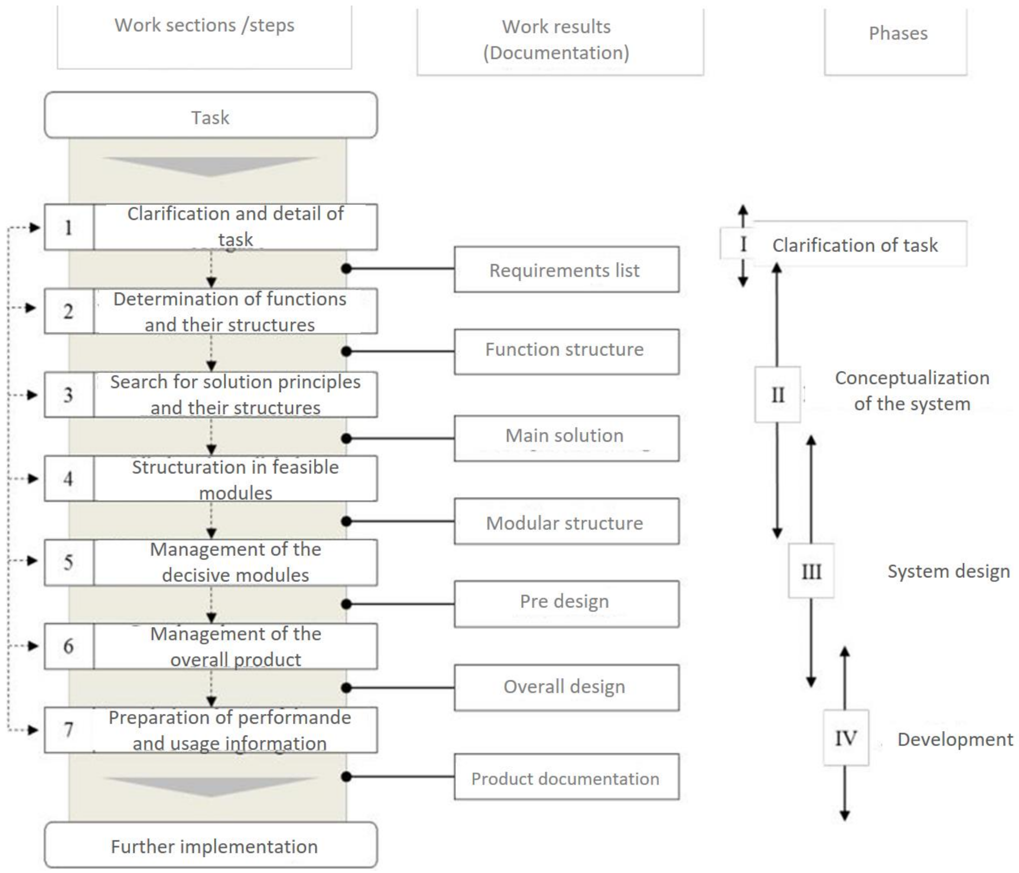

Figure 18 VDI 2221 (in conformity with Pahl et al., 2007, P. 22)

First, the task is clarified and detailed, resulting in a complete list of requirements. From that point, the functions are derived, which are joined together to create a functional structure. After that, the third step is to look for general solution possibilities that will be connected in the main solution concept. This will be structured feasible modules and in the fifth step they will be defined, considering the crucial parts for the pre-design. Consequently, they will be combined into an overall design, which will be the basis for further modifications. It is important to update during the process the requirements list created at the beginning. It is also important the final document, called the product documentation, created during the course of the previous phases (Ehrlenspiel, 2009, P. 253).

The representation of the VDI 2221 suggests a sequential characteristic (Lindemann, 2009, P. 44). Nevertheless, it is an explicitly iterative procedure model, that allows jumping forward and backwards during the different phases (Pahl et al., 2007, P. 21).

3.2.2.2 Munich Procedure Model (MVM)

The fundamental principle of the Munich Procedure Model (MVM) lies in the fact that it provides a method for problem-solving. It is, as the VDI 2221, independent from specific disciplines and it can find application in different fields.

The procedure is divided into three main steps. First, the objective and the problem are analysed. Subsequently, it takes place the generation of alternative solutions before taking a decision (Lindemann, 2009, P. 46).

The MVM is represented as a map of developments in the form of a network. The different steps can be followed individually depending on the situation (Lindemann, 2009, P. 47). For that reason, it is possible to bypass forward or backwards the elements. It is therefore an iterative procedure model. The representation of the steps as an overlapping circle implies that the processes sometimes are coupled or overlap each other (Ponn & Lindemann, 2011, P. 19). In the figure below the MWM is represented with its seven steps.

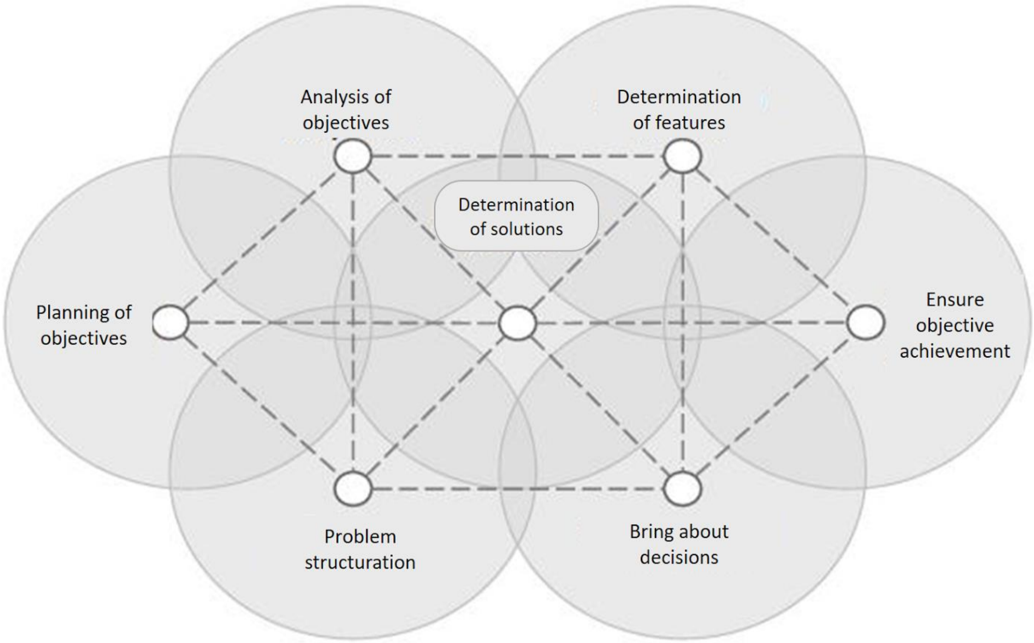

Figure 19 Munich Procedure Model (Lindemann, 2009, P. 47)

Generally, the objectives start with the planning. In the basis of the analysis of situations some concrete measures in relation with the environment will be derived. The analysis of the objectives describes the clarification and description of the desired state of the objective. It is the recognition and ordering of the requirements. The problem structuration deals with the definition of the key action lines, the system will be described in an abstract way and based on parts of the system to reduce complexity (Lindemann, 2009, P. 48). The generation of solution ideas is carried out through the analysis of the mentioned solutions as well as the development of other solution possibilities. Most of solutions will be parts of solution that will be joined in an overall concept. The analysis of the features includes the effort to understand the relevant characteristics of the system features relevant for the solutions. Through the rating of solution ideas and alternatives, decisions can be made during the project (Lindemann, 2009, P. 49). At the last point of development, it should be ensured that the objectives are achieved, to minimize risks (Lindemann, 2009, P. 50).

3.2.3 Agile model summary and classification of a generic innovation process

In this chapter some Agile procedure models which are considered relevant will be presented. They are Scrum, Design Thinking and Lean Startup. Theoretically there exist a lot of other Agile concepts but they are not of application in this work. For example: the so-called Lean Development or Open Organization (Gürtler & Lindemann, 2016, P. 492).

3.2.3.1 Scrum

The most Agile procedure model for product development is called Scrum. It was originally conceived for software development, but it has application in several other fields (Gloger, 2016, S. 14f). In essence, it is a method for project management and product management, in which the progress of the project is the central point. (Hanser, 2010, S. 61). The method is complex and it will therefore explained now in more detail.

Scrum stipulates six roles, six meetings and eight artefacts and provides the framework for the development activities (Gloger, 2016, S. 9). An overview of the role distribution can be seen in the figure below:

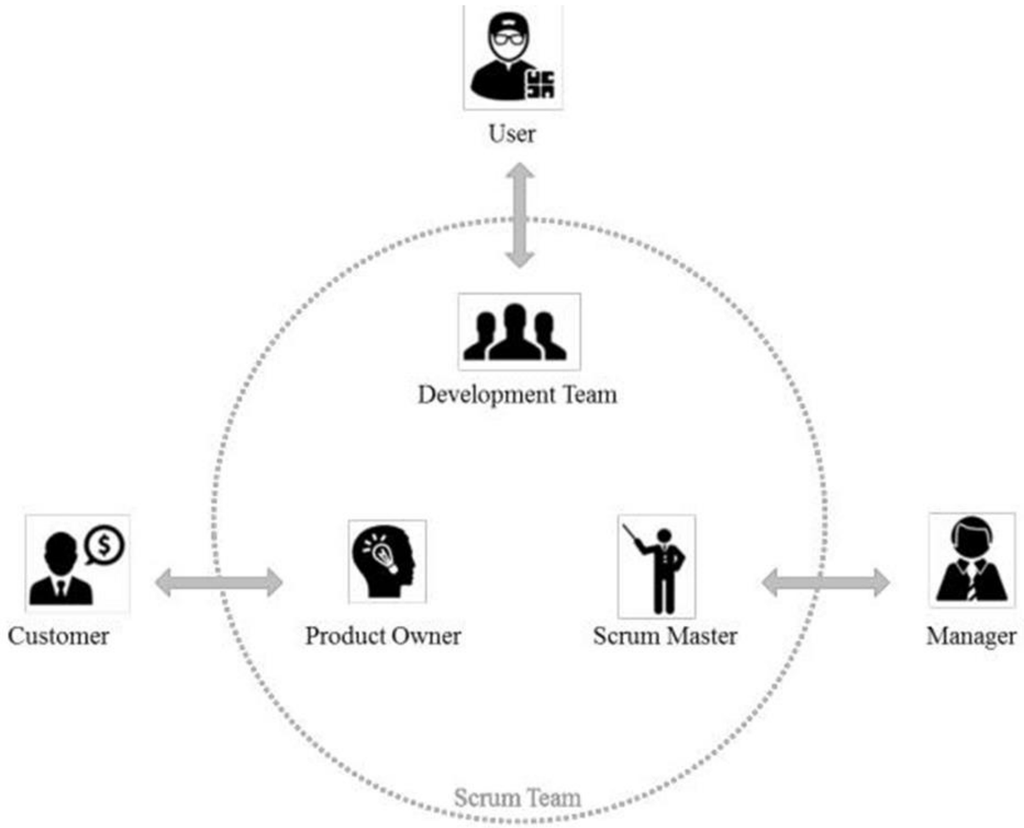

Figure 20 Roles in Scrum (in conformity with Gloger, 2016, P. 9)

The Scrum team is composed of the development team, the product owner and the Scrum master (Schwaber & Sutherland, 2013, S. 4).

The developers are responsible of the creation of the product. They work as close as possible with the end users and they obtain the requirements (usually in form of User Stories) thanks to them. They are also responsible for the design and the quality of the product (Gloger, 2016, P. 64). The team is freely organised, it composed of interdisciplinary members and they renounce to hierarchical or similar organizational distributions (Schwaber & Sutherland, 2013, P. 5f).

The product owner plans and controls the development process. He designs the exact vision of the product and sets the boundary conditions (Gloger, 2016, P. 77). He is required to do the force the decisions, if every development step is following the objectives and if the product increments fulfill the requirements (Gloger, 2016, P. 81). Furthermore, he manages the Product Backlog (explanation follows), which has to be constantly reviewed and newly prioritised (Schwaber & Sutherland, 2013, P. 5). As a summary, he is consequently responsible for the concrete outcomes of the development project (Gloger, 2016, P. 77).

The Scrum Master leads the whole Scrum team. He takes care of the productivity of the team, for example promoting the internal communication. Also, he is responsible for the fulfilment of the Scrum processes and takes care of the emerging problems or obstacles that could appear. He is the interface with the Manager and promotes the implementation and acceptance of the scrum processes in the organisation (Gloger, 2016, P. 85; Schwaber & Sutherland, 2013, P. 6).

The Manager is the representation of the Organisation or business in which the Agile development with Scrim is being carried out. He prepares the resources and guidelines and creates the company framework for Scrum (Gloger, 2016, P. 101).

The Customer is defined as the client and the one who funds the development project (Gloger, 2016, P. 98). It must be distinguished from the User, who will use the final product (Gloger, 2016, P. 100).

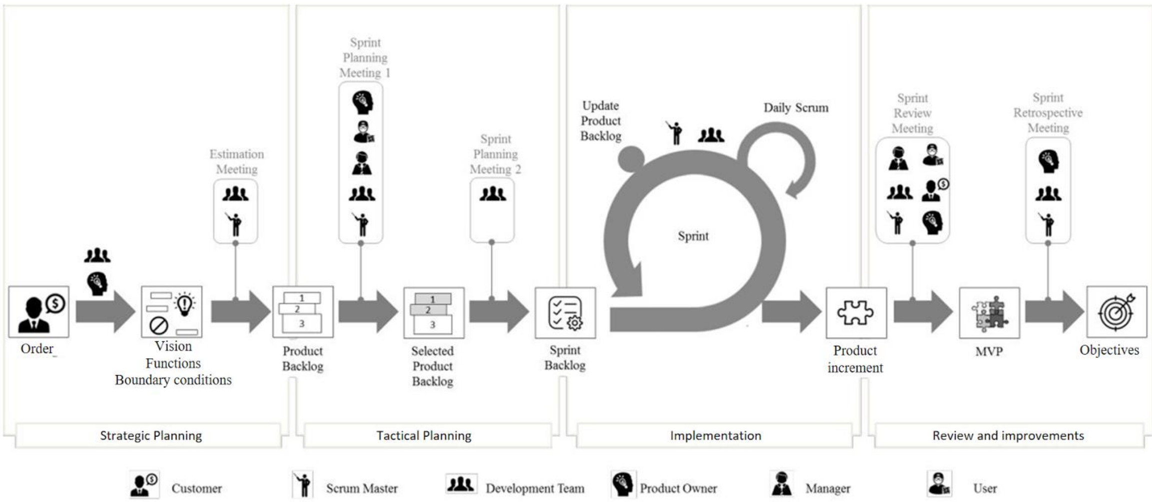

Figure 21 The Scrum Process (in conformity with Klein, 2016, P. 65)

Generally, the process can be divided into four phases: the strategic and tactical planning, followed by the implementation as well as the control and improvement (Klein, 2016, P. 65).

The strategic planning is composed of several steps. First the product owner (usually together with the development team) designs based on the client order, a fundamental idea of the product, from which a vision arises (Gloger, 2016, P. 116). It is also important to define the boundary conditions (the constraints) (Gloger, 2016, P. 121). For that purpose the Product Backlog will be built. It describes the collection of all functions that a virtual product has to have. It doesn't have to be viewed as a collection of strong requirements or specifications, but more as a loose compilation of the client wishes. In this context it is recommended the preparation of User Stories (Gloger, 2016, P. 124). It is important to take care of the Product Backlog from its creation, updating and prioritising it always (Schwaber & Sutherland, 2013, P. 9).

The transition to the tactical planning gives the Estimation Meeting. The Scrum Master prioritises, talking with the developers, the yet unstructured parts of the Product Backlog, depending of the future needs of the customer (Gloger, 2016, P. 132) and evaluates the approximate amount of effort (Gloger, 2016, P. 141f). It is important, more than the estimations, the so-called Velocity. This means the amount of functionalities that can be achieved by a team during one Sprint (fixed time frame of the development activity) (Gloger, 2016, P. 145), so a first Release Plan for the Product Increment can be built (Gloger, 2016, P. 146). On the basis of the results, the sequence for the implementation of the functions will be defined (Gloger, 2016, P. 148).

The tactical planning is composed by the two Sprint Planning Meetings. During the first one, the Product Owner, the Scrum Master and the Developers define together with the user and the management the objective of the Sprint (Gloger, 2016, P. 12). In this Sprint objective there will be expressed how many and which items from the Product Backlog should be released. This will be called Selected Product Backlog (Gloger, 2016, P. 149). In the second meeting, the Sprint Planning Meeting 2, the developers will discuss how they can achieve the objectives and they will express it in the Sprint Backlog.

After this process, now the practical implementation of the development project can start in the so-called Sprint. It is important that towards the end of every Sprint one product increment is delivered. If there are sufficient increments, they can be joined together in what's called a Minimum Viable Product (MVP) (Gloger, 2016, P. 151).

The MVP describes the first minimal and functional product, that is derived for a series of Sprints and can always be improved and which can provide important feedback from the customer (Glatzel & Lieckweg, 2014, P. 23). In every Sprint there will be a tuning meeting, the Daily Scrum, held every day. Through a status check (what did I achieved since the last Daily Meeting, what do I want to achieve for the next, what do I have to to achieve it?) a synchronization and harmonization of all team members will take place (Gloger, 2016, P. 171). An important feedback will be obtained thanks to the presence of virtual users. Through the review of requirements (User Stories), it will be possible to assess if the objectives have been met.

Then, the Sprint Review and the Sprint Retrospective follows. In the first one, the MVP is presented by the Scrum Team. For that purpose several adjustments, such as the determination of new functionalities or the prioritization of rework, can be performed (Gloger, 2016, P. 177). During the Sprint Retrospective, the Scrum Team analyses internally, how can they improve continuously and how can they learn looking back and carrying out an analysis of the work processes (Gloger, 2016, P. 182). Subsequently, the next cycle will begin with the Sprint Meeting 1.

Some interesting variations of this method have also arised, as the Moonlight Scrum (Diebold 2013), appropriate for distributed teams with part-time developers working during non-overlapping hours who only have a small amount of effort available per week. Another interesting approach is the one proposed by Timo Punkka in terms of Agile hardware and Co-Design, with Scrum methods included (Punkka 2012). Some more variations exist but they will not be used as a reference.

3.2.3.2 Design Thinking

Design Thinking is a method, that is human-oriented. The needs of the potential clients and users of a new product (“desireability”) are constantly monitored through observation, empathy and early feedback. As well, characteristics such as technological feasibility and the economic viability are also taking into account (Brown & Katz, 2009, P. 19). In order to successfully be in the market, the future product should fulfill all three requirements. The principal method of the Design Thinking process is represented in Figure 11. It is an Agile method because each phase should not have a sequential order. The connections only mean feedback that can be obtained through constant interaction with the users (Plattner et al., 2009, P. 114).

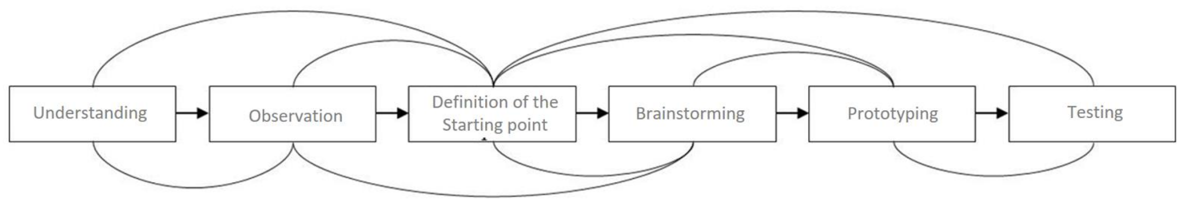

Figure 22 Design Thinking Process (Plattner et al., 2009)

The starting point is the Understanding, which means the definition of the tasks and objectives of the group. The first fundamental criteria for the success of the method and its structure will be defined (Plattner et al., 2009, P. 117). In the Observation phase the team has direct contact with the target group and tries to get the first fruitful insights. The focus there should be in detecting implicit or explicit needs, wishes or trends (Holloway, 2009, P. 51). The information obtained will be used for teh definition of the starting point and the criteria to rate the results. At this point, there should be decided if more research should be carried out or if the process should continue with the following phases (Plattner et al., 2009, P. 120).

During the brainstorming, in a short period of time a big quantity of potential solutions should arise. It is important to note that the proposals do not have to be evaluated qualitatively now. The point is to generate a quantitatively high number of potential ideas from which later the selection can be refined and get an appropriate solution (Uebernickel et al., 2015, P. 30).

Some factors for the evaluation are the ones explained previously: desirability, feasibility and viability (Brown & Katz, 2009, P. 19). The selected solutions will be converted with Prototyping in a fast, visual and communicative form for presentation (Plattner et al., 2009, P. 120). The last step is to test the prototype with as many future users and clients as possible. Thanks to this essential feedback the strengths and weaknesses of the product will arise (Plattner et al., 2009, P. 124).

The use of interdisciplinary teams is promising (Holloway, 2009, P. 51). Furthermore, the division of Design Thinking processes in divergent and convergent phases is also interesting (see figure below).

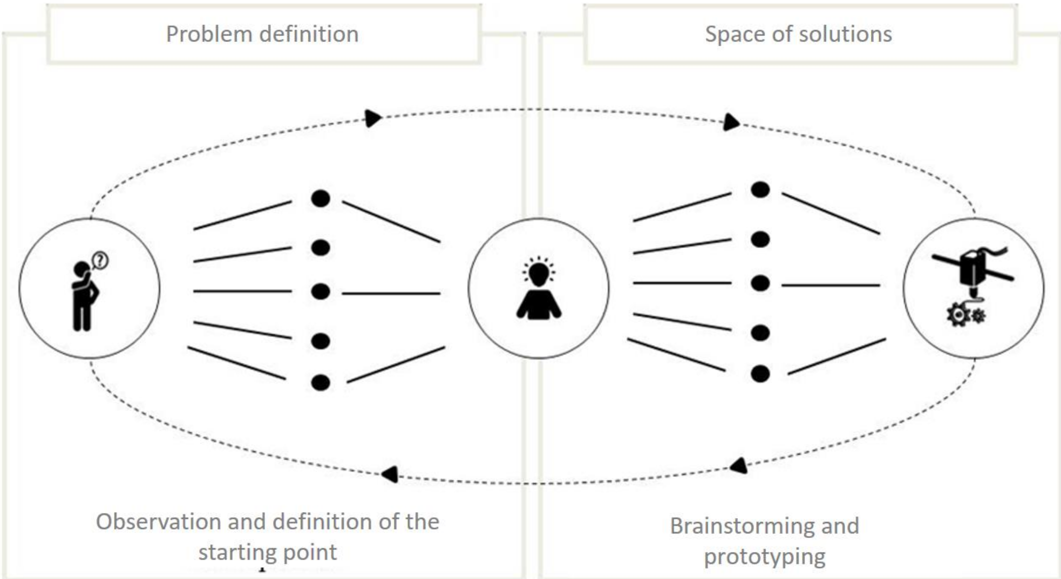

Figure 23 Divergent and convergent phases in Design Thinking (in conformity with Lindberg et al., 2011, P.5)

During the analysis of the problem definition and the target group, a divergence of ideas takes place, where many potential users will be taken into account. The important information will be aggregated and rated with the definition of the starting point, and then there will follow the convergence of possibilities. The behavior is similar to the other phases.

During the search of solutions, many ideas will be generated in order to choose one and convert it into a prototype (Lindberg et al., 2011, P. 5).

3.2.3.3 Lean Startup

The Lean Startup procedure model is linked with process of creating a company. The basic idea is that all processes from the creation of the company until the product launch should be managed as lean as possible and keeping it with a minimum of effort (Ries, 2015, P. 25 und P. 73). For that reason, there is not a fixed process with phases as in other methods. The focus is not to plan for the long-term, but to follow the principle "build-measure-learn", and to be able to adapt to the changes as quickly and effectively as possible (see figure below). It is therefore an Agile method.

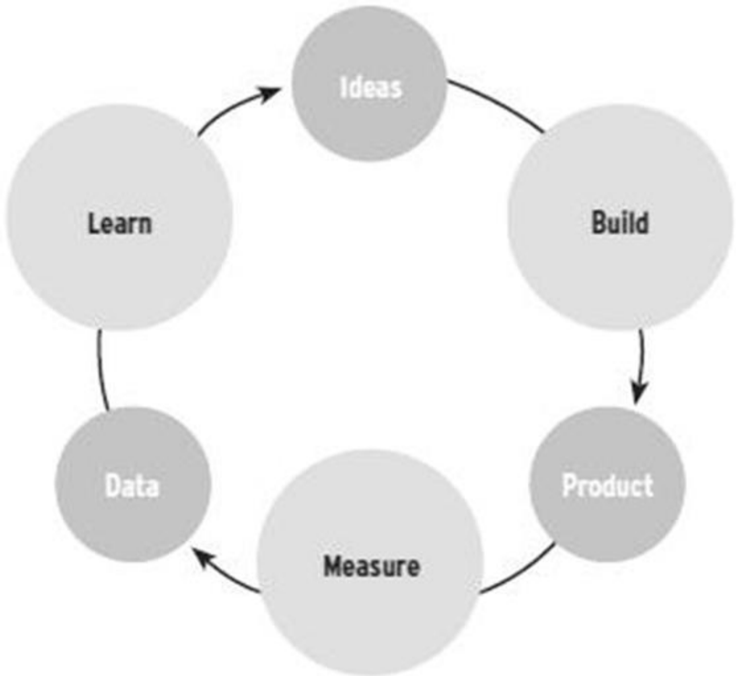

Figure 24 Method of the Lean Startup (Ries P. 73)

Before the actual cycle begins, the hypothesis will be first defined. They are benefit assumptions because they represent the value of the product or service. Growth hypothesis describe how the Startup can get and convince new clients. Hypothesis will be finally tested and adjusted. This is done with the fastest and cheapest fabrication of a first product, the minimum viable product (Ries, 2015, P. 74). To have the minimum functions doesn't mean that the product is complete. Some functions will be later left apart for efficiency purposes (Glatzel & Lieckweg, 2014, P. 23).

Then it follows the direct interaction with the clients. The MVP is seen as an experiment that can produce a feedback reaction in the users. These reactions can reveal important information and be used to get conclusions (Ries, 2015, P. 73). It is analogue to the Plan-Do-Check-Act (PDCA) cycle (Moen & Norman, 2009). In that case, the results of the phase "Act" are prepared to be used as an input for the next phase "Plan" (Goll & Hommel, 2015, P. 9). The PDCA cycle can be used for predefined processes, while in the Lean Startup the experimental part is the fundamental one.

Measuring customer feedback, it is important to determine if the efforts carried out have been fruitful. Based on this, some conclusions can be drawn, to see if the Startup is going in the right direction or some pivoting should be needed (Blank, 2013b).

3.2.4 Summary and classification of a generic innovation process

Agile procedure methods come originally from the software development industry, and specially in this field is where most of the Agile processes can be seen (Link, 2014, P. 74).

But also in some other disciplines it has application. Morris et al. (2014) replaces the word “Software” from the Agile Manifest (Beck et al.,2001) with “Innovation” and transfers by doing so the Agile approach for the development of innovations. By the same token, there have been efforts to transfer the Agile approach to other applications that represent the domains of the planning-oriented version. For example, Klein (2016) proposes an Agile engineering method for the fabrication of of machines and facilities.

Boehm & Turner (2004, P. 26-50), on the other side, proposed several criteria in order to choose Agile or planning-oriented methodologies, recommended by software developers. These are represented in table below and can be applied theoretically to other disciplines.

Table 4 Criteria for the decision of Agile or planning-oriented methods (in conformity with Boehm & Turner, 2004, P. 51f)

	Agile approach	Planning-oriented approach
Application		
Overarching goal	Fast value creation, Flexible reaction	Prevision, stability, high safety
Size	Small teams and projects	Big teams and projects
Environment	Dynamic, quickly changing, Project-driven	Stable, slow changes Project/organisation-driven
Management		
Customer relation	Engaged customer, focus in prioritized increments	Customer interaction by need, Focus in contract determination
Planning and control	Plans internalized, qualitative control	Documented plans, quantitative control
Communication	Implicit, interpersonal knowledge	Explicit, documented knowledge
Technology		
Requirements	Informal and prioritised Stories and test cases. Continuous changes and adjustments	Formal Project, Skills, Interfaces, Quality, Changes predictable
Development	Easy design, fast increments, cheap rework	Complex design, long-term increments, expensive rework
Testing	Feasible test cases define requirements	Formalized testing plans and processes
Human		
Customers	Collaborative, representative, authorised, informed, on-site	Collaborative, representative, authorised, informed, not always on-site
Culture	Determined by freedom (Success through chaos)	Determined by working branches in procedures and processes (Success through system)

It can also happen, that a project has properties of both fields. For that cases there exists an hybrid mixture of both domains (Boehm et al., 2002, P. 187). But in the practice, the development engineers usually take conventional methods, that can be established without big organizational efforts (Klein & Reinhart, 2014, P. 227). When the Agile methods are presented, they fear losing control over the established control and planning mechanisms (Kirchhof & Aghajani, 2010, P. 3). These uncontrolled activities can lead to an “Agile chaos” (Kirchhof & Aghajani, 2010, P. 4). For that purpose, Agile methods are in practice used predominantly in a mixture form or for selective cases (Komus, 2013, P. 84).

Some examples can be found in Sommer et al. (2015), where the hybrid combinations are researched in seven companies of technology-intensive fields. They discovered that the Scrum method increased efficiency at the operative level while the use of the Stage-Gate model was useful for the strategic level. Cooper (2016) reached similar results, researching about the integration of Agile and State-gate models, Böhmer et al. (2016) describe an Agility in product development through the simultaneous use of systematic models and repeated prototypes.

To conclude, it is important to remark, that because of the high complexity, the individual framework conditions and the permanent dynamics of the current development projects, there hasn’t been created yet a unique or ideal method for the development process (Lindemann, 2009, S. 37). The following aspects play a major role in this context:

-Market complexity:

e.g. increasing demand of multifunctionality and customized products

-Organization complexity:

e.g. increasing number of playing actors

-Process complexity:

e.g. increasing linkage of the different processes

-Product complexity:

e.g. increasing variety of products (Lindemann et al., 2009, S. 5)

These factors affect especially the development of physical products, because the combination of different disciplines such as mechanics, informatics or electronics play a major role (Klein & Reinhart, 2014, P. 225; Lindemann et al., 2009, P. 4). A physical product can be understood as a complex system that is composed of a wide variety of elements. These are linked with each other (diversity of relations) and have different interfaces, for example with the environment. Furthermore, such as system takes different states and has some dynamics (Lindemann, 2009, P. 10). These factors make the physical product and its development a something complex.

Finally, it must be stated that a flexible and mixed approach of different procedure models and their sub-methods would be important for the success of the product development. In chapter 4, an Agile Framework that comprises the presented models and methods will be presented. In conformity with Böhmer et al. (2016, P. 919), here a classification of the different procedure models in the generic innovation process is represented as a principle (see figure below).

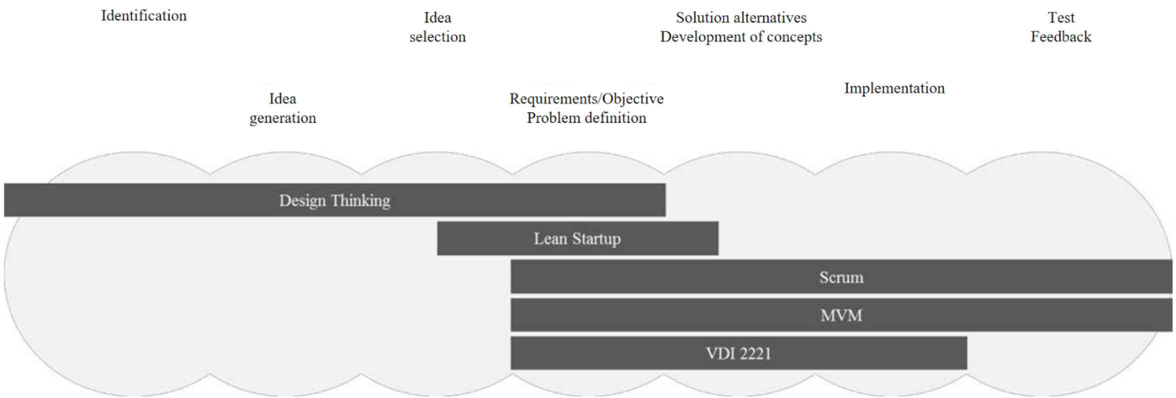

Figure 25 Classification of Agile und iterative Procedure models in a generic Innovation process (in conformity with Böhmer et al., 2016, P. 919)

The single steps of the generic innovation process have been considered as the fundamentals for the findings of the preceding chapters, so that the presented methods can be ordered. In conformity with the single development phases of the VDI 2221 and the MVM, the following levels would replace the single steps:

-Requirements, definition of the objectives to the respective problems

-Solution alternatives, development of concepts

-Implementation

-Test, feedback

The MVM would include the four commented steps, while the VDI 2221 the first three steps.

3.3 The meaning of artefacts in procedure models of the product development

An important distinction of this work will be the weighting in the creation and use of the documents and artefacts. In traditional and iterative methods, the documentation has a great importance (Hanser, 2010, P.5). For example, the VDI 2221 specifies explicitly the creation of different documentation about the results (see Figure 7).

Agile processes should be managed as lean and flexible as possible (Doemer et al., 2012, P. 116), something that is in contrast with the extensive use of documentation. In the field of software, the developer usually sees the documentation as useless and unnecessary (Selic, 2009, P. 11). The Agile Manifest explicitly explains that a functional software needs to have extensive documentation (Beck et al., 2001)

It is important to take into account, that these statements are only made in the field of software development. When developing physical products, usually the strategy is complex and should be approached following systematically an Agile orientation (Böhmer et al., 2016, P. 920).

The omission of the documentation can have negative effects on the development project (Cao et al., 2009, P. 333). Erickson et al. (2005) states that in big projects the lack of a sufficiently formal design-architecture can lead to some ignored problems and serious consequences. This means, that in big Agile projects there should be carried out a documentation for the successful coordination of the activities and teams (Bass, 2016, P. 3). Furthermore, the procedure in all Agile methods includes the building of creation of an implicit knowledge and skills by the team members (Cockburn, 2002, P. 7). If the development and the progress of the project is not sufficiently documented, at a later stage there could be difficulties in the understanding of the different team members (Cao et al., 2009, P. 333). Boehm & Turner (2004) say that in this case, the creation and illustration of an implicit knowledge base can bring big advantages in the flexibility and velocity of the Agile methods.

According to Cockburn (2007), if there is also a documentation in the software development, then it will be sufficient with the existing one. The following applies: the number of documents provided should be kept to a minimum, omitting what's not necessary and keeping only relevant information (Rüping, 2003, P. 193). The requirements and the measurement of the documentation is therefore context-dependent, and for that purpose the quality of the demand of information should be always determined case-by-case (Hoda et al., 2010, P.1).

Finally, it is important to note that in the development of physical products a certain degree of documentation is essential. This means that many artefacts should be created during the innovation processes. As this field has not been researched as of now, in the following chapters there will be a focus on the artefacts.

4 Application of Agile Methods to Product Development

After reviewing the state-of-the-art of agile product development methods, in this chapter an explanation will be carried out, describing the tools used for the application of the methods in the real project: the development of an hyperloop prototype.

By means of a research on the literature, the framework will be introduced theoretically and filled, but before, a connection in comparison with the data from TMS will carried out. The focus is in the Artefacts and their role as well as their influence in the development processes of physical products.

4.1 Summary and organization of approaches

In this chapter the most important approaches will be introduced. For that purpose, first a research on the literature of the different approaches was carried out.

4.1.1 Existing approaches

A first approach for the introduction is exposed by the work “Agile project management for systems in the field of regulations” (APS) of the Association for Systems Engineering e.V (GfSE). This work introduces the investigation of agile project management applied to systems in the regulatory field. In it, the model of the figure below 16 was developed.

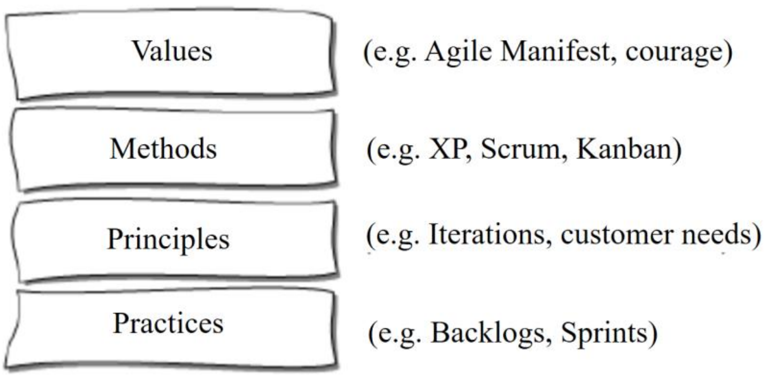

Figure 26 Layer model on the aspects of Agile (Buchholtz et al., 2012, P. 163)

The model is composed of four layers. To structure the values of the Agile Manifest (Beck et al., 2001), several procedure models were created, such as Scrum. These were detailed with several principles, such as the customer needs. The layer below are practices that are of application for the higher levels. It is important to note that this model doesn't collect a detailed description of the parts comprising each layer. Thus, a complete comprehension of Agility in project management needs something more than the layer model (Buchholtz et al., 2012, P. 163), it needs more detail.

As explained, the systematization of the Artefacts is interesting for this work.

4.1.2 Classification of approaches

An initial approach is the classification of Artefacts depending on the project phases. Kuhrmann et al. (2013, P. 8) distinguishes the following Artefacts of the agile project management in software development: requirements, programme code, tests, deliverables, planning and control. These can be divided into planning, requirements and specifications, change management and testing (Femmer et al., 2014, P. 3). With this in mind, Bass (2016, P. 26) developed a detailed categorisation for Artefacts:

- Planning (e.g. Sprint plan)
- Requirements (e.g. Product backlog)
- Development (e.g. Software code)
- Testing (e.g. Testing reports)
- Change Management
- "Governance" Artefacts

The last category entails Artefacts that cannot be included in any other category. These are for example risk evaluations or product standards.

Also, a classification of the different types of Artefacts can be made. In the figure below a classification of three categories of Requirements-Artefacts can be seen according to Liskin (2015).

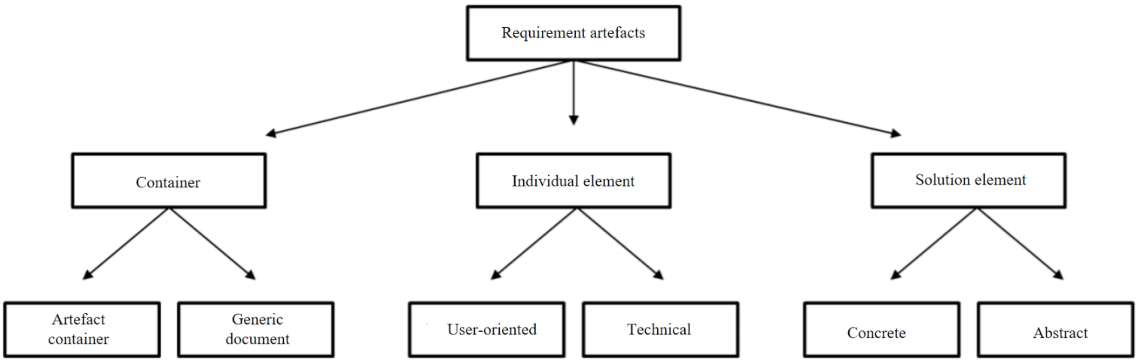

Figure 27 Types of requirement-Artefacts (in accordance with Liskin, 2015, P. 136)

A container can be defined as a type of gathering point. They are documents that give cohesion to the project. This can be the so-called Artefact-container that is composed of individual or solution elements. An example would be the product backlog. A container can also be a generic document that is continuously updated (e.g. a text document for the description of the product) (Liskin, 2015, P. 136). Individual elements are either user-oriented (e.g. use cases) or technical (for example the requirements of the system). The last type of artefact is the solution-element. These are either concrete (e.g. a GUI mockup) or abstract (e.g. a calculation programme) (Liskin, 2015, P. 137).

Another classification of Requirement-Artefacts is carried out through the analysis of several strategies to the implementation of Requirements engineering. In this case, the Artefacts can be divided into three categories:

- Solution - oriented: focus in the customer
- Function - oriented: focus in the application cases and interfaces
- Problem - oriented: focus in the commercial and economic needs (Méndez Fernández et al., 2012, P. 19f)

A detailed classification can be obtained through the use of the methods and resources. Alves & Jardim Nunes (2013) carried out an analysis in terms of the use in service design. In conformity with the “Six types of vision” (Roam, 2008, P. 73ff), the Artefacts were divided into six groups. The “Six types of vision” are:

- Who and what
- How much
- Where
- When
- How
- Why (Roam, 2008, P. 78ff)

Each group was divided into four clusters by two crossing axes. For example the division of “Why” can be seen in the figure below.

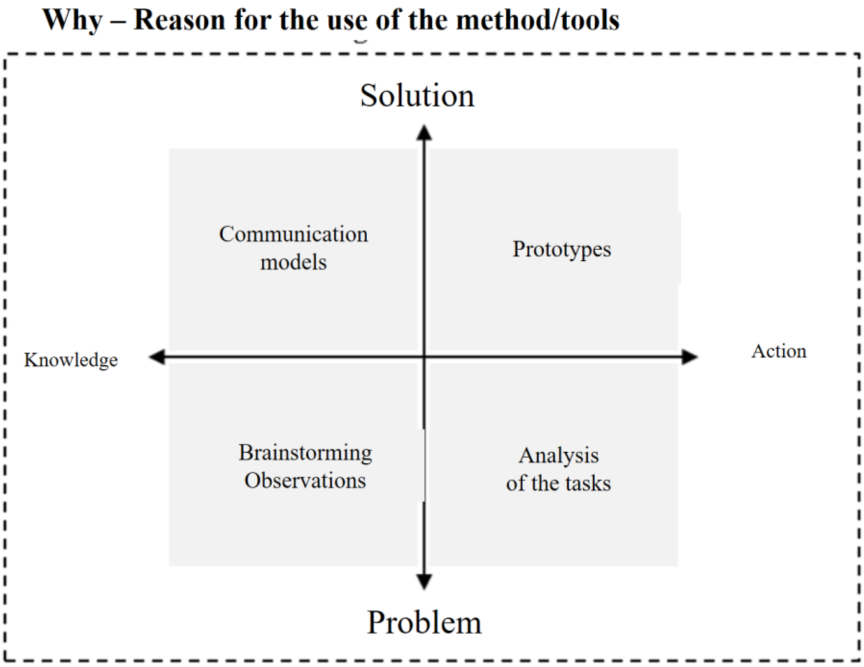

Figure 28 Dimensions for the categorization of the methods and tools depending on the reason of use (in conformity with Alves & Jardim Nunes, 2013, P. 222)

Methods, tools and Artefacts can be classified with the question: “Why are they used for?” Through the division in action and knowledge, as well as solution and problem, four clusters can be obtained with their own characteristics (Alves & Jardim Nunes, 2013, P. 222). In the table below an overview of the six categories that can be used for the classification of methods, tools and Artefacts. For a better understanding, an example of a cluster (indicated with a point). The “How much” has been neglected for its irrelevance in the thematic.

Table 5 Six categories for the classification of methods, tools and Artefacts in Service Design (Alves & Jardim Nunes, 2013, P. 222-225)

Question	Description	Cluster	Example method/artefact
Why	Reason or motivation for the use	Solution / Knowledge / Action / Problem	Observation
Who	The adressees: who will be appealed by the use	Specialist / Designer / Other stakeholder / User	Service (Blueprint)
What	Content coverage: in which field is the application relevant	User / Offer / Context / System	Stakeholder-Mapping
How	The way of representation: how is it going to be implemented	Participative / Informal / Formal / Non-participative	Interview
When	Time point: the mentioned activity in the design process	Reflexion / Knowledge / Action / Operation	Prototyping
Where	Place of the application or use	Public / Inside building / Outdoors / Private	Analysis of the scenario

A last consideration is made regarding prototypes, because these important Artefacts are represented in the innovation process. In the past there wasn't a focus in the development of innovation in the process itself, it is called Context-orientation (Vetter, 2011, P.6). Meanwhile, the emphasis is made in the innovation itself, whose physical form is expressed during the processes as a prototype (Vetter, 2011, P. 12). Then, there is a transformation to the Object-orientation (Vetter, 2011, P. 95). For that purpose the prototypes are classified separately in the Agile Framework. These can be:

- Concept prototypes
- Geometric prototypes
- Functional prototypes
- Technical prototypes (Kampker et al., 2016, P. 76)

These can order the generic innovation process of Chapter 3.2.4. It can be seen in the figure below, where the classification of the different phases of the process is explained.

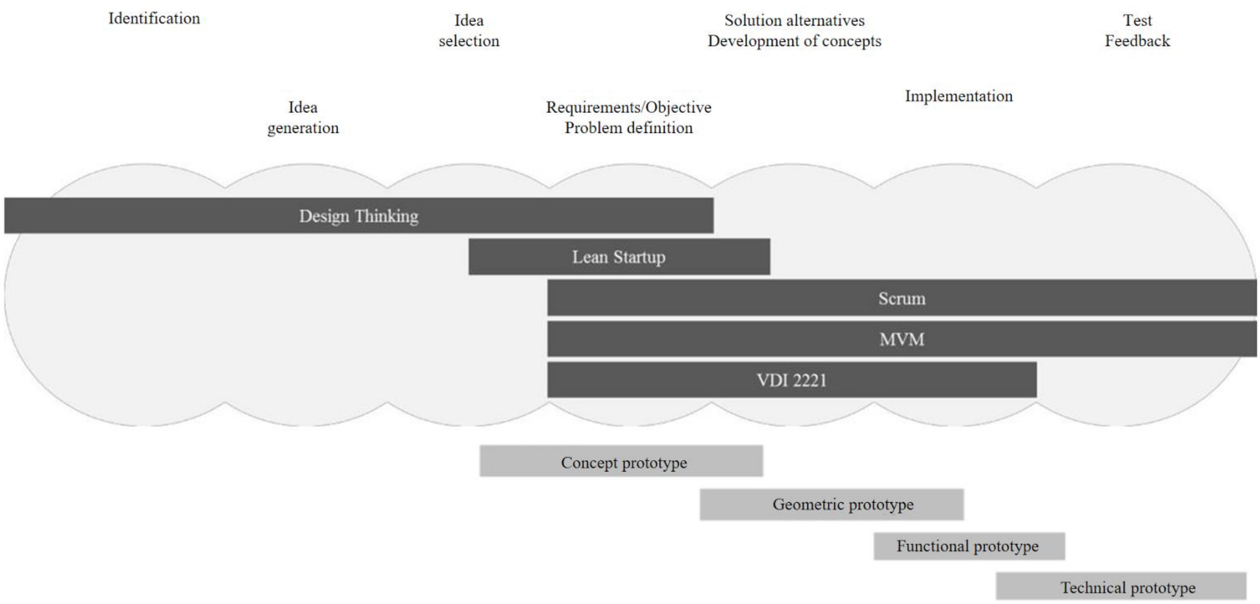

Figure 29 Classification of agile and iterative procedure models in a generic Innovation process, Prototypes included (in conformity with Böhmer et al., 2016, P. 919 & Kampker et al., 2016, P. 76)

After this organization, now the challenge will be selecting the most appropriate methods that can be applied to the real project in order to evaluate their performance during the course of the project and to be able to draw fruitful conclusions.

4.2 Selection of the approaches to be analysed in-depth and applied in the project

As can be seen observed in the figure above mentioned (Figure 28), there is a clear separation between methods used for the initial phases of the project (identification, idea generation) and methods used for project implementation.

4.2.1 Selection criteria

In order to select the methods for their application in the project, the selection criteria were based in the feedback from previous projects, taking into account also the characteristics of the current project:

-Timeframe: 1 year.

-Number of team members: +30 people.

-Budget: uncertain and dependent on partnerships achieved.

-Project technical complexity: high.

-Experience of team members in Agile methods: low.

The main characteristics that were considered in order to choose methods were:

1. Ease of implementation
2. Range of application within the process
3. Number of available resources online
4. Applicability for a non-commercial project

4.2.2 Decision of the selected methods

Taking account these four parameters, the final decision was to take the Design Thinking and the Scrum methods as the basis for the technological product development and have the Lean Startup used as a framework for the use in the fundraising phase, because it has a focus on iterating for the customer, that in this case could be the company supporting the team with funds.

4.2.3 In-depth explanation of the selected approaches

In the current chapter, there will be an emphasis in exploring the selected approaches more in depth in order to begin planning of the implementation.

4.2.3.1 Design Thinking

Design Thinking is a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity (Brown 2008, 3). It can also be described as a human-centered, prototype-driven process for innovation that can be applied to product, service, and business design (Cohen 2014).

The Design Thinking approach tries to integrate design, engineering, science, and business skills all together, aiming at the collaboration of teams and iterative improvement to achieve disruptive innovation and create groundbreaking products. It is based in learning through creating rapid conceptual prototypes (Plattner et al. 2009), (Vetterli et al. 2013). This is how the approach for product development looks like:

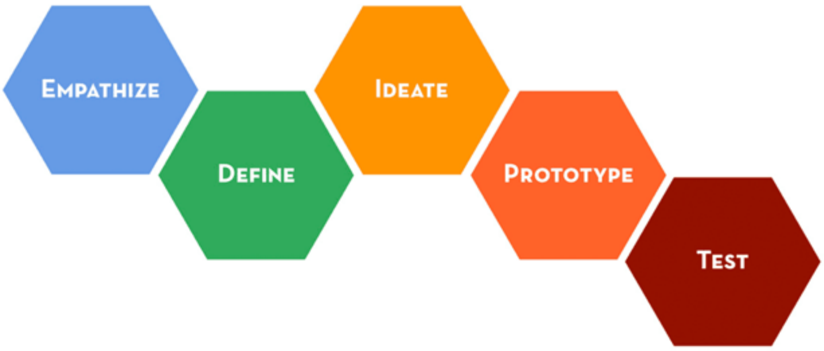

Figure 30 The Design Thinking 5 Step Approach (Plattner, Meinel and Leifer 2010)

As can be seen, the approach consists in five basic steps: Empathize, define, ideate, prototype and test, which mean the following (Plattner, Meinel and Leifer 2010):

- Empathize:

This step has to do with the understanding of users, trying to find out their needs and to establish the benchmarks, discovering what will make them buy the products. Using this human-centered approach, the process will take into account the preferences of the users to avoid creating something that people will reject. Empathizing involves processes such as interviewing people, researching or using empathy maps.

- Define:

Define means deciding, from the understanding of the needs and insights of the user, which problems are going to be solved and what features can make the product successful. Defining is always related to design and it is something that never ends.

· Ideate:

Ideation means generating ideas from the scratch. For this purpose, there are several methods such as: brainstorming (Osbom 1953), the 6-3-5 method (Rohrbach 1969) or bodystorming (Lane 2003). What is pretended with this step is to obtain a big pool of ideas that will later be useful and to avoid judging ideas beforehand.

· Prototype:

Prototyping consists in combining these ideas, getting them out of the mind and bringing them to the physical world. A prototype can be everything that takes a physical form (Stanford 2012a), such as: post-it notes, objects, spaces, interfaces or a storyboard. The prototype is useful to show your vision, deepen your understanding of the user and to keep on learning. However, prototypes should command only as much time, effort, and investment as is necessary to generate useful feedback and drive an idea forward (Brown 2014, 91).

· Test:

The next step is testing your prototypes and ideas with the user, which means experimenting to obtain valuable feedback and data that will later be used to improve the designs. For example, on websites and software, the A/B Testing could be used to test two different prototypes and see the changes in behavior of the users (Dixon et al. 2013).

Sometimes these steps are showed in books and media as a loop or a cycle. However, as some researchers state, the process is in reality more chaotic and the activity of choosing the next stages is more complicated, although it can be learnt (Plattner, Meinel and Leifer 2010). Therefore, the Design Thinking approach could be more accurately represented as:

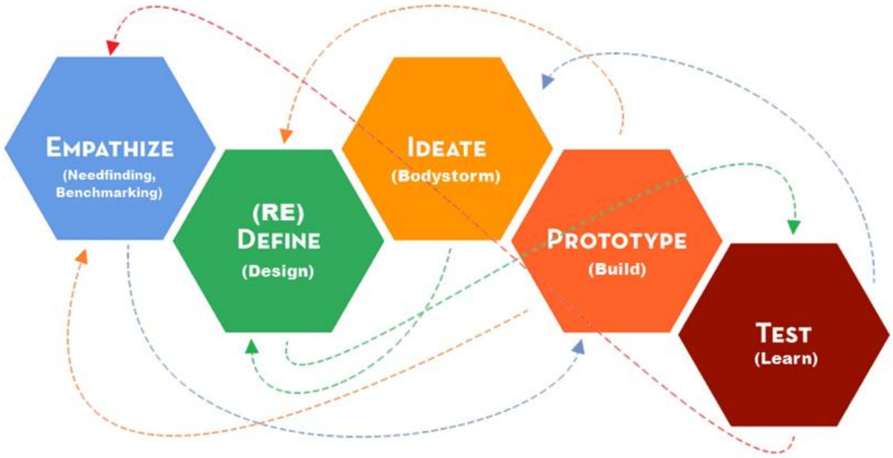

Figure 31 The Design Thinking 5 Step iterative interpretation (Vicén 2015)

In the image above, the arrows represent iterations and changes in activity that can occur during the product development process. As Tim Brown ensures, Design Thinking can seem chaotic at the first time, but it's because its architecture differs from the linear, milestone-based processes. Design Thinking is conceived as a process of iterative cycles of prototyping, testing and refinement (Brown 2008). At the Hasso Plattner Institute at Stanford, they recommend iterating both by cycling through the Empathize-Define-Ideate-Prototype-Test loop as well as within each of the steps. They recreate the model simplified as a linear progression, but advise that it can be used in various orders. The aim is to adapt the process to each team's own characteristics and style of work (Stanford 2012b).

The Design Thinking also conceives a system with three overlapping spaces that are far from being a sequence of orderly steps: *Inspiration, Ideation* and *Implementation*:

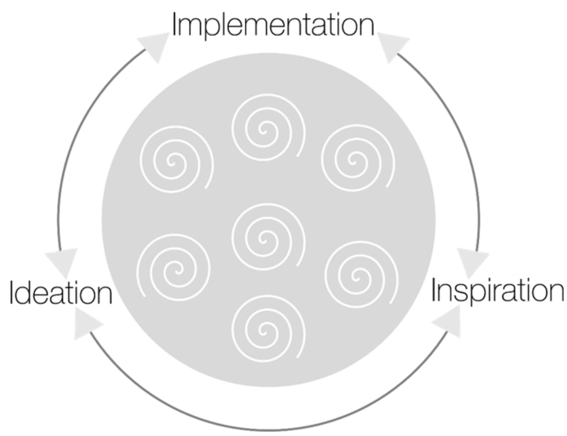

Figure 32 The three spaces of Design Thinking (Brown 2008)

They are defined as follows:

-*Inspiration:* circumstances that motivate the search for solutions.

-*Ideation:* generating, developing and testing ideas that may lead to solutions.

-*Implementation*: the design of a path to market.

Throughout the literature, the only information found is that these steps will be repeated in loops as the project advances, specially inspiration and ideation, as ideas are developed and refined.

The Design Thinking approach also includes some rules that should be taken into account, which are summarized down below:

· The Human Rule:

All innovations should have a human-centric point of view, meaning that the aim of developing new products should be to satisfy human needs, because all design activity is ultimately social in nature (Plattner, Meinel and Leifer 2010).

- The Ambiguity Rule:

To apply design thinking, ambiguity should be preserved because innovation needs experimentation and discovering things that cannot be controlled. The design thinker should be therefore able to see things differently with an open mindset.

- The Re-Design Rule:

Design thinkers should try to understand how inventions have been done in the past to be able to create foresight methods to estimate future social and technical conditions.

-The Tangibility Rule:

There's the need to transform ideas into physical world prototypes and products because they facilitate communication and help entrepreneurs to share their vision with users, customers and other people. This is one of the foundation stones of all the design thinking philosophy.

Furthermore, some researchers have found out that this new product development method shows an iterative structure based on divergent and convergent thinking (Meinel et al. 2011). In essence, the divergent thinking process (exploring many different solutions) takes places when Observing and Ideating, while the convergent thinking process (deciding a correct answer from different possibilities) is used for Synthesizing and Prototyping.

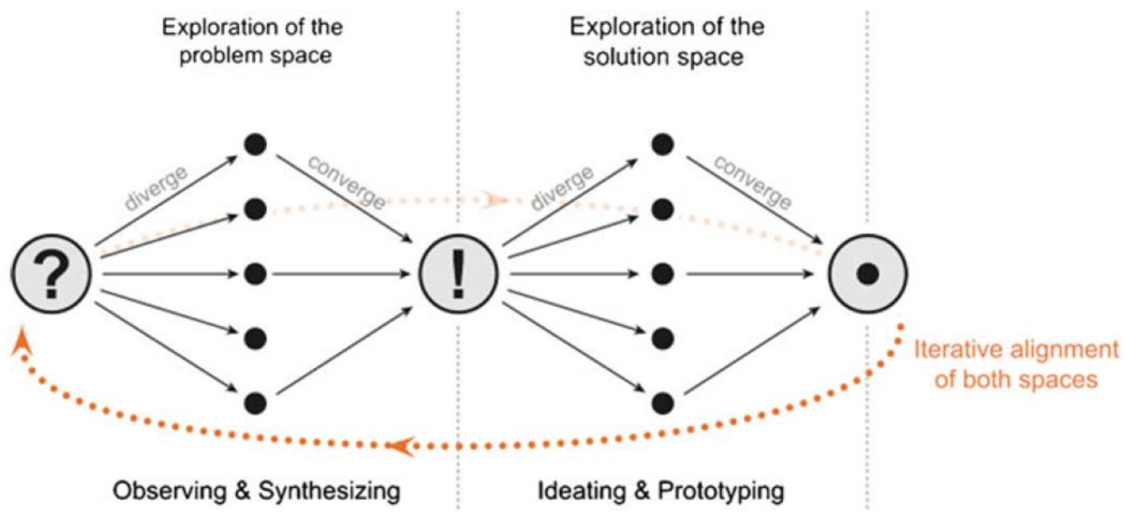

Figure 33 Problem and solution space in Design Thinking (Meinel, Leifer and Plattner 2011)

4.2.3.2 Lean Startup

The Lean Startup method is the application of Lean Thinking to the process of innovation (Ries 2011, 15) and entrepreneurship.

The Lean Startup method is all about learning how to manage an organization in a context of extreme uncertainty to create disruptive products and services.

Eric Ries treats projects as experiments and the main objective of his approach is to achieve *validated learning* to be able to create a sustainable business. He describes this concept in (Ries 2011, 46) as:

"Validated learning is the process of demonstrating empirically that a team has discovered valuable truths about a startup's present and future business prospects. It is more concrete, more accurate, and faster than market forecasting or classical business planning. It is the principal antidote to the lethal problem of achieving failure: successfully executing a plan that leads nowhere."

How to achieve validated learning?

Eric proposed that, by running experiments iteratively, developers could be able to constantly test hypothesis and verify if they were doing progress fitting the customer needs or if they were pulling in the opposite direction instead and needed to pivot. This is one of the most important elements of the Lean Startup method and it was called the *Build-Measure-Learn loop as* seen in Figure 24.

The feedback loop consists of three basic steps that every product development process should follow: *Build-Measure-Learn*.

· *Building* means transforming ideas into products or features that can be showed to customers to get the maximum learning at a certain point of development. Building doesn't necessarily mean creating something physical: smartphone APPs can also be built, or software programs, or even business model strategies. Building also refers to building parts of a product: in big projects, entrepreneurs can apply this philosophy in several parts of the development process.

· *Measuring* refers to the need of evaluating customer reactions caused by the product, which will for sure provide the organization with very valuable data that will allow to make important decisions in the future. For this purpose, the correct metrics should be considered, avoiding the so-called *vanity metrics,* numbers used to judge startups that don't give information about the efficacy of the team and that give the best good-looking picture possible.

Examples of these are registered users, downloads or raw pageviews. The change in mindset would be using *actionable metrics* like retention or repeat usage, that allow entrepreneurs to avoid having a false sense of success. These metrics are the ones used in innovation accounting and should be actionable, accessible, and auditable (Ries 2011, 141). Measuring technical feedback and business profit are two different

· *Learning* is the ability to decide, based on the metrics and the previous information, whether to pivot or persevere in the next iteration in order to obtain a successful new product. It is basically based on evaluating if the hypothesis that the team formulated about the customers are true or not. While persevering means to keep on working the same way, a pivot requires, on the one side, considering all learnt before, and on the other, changing the fundamentals of the strategy to achieve a greater learning.

These three steps, repeated iteratively, are the basis of the new product development strategy ideated by Eric Ries. If the time required for each iteration is minimized, the product development process can be accelerated (Ries 2011).

As Steve Blank explains, this loop was later extended with three more steps in-between the main ones to avoid understanding the loop as simply building products and throwing them out of the building (Blank 2015): *Ideas*-Build-*Product*-Measure-*Data*-Learn.

Build is used to test Ideas, and *Product* involves having the prototypes ready to measure. Lastly, *Da*ta is understood as the use of information to refine the learning.

Where to start?

The aim of the loop is to maximize learning through incremental and iterative engineering (Ries 2010), and Eric Ries' proposal starts with new ideas, both in already established companies or in startups. Nevertheless, some complain that the process really starts with *hypothesis*, educated guesses that require experimentation and data to validate. This is due to the thought that ideas are merely insights that immediately require plans to bring them to fruition (Blank 2015). This is not desired because it links to the traditional waterfall model, in which the product development occurs step-by-step without using the potential of customer-feedback.

How to start?

By creating a *Minimum Viable Product (MVP)*, which is the version of a new product which allows a team to collect the maximum amount of validated learning about customers with the least effort (Ries 2014). This term was first coined by Frank Robinson and later on popularized by Eric Ries and Steve Blank in the fields of software and app development. As explained by Steve Blank in his post "Perfection by Substraction: The Minimum Feature Set"

(Blank 2010), the MVP is not the end goal of the product development process, but just the easiest way to sell a vision to the *earlyvangelists*, people in between early adopters and evangelists that will be willing to take a risk on the product or service offered, although it's not yet finished.

4.2.3.3 The Scrum method:

The Scrum development method consists in iterations of about 30 days called *Sprints* in which the following occurs:

First of all, the team roles are defined as described in (Schwaber 2004):

- The Scrum Master:

  Is responsible for the Scrum process, teaching Scrum to every member of the team, implementing Scrum to fit in the organization's culture and still delivers the expected benefits, and for ensuring that everyone follows the rules of the Scrum methodology.

- Product Owner:

  Is responsible for representing all interests of the stakeholders in the project and the final system. He/She obtains the funding for the project by creating the project's initial overall requirements, return on investment objectives, and release plans (product backlog).

- Team Members:

  Are responsible for turning the Product Backlog into progress of functionality within an iteration. To do so, the cross-functional teams are self-managing and self-organizing.

Every 30-day Sprint is structured as follows (Schwaber 2004):

1. Sprint Planning Meeting (8 hours):

· First 4 hours: the Product Owner presents the highest priority Product Backlog to the Team. The Team questions him or her about the content, purpose, meaning, and intentions of the Product Backlog. When the Team knows enough, but before the first four hours elapses, the Team selects as much Product Backlog as it believes it can turn into a completed increment of potentially shippable product functionality by the end of the Sprint. The Team commits to the Product Owner that it will do its best.

· Second 4 hours: Team plans out the Sprint. Because the Team is responsible for managing its own work, it needs a tentative plan to start the Sprint. The tasks that compose this plan are placed in a Sprint Backlog; the tasks in the Sprint Backlog emerge as the Sprint evolves. At the start of the second four- hour period of the Sprint planning meeting, the Sprint has started, and the clock is ticking toward the 30-day Sprint time-box.

2. Daily Scrum (15min):

The purpose is communication and synchronization. Every day, the team has a 15-minute meeting where each one answers this three questions: what have you done since the last Daily Scrum? What are your plans until the next Daily Scrum? What impediments are you finding on your way?

3. Review Meeting (4 hours):

The team presents its results at the end of the Sprint to the Product Owner and interested stakeholders. The purpose is to decide the next steps of the team.

4. Retrospective Meeting (3 hours):

After the Sprint and before the next Planning Meeting, the Scrum Master encourages the team to follow the Scrum guidelines and improve aspects for the next Sprint.

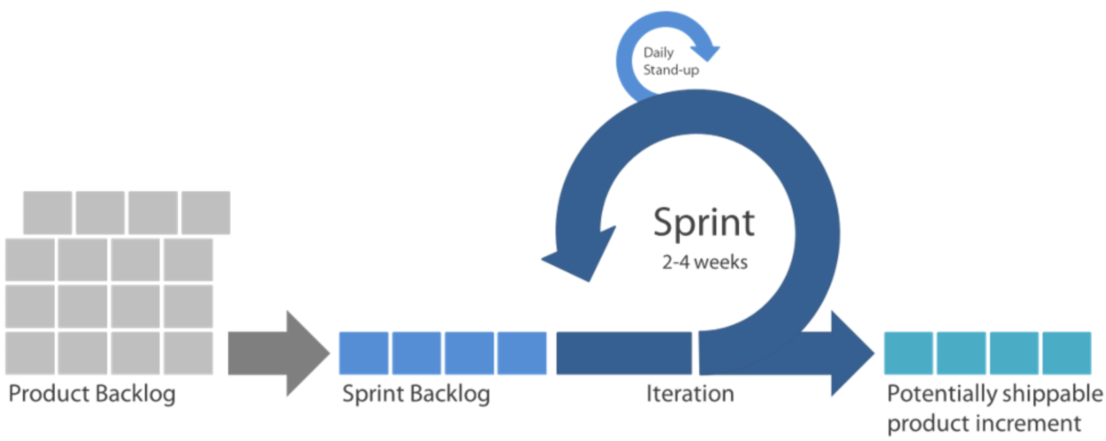

Figure 34 The Scrum method

4.2.4 Summary

As can be extracted from the previous chapters, in the first three phases of the generic innovation process (Identification, Idea generation and Idea selection) is the orientation to desirability the most important. The main methods from Design Thinking, centered in the human and his needs, are here applied. It is interesting the change between divergent and convergent phases. During the Identification phase, the divergence is used and through the use of Artefacts the general impressions are finally together. Then follows the generation of ideas (wide-range), and through the selection of the best ideas the convergence takes place.

For defining the requirements, the objectives or the problems, methods from all procedure models are used. At this point only, viability and feasibility aspects of the innovation are taken into account.

The determination of solution ideas and functionalities, the development of the general concept as well as the implementation follow the technical layer.

Prototypes are the elementary artefacts. Through their regular creation and use they can be used to obtain regular feedback. As well, the creation and conservation of the containers is an important process in order to maintain a good overview of the whole project. In specific situations some special methods and Artefacts such as the decision-making methods are a good possibility to control the development process.

As stated, the Design Thinking method is especially useful for the start of the innovation process. In combination with the Lean Startup, the prototyping is greatly emphasized. This artefact has an important meaning as an experimental object of the Agile development. The "pivot" of the Lean Startup is a special method that provides a solution for the gridlocks in the development processes.

The Scrum, originally from the software development field, is very complex and provides methods and Artefacts with an exceptional and unique description and designation. For example, the Product Backlog or the Estimation meeting are some of them. These methods and Artefacts can as well be integrated in the project. An important and valuable property from Scrum is, that the focus is in the progress of the project (Hanser, 2010, P. 61). It is therefore a method that is generally useful for Project Management. Thus, the special processes and activities of Scrum can be very valuable for the Agile development.

4.2.5 Implementation planning

With this information, an initial planning for the implementation of the approaches in the real project can be carried out. At this point, the phases of the project have been correlated with the phases of the innovation process, the theoretical methods used, the expected resulting prototypes and the phases of the development of this thesis. In green the selected approaches can be identified.

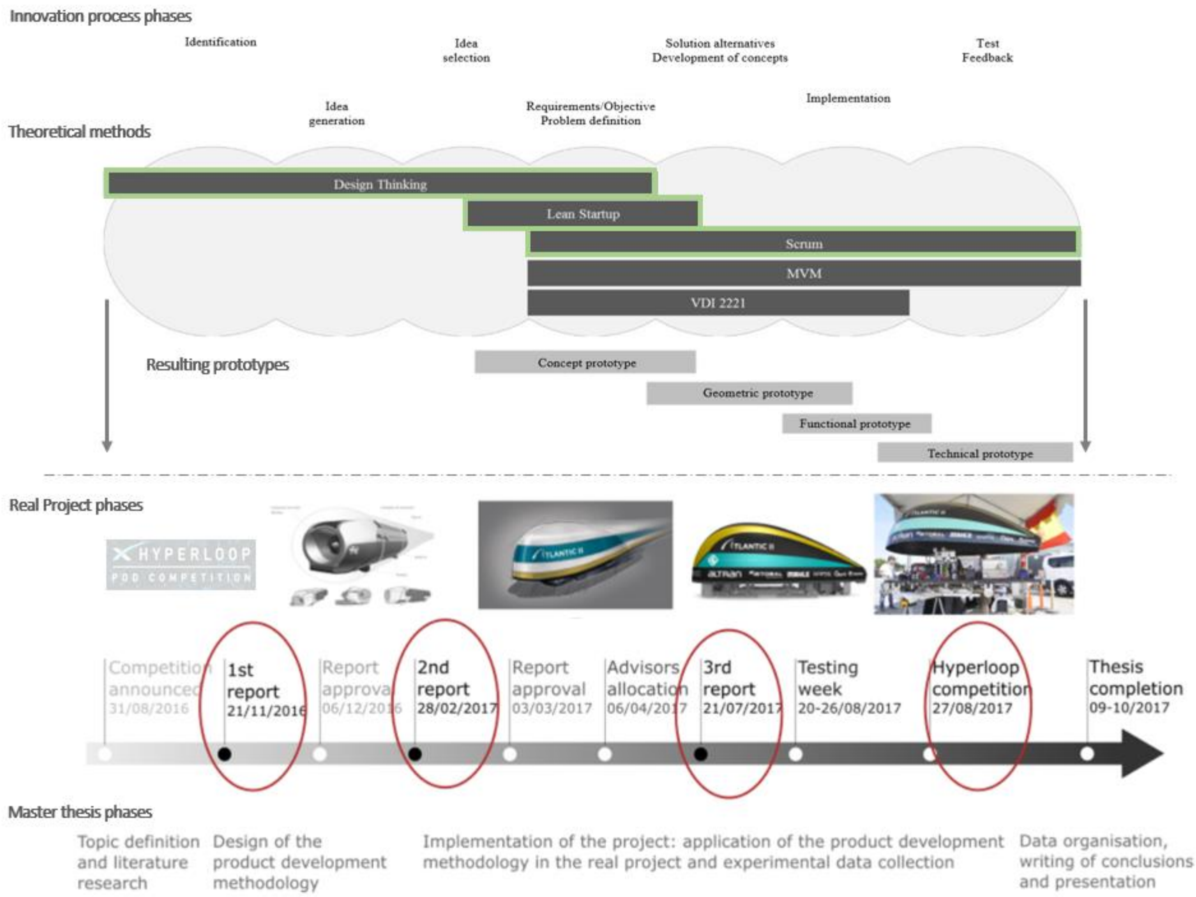

Figure 35 Relation between project and methods (Vicén 2017)

As can be seen in the figure above, the main method used in the first phases of the project was the Design Thinking method. In order to proceed with the implementation of the method, it is important to present the phase previous to the Identification phase, that will be called Pre-Identification phase: it is basically the process from the announcement of the competition in August 2016 until the creation of the team. The process can be explained in the figure below:

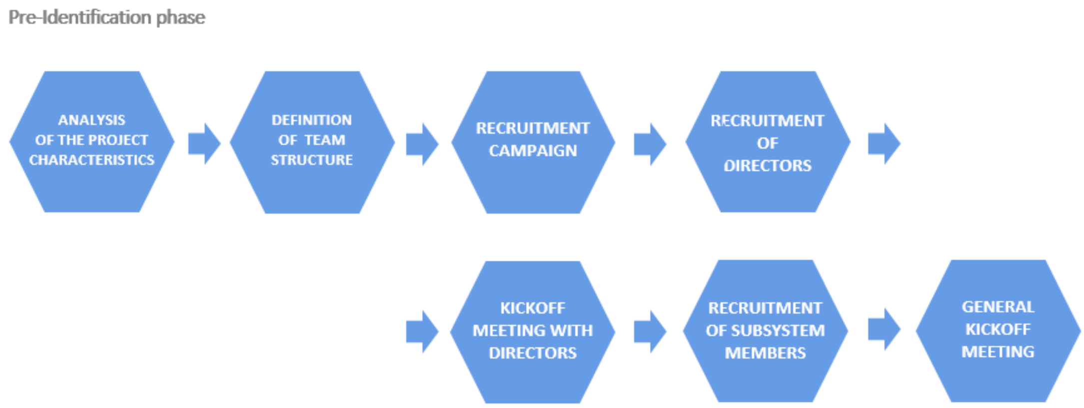

Figure 36 Pre-identification phase (Vicén 2017)

The pre-identification phase consisted in the analysis of the project characteristics by the three team leaders, from which a structure for the new team was defined:

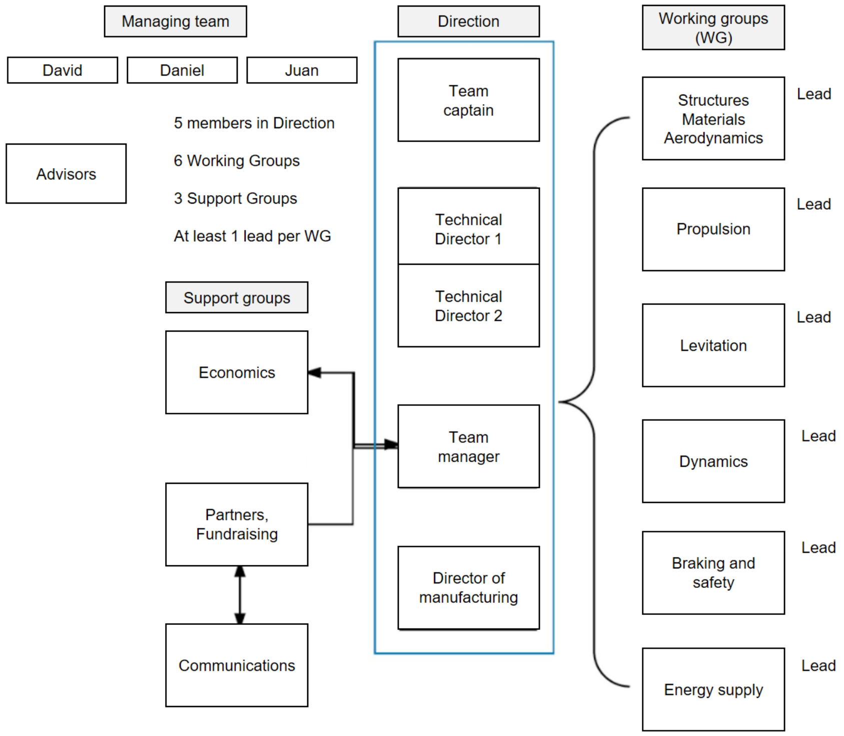

Figure 37 Initial structure of the Hyperloop UPV team (Vicen 2017)

After this process, a recruitment campaign was launched at the University to have a wide variety of profiles and from that point, after the revision of the profiles and several tests and interviews, a team of technical directors was chosen. As the directors are of high value for the project, and their goals and values need to be aligned with the team leaders and to be transmitted to the rest of the team, a special meeting was held in order to establish the general guidelines of the project and the philosophy to lead the sub-teams.

In this meeting, the three team leaders explained the basics of the Design Thinking, Lean Startup and Scrum methodologies with a special focus in applying them to the real project. It must be stated that the iterative processes, as can be seen in the figure below were applied in both the design and the assembly phases, but not in the testing phases because the testing processes were rather linear and with low uncertainty. It is also important to note that the method of Scrum was applied with small working groups (maximum 4-5 people) in order to ensure a good control of the procedures. The only bigger Scrum team was the last one, because the assembly process was carried out in different places and with different people. The last days, for example, about 10-15 were working on the prototype at the same time.

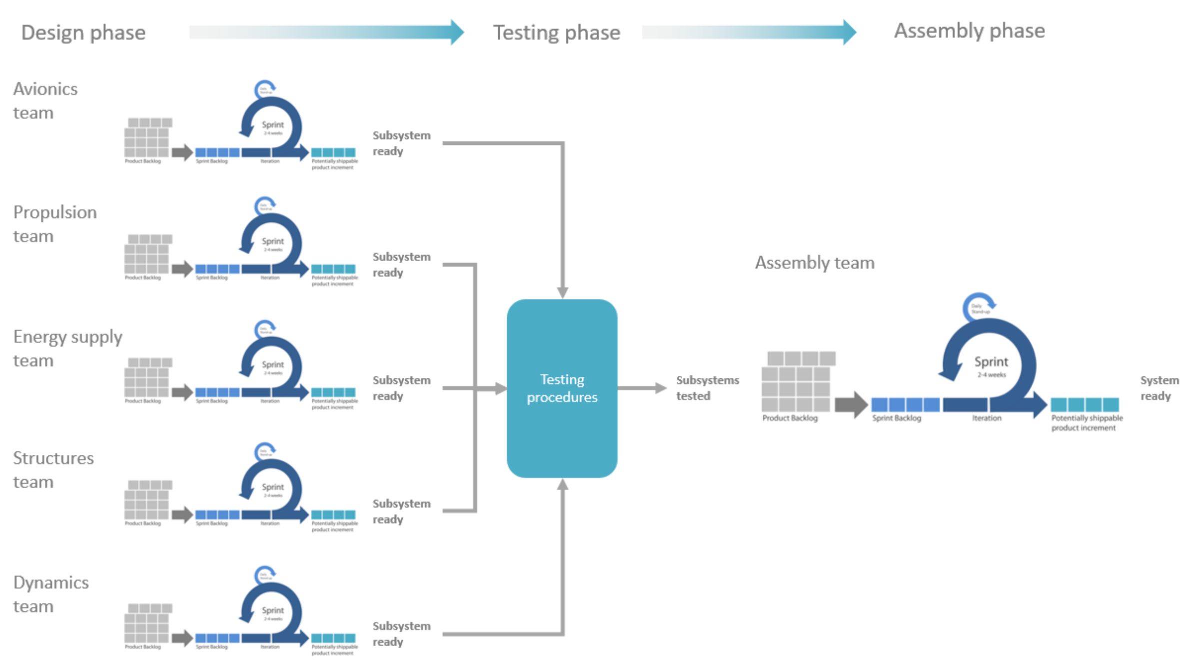

Figure 38 Application of the Scrum method to the project (Vicén 2017)

The following structure of meetings was proposed to the direction team in order to ensure constant and iterative weekly processes:

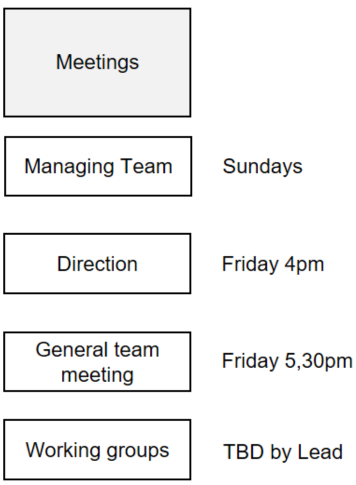

Figure 39 Meeting structure of the Hyperloop UPV team (Vicén 2017)

The use of Design Thinking was also important to decide this structure, as can be seen below:

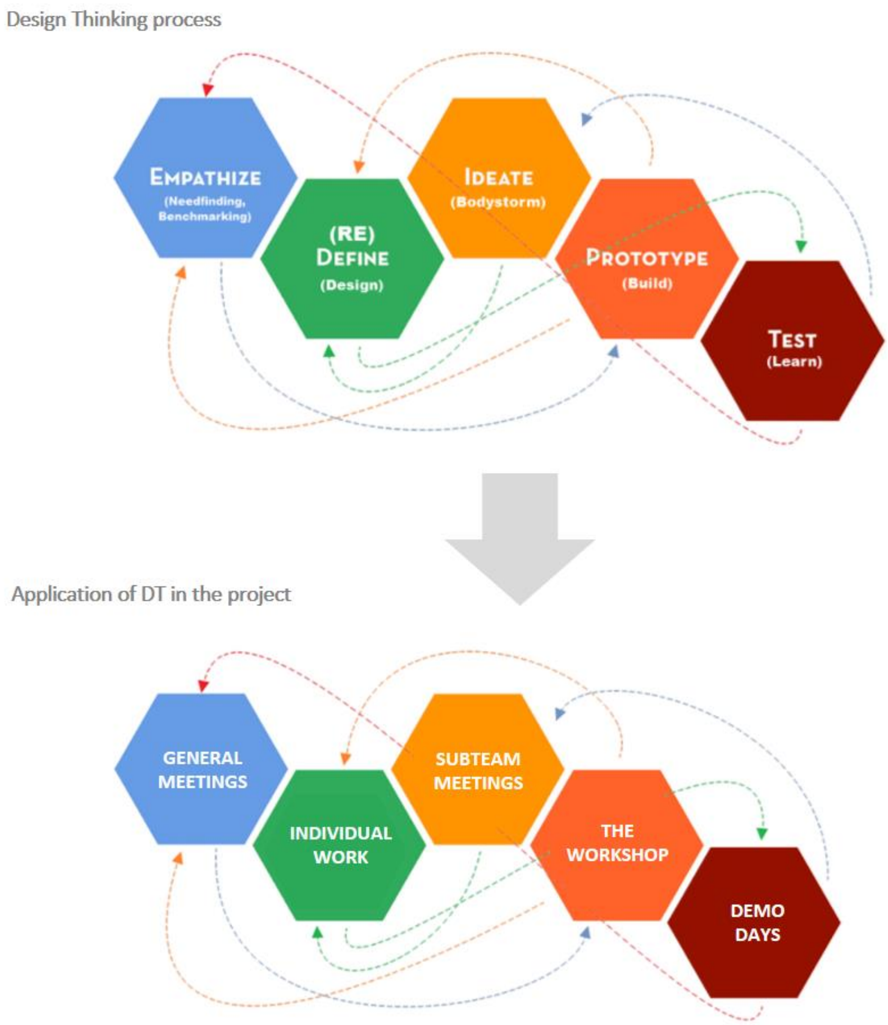

Figure 40 Implementation of Design Thinking in the project (Vicén 2017)

Setting the iteration time was a major decision. As students do not have a full-time for the project, it was difficult to set daily routines. That's why the decision was to do the cycles per weeks, the "Daily Scrum" became then the "Weekly Scrum". Also, the Sprints needed to be rescheduled, because the team had to deal with an important uncertainty factor: the deadlines to present the technical documents.

The team didn't know when to hand in the next technical report until the SpaceX judges approved the previous one. That's why Sprints needed to be extended to 2-5 months instead the normal 2-4 weeks. In the figure below the main deadlines can be seen:

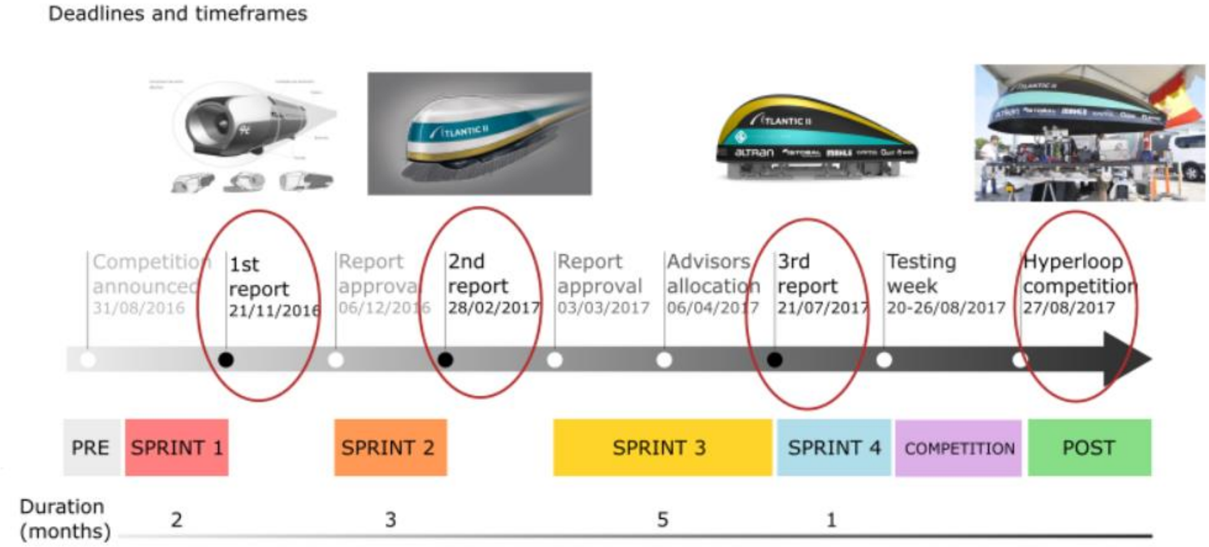

Figure 41 Deadlines in relation with Scrum sprints (Vicén 2017)

In the picture, it can be seen that there is a space in between sprints, this is due to the fact that SpaceX needed to take some time from the reception of the technical documents to the verification and the acceptance to pass to the next selection phase. After the second document, the team was finally accepted to build the prototype and enter the competition and from that point the processes started to become more fluid without dead times.

In the figure below, as stated earlier, the adaptation of the Scrum iterative process to the real project due to the aforementioned conditions can be seen:

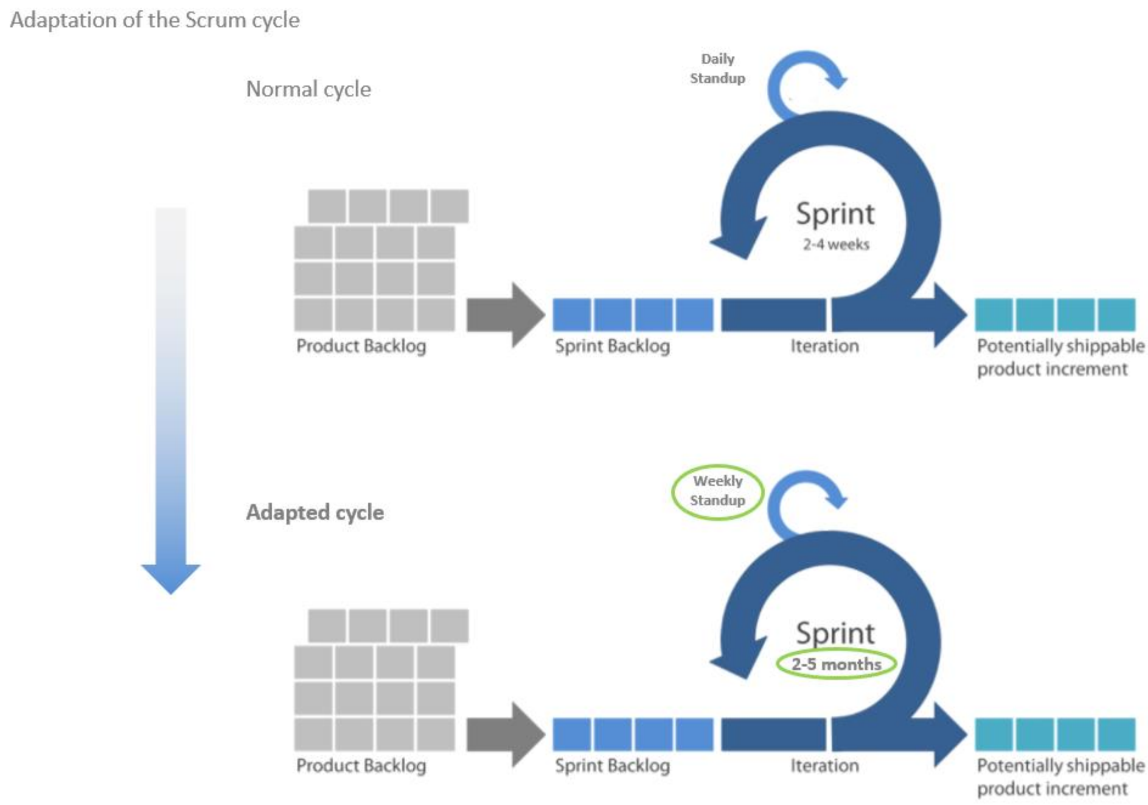

Figure 42 Adaptation of the Scrum method by sprints to the real project (Vicén 2017)

In order to plan the sprints, there was a general direction meeting (only tech directors) and afterwards a general meeting (all teams together) before each sprint. This process was carried out in accordance to the "Sprint Planning Meeting", with the objective of presenting the Product Backlog to the Team and selecting all together reasonable shippable functionalities and deliverables to be done. These meetings were on Fridays, so the subsystems had time to think about everything during the weekend and on Monday/Tuesday they had to meet to plan the Sprint (second part of the Sprint Planning Meeting" as explained in Chapter 4.2.3.3.)and start with implementation of the items in the sprint backlog.

At that point, student teams should carry out an iterative process consisting on: individual work during the week, weekly sub-team meetings (e.g. the Avionics sub-team) to keep working and at the end of the week presentation of the status of the progress to the rest of the members in the general meeting, explaining what they had done during the week, what they were planning to do, what were the needs of the subsystem and which could be potential bottlenecks that limit their performance. For this purpose, some presentation templates were developed. An example can be seen in A2 for the Avionics subsystem.

At the end of each Sprint, "Review Meetings" were planned to present the results of the Sprint to the team and to the team leaders. As it is obvious, only the final result is the one that was presented to the final stakeholders (the judges of the competition). Also, during the general meetings after the Sprints, some "Retrospective meetings" were carried out to encourage the team to keep following the procedures.

And this is how the planning was done to ensure the use of Agile methods in the real project.

5. Results of the data collection

5 Results of the data collection

In the following chapter, the results of the data collection process will summarised and explained. First, a comparison of the artefacts from the real process and the literature will be carried out. After this comparison, the chronological arrangement of the data will be performed and some conclusions will be drawn.

5.1 Comparison of the artefacts of the real process and the literature

5.1.1 Identification

The first event that causes the reaction of the team is the email sent by the organization, explaining that a Hyperloop competition is going to take place, inviting students from all over the world to participate in the competition. In the invitation to the competition, a report was included explaining all technical details for participants. At this point, the team formulates the objective, which is the first artefact, thanks to the given information:

“Hyperloop UPV wants to build a functional prototype for Hyperloop Pod Competition II, passing all the safety tests and being the fastest team with successful deceleration.”

Subject: Announcing SpaceX Hyperloop Pod Competition II

We have been so excited with the results and designs for the first Competition that we have decided…to do it again! Based on the high-quality submissions and overwhelming enthusiasm surrounding the Hyperloop Pod Competition, SpaceX is moving forward with a second installment of the competition: Hyperloop Pod Competition II, which will culminate in a second Competition Weekend in Summer 2017 at SpaceX's Hyperloop test track.

We have attached the Rules document. There are some differences from Competition Weekend I rules, with two important updates being:

- This competition will purely be a student competition.
- Pods will be judged solely on the maximum safe speed achieved with successful deceleration (i.e. not crashing).

We hope you will consider participating again this year. To apply, your first deadline is filling out the Intent To Compete from at www.SpaceX.com/Hyperloop/Submissions by September 30, 2016.

Figure 43 Email sent by the company SpaceX announcing the competition, first motivation to join the challenge (SpaceX, 2016)

5.1.2 Needs definition and synthesis

After the creation of the team, the first step was to provide every member in the team with the mentioned “Rules document” in which all the details of the competition were explained. After that, the technical directors and leads of each subsystem were selected according to the time availability, skills and motivation. In the first direction meeting, the management team (Daniel, David and Juan) united the team directors and used the Minutes to synthesise the main needs of the project. As stated by the rules, the first needs were established:

1. The Preliminary Design Briefing will include:

1. Description of team and updated list of all associated team members and advisors
2. Top-level design description for Pod. Teams are allowed to revise their design in subsequent submissions, so consider the Preliminary Design Briefing to be a "best initial guess." At a minimum, this should include, where applicable:
a. Estimated Pod dimensions
b. Estimated Pod mass by subsystem
c. Estimated Pod power consumption by subsystem
d. Pod navigation mechanism
e. Pod levitation mechanism (if any)
f. Pod propulsion mechanism (if any)
g. Pod braking mechanism
h. Pod stability mechanisms (e.g. attitude and lateral motion)
3. List and description of any stored energy on the Pod (e.g. pressure vessels, batteries)
4. List of hazardous materials, if any
5. Top-level description of safety features, including any hardware and software inhibits on braking during the acceleration phase

Figure 44 Needs definition applied to the Hyperloop UPV team (SpaceX, 2016)

In addition to the need definition, a framework was established for communication and folder sharing. For communication, the system that was best suited was Whatsapp. Although it can seem a very informal tool, in the case of the Hyperloop UPV team, due to the high quantity of young students and high volatility (students were always in different places because there wasn't a main space to work), this method resulted to work very well. A group for each subsystem was created, and was correctly marked and named in order to distinguish it from the rest.

The advantages of the system were that it was very easy and fast to use, and the people used to respond very quickly to easy questions, contribute to the exchange of information and there even was a channel special for "Announcements" in which only one-directional communication could be carried out. For example, all important meetings were posted there as well as other important deadlines.

The only disadvantage of the tool was that it was tricky to deal with large documents in the mobile phone. For that purpose, a common Google Drive file exchange system was proposed. In the Drive all important information was stored, including the register of all meetings in form of presentations of each subsystem and minutes about the discussions and decisions taken during the meeting. a Google Calendar was also shared with all team members.

The team also did an extensive work to know more about other teams and about the state of the art in each subsystem.

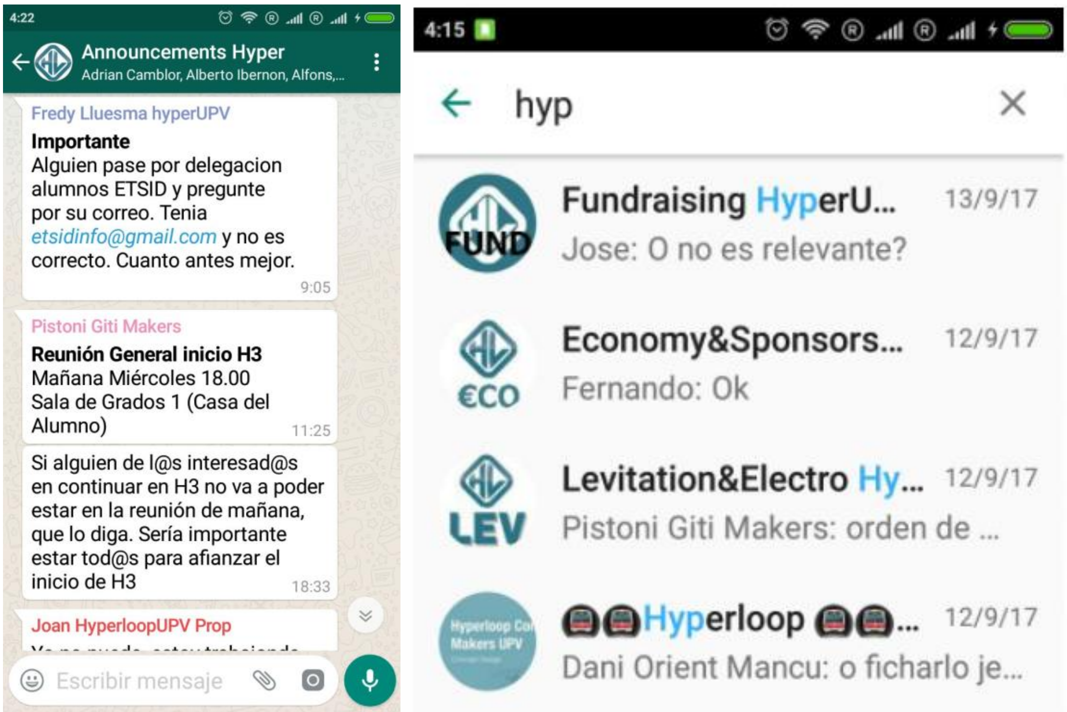

Figure 45 Overview of the Whatsapp framework for Hyperloop UPV, including the "Announcements" group (Vicen 2017)

Another useful tool was the open-source web platform Trello, and it was used by the subsystems to track their tasks and to-do's. One example is the one carried out by the Avionics team, shown below:

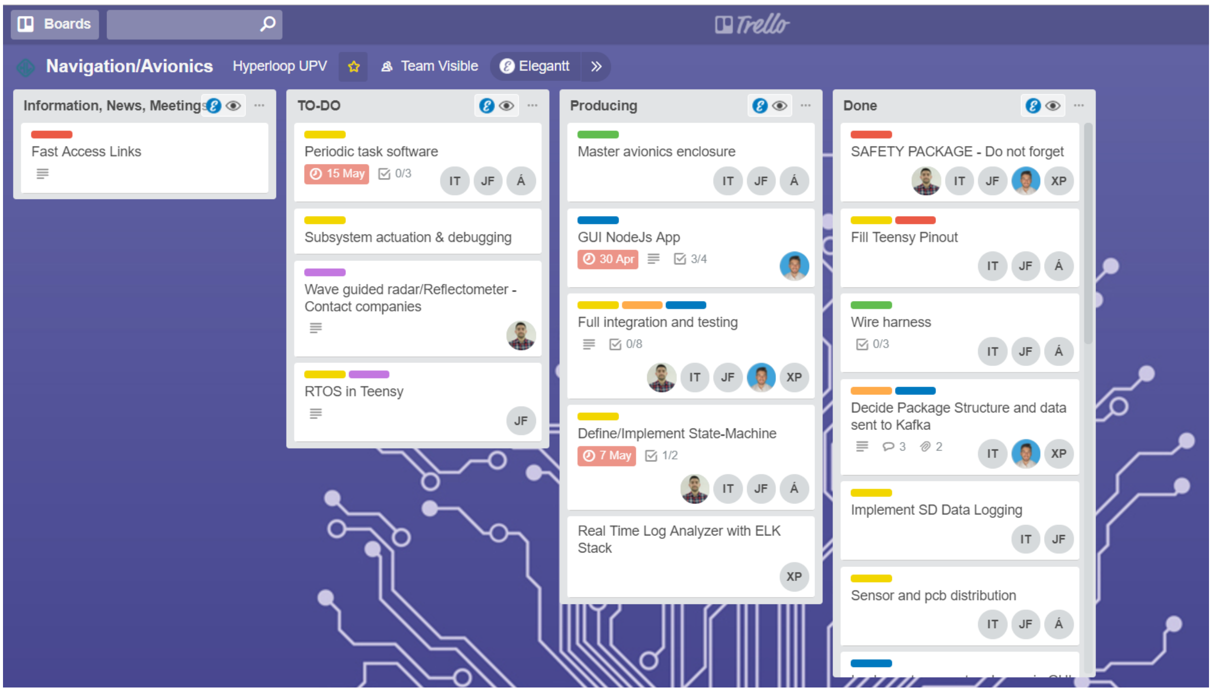

Figure 46 Trello board of the Avionics team, with the new and done tasks (Vicen 2017)

5.1.3 Idea generation

Once the framework was established and the needs were defined, the teams were given freedom to research on literature and to speak with professors and other experts to find out disruptive ideas to deal with the problems. Each sub-system should meet and talk about their findings, proposing different ideas and then converging into several feasible solutions: brainstorming.

The main artefacts at this point were recorded at the presentations that the sub-teams carried out each week, and an example can be found in the figure below:

DC-DC CONVERTER

	Mean Well SD-350C-24	TDK LAMBDA model CC10-2412SF-E	CUI Inc model PYB30-Q24-S5-H-U	CUI Inc model PYB15-Q24-S3-H-T
Input Voltage (V)	70	24	9 -- 36	9 -- 36
Output Voltage (V)	24	24,00	5	3,3
Output Current (A)	14,6	1/0,8	6	4
Output power (W)	350,4	10	30	15
Weight (kg)	1,1			
Prize (€)	104,46	24,79		

Figure 47 Example of chart showing different options for the selection of a DC-DC converter, carried out by the Energy subsystem at Hyperloop UPV (Vicén 2017)

It must be noted that general meetings were used as important feedback generators, because it was the time were all technical directors were together and the presentations used to follow the following order:

1. What did the team do this week?

2. What is the team working on?

3. Is there any bottleneck? How could the team overcome it?

4. Which are the next steps?

5.1.4 Idea selection

After the ideas were generated, a **direction meeting** was held in which subsystem leads presented the main ideas to the management team, and after that, a first synthesis of the possible solutions was selected. In case subsystem leads considered that more people from the subteam should be needed for the selection of an idea, the management team was always flexible and eager to check his/her opinion.

It is important to note that, as in the case of the Scrum method, the processes in the real life were also iterative, and the main objective was to carry out the sprint every week to get knowledge and to keep testing and iterating. The final deliverables were always the deadlines established by SpaceX to hand out documents.

This can be seen in the following figure:

Figure 48 Deliverables of the Hyperloop Pod Competition II and the prototypes of each one until the real idea implementation (Vicén 2017).

It is also important to mention the relevance of the weekly General Meetings carried out on Friday afternoons. During these processes each subsystem didn't only get very valuable feedback, but was able to inform others about the status of its subsystem. At the end, this allowed all team members to have a good overview of the project.

Figure 49 Example of a weekly General Meeting, in this case Propulsion subsystem talking (Vicén 2017).

5.1.5 Requirements, Objective or Problem definition

In the case of the requirements, with SpaceX rules at hand and all the information obtained from the previous steps, the analysis of the current situation can be carried out. In the case of the Hyperloop Pod Competition, almost all information was provided by SpaceX, so the analysis of the situation, the objective, and the problem definition could be summarized as:

There is a competition with some rules and requirements specified by SpaceX and the team is composed by several subsystems, including technical (levitation, propulsion…) as well as support (fundraising, marketing, design) in order to achieve the objective of creating a Hyperloop vehicle for the competition. The team is collaborating with an American university to develop the vehicle in collaboration. The Spanish team will be in charge of the chassis, fairing, energy, manufacturing and friction braking subsystems, while the American team will be in charge of the pneumatics, magnetic braking and levitation skis. The main challenge is to get all parts done on time and proceed to the assembly process as soon as possible at Purdue University. After this process, the prototype will be shipped via ground transportation to Los Angeles, where the competition is held, to pass all the safety tests.

The case of the business model doesn't apply in this project since it is not a market competition, but rather a technological competition.

5.1.6 Solution alternatives and Concept development

Once each subsystem defined its requirements, now the proposal of alternative solutions takes place. After several iterations and sessions of brainstorming between subsystems and during the weekly General meetings, the teams arrived to concrete solutions. The artefacts provided at this point are very different depending on the subsystem.

For example, in the case of the Avionics subsystems they were expressing their ideas with schematics, like the one below:

Figure 50 Schematic of the Avionics system showing the GUI and the connection with the sensor and microcontroller (Vicén 2017).

In the case of the structures system, the artefacts are technical drawings, such as the one below, which represents the shell:

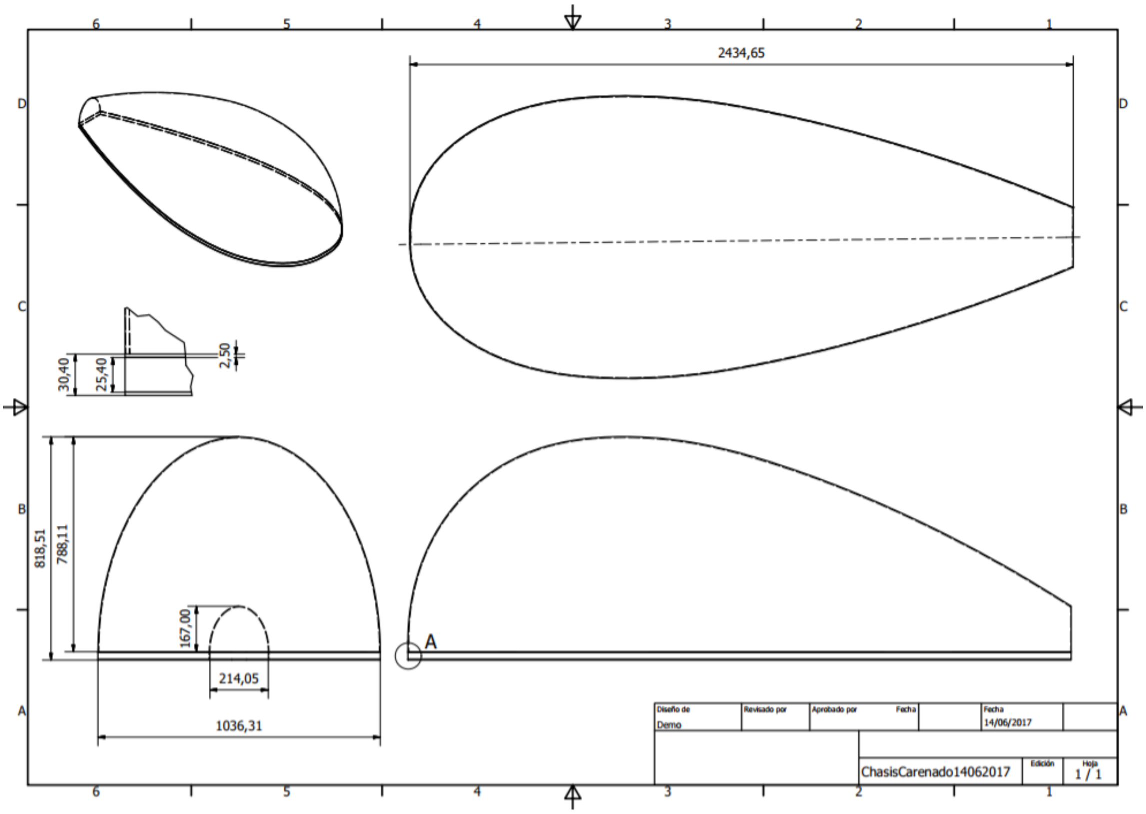

Figure 51 Technical drawing of the fairing carried out by the Structures subsystem (Vicén 2017)

In the case of the energy subsystem, for example, they used circuits to represent the wiring:

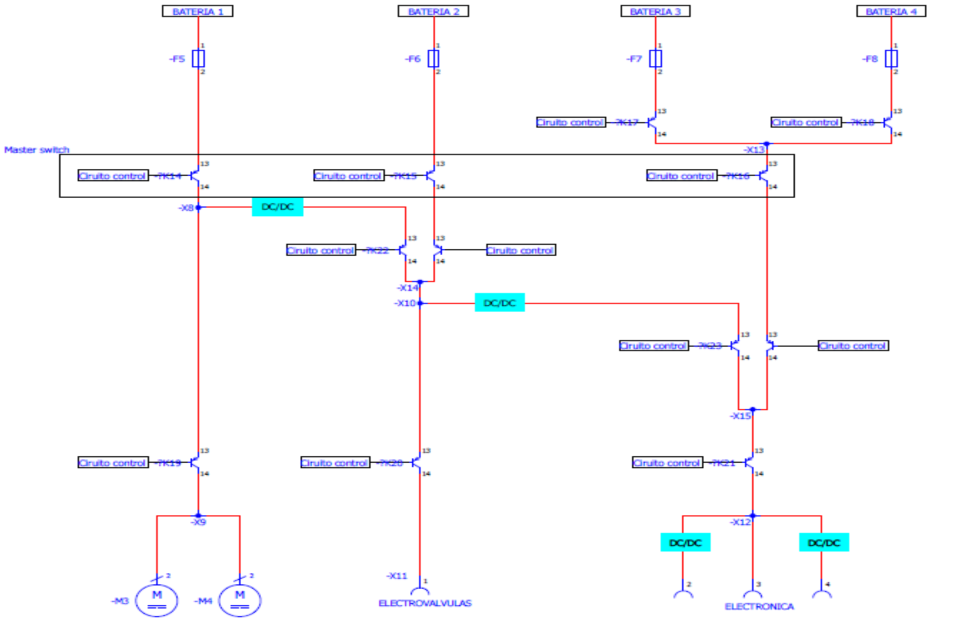

Figure 52 Circuit diagram carried out by the Energy subsystem at Hyperloop UPV (Vicén 2017).

The propulsion subsystem carried out estimations of the dynamics of the system, in the form of charts and programming code in Matlab software:

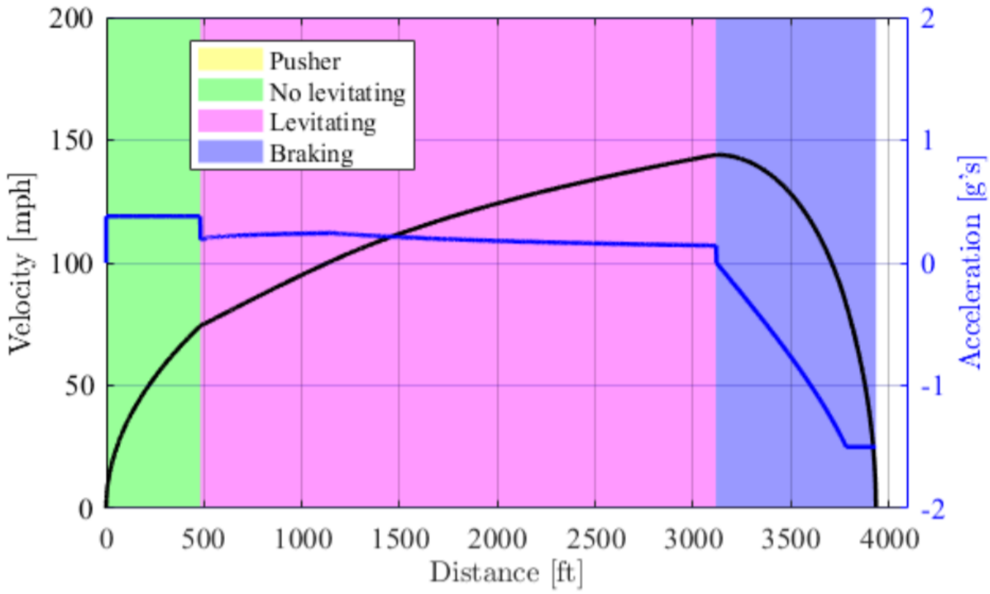

Figure 53 Charts of velocity profiles carried out by the propulsion subsystem (Vicén 2017).

And finally, also some simulations in software such as ANSYS were carried out to study for example the magnetic behavior:

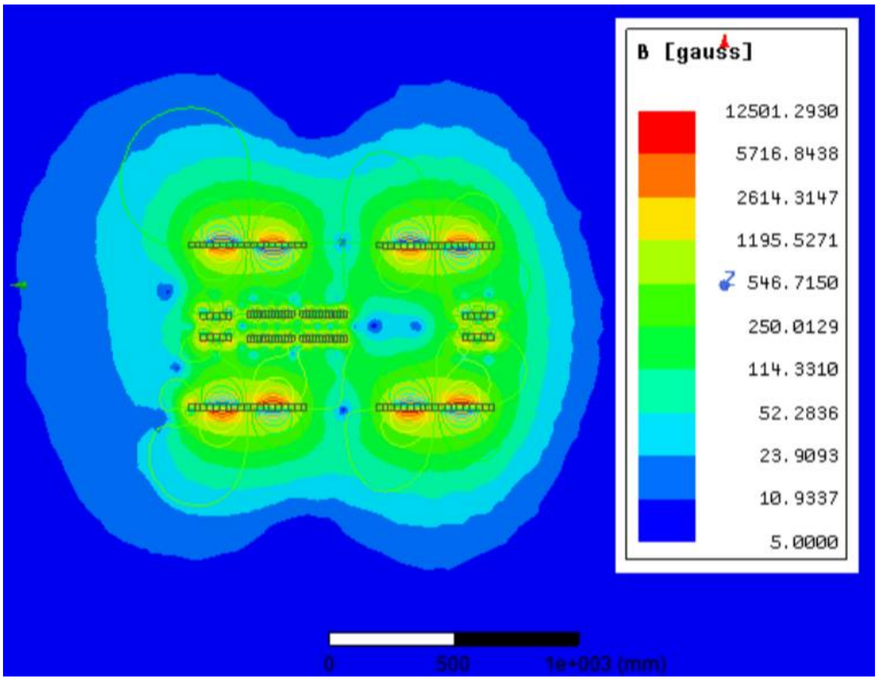

Figure 54 Magnetic simulation of the magnetic field distribution of the vehicle carried out by the levitation team at Hyperloop UPV (Vicén 2017)

All these data were summarized in the two reports sent to SpaceX, which after reviewing the documentation gave its approval and selected the team for the competition. Once this was achieved, at the beginning of March, the team was ready to start implementation of the project.

5.1.7 Implementation

During implementation, the same procedure as with the last chapter was observed. Once all subsystems had their parts ready to purchase or to machine, some buffers with Microsoft Excel were created to be more efficient. The main two were the Machining buffer and the Purchases buffer. In the first one, everything related to machining parts and structure elements was added to the queue, everything divided into subsystems. On the other side, the buffer of Purchases was aimed at general purchases that do not imply machining. For example: sensors or velkro.

One example of the Product Backlog buffers can be seen in A3.

The team found really valuable the existence of such buffers to keep everything organized and to avoid missing things to purchase. Being able to check at any time how or where is your product was another advantage. The feedback received by the team was therefore positive.

The implementation process was one of the most valued by the students, who were able to apply their knowledge and see their creations take shape. It is the case of the fairing and chassis manufacturing, that was performed at a workshop near the University (see figure below):

Figure 55 At the workshop in Beniflà, preparing the fairing mold (Vicén 2017).

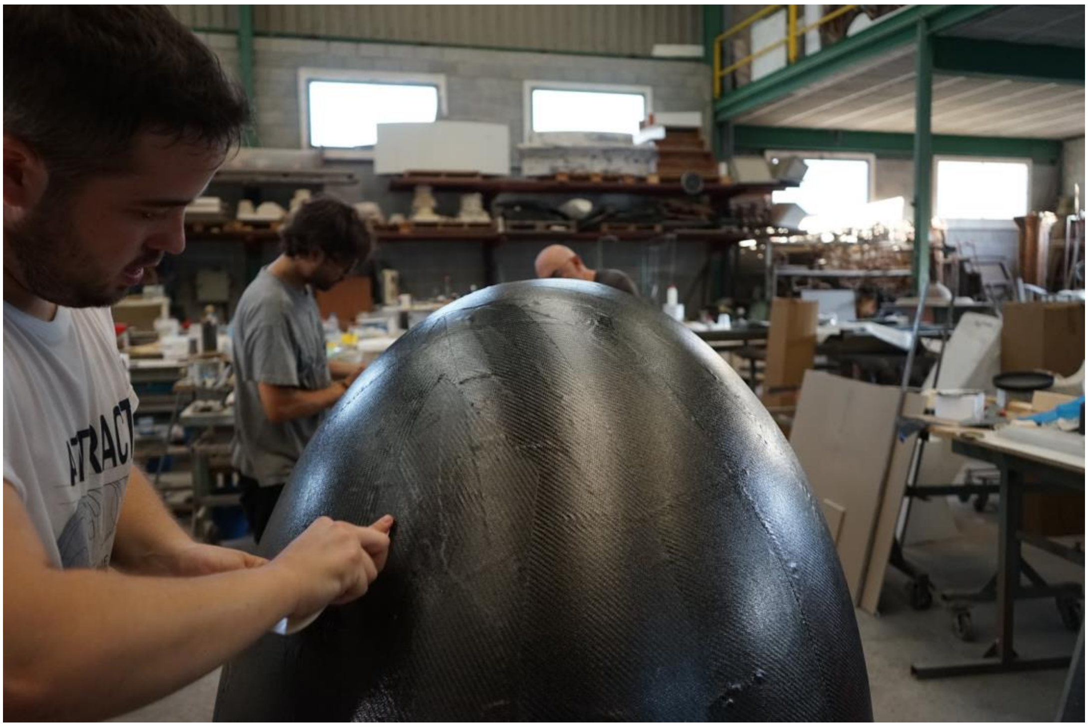

Figure 56 Adding the carbon fiber (Vicén 2017).

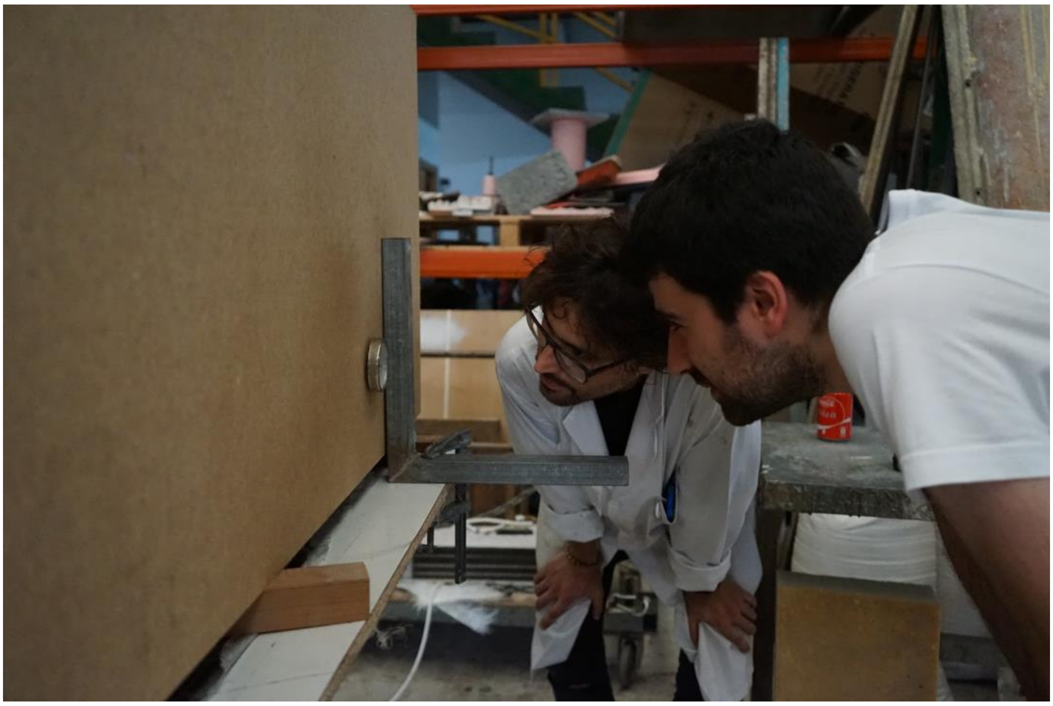
Figure 57 Curing the carbon fiber in a do-it-yourself oven (Vicén 2017).


Figure 58 Prototype reception at Purdue University in Indiana, USA, July (Vicén 2017).

Figure 59 The team finishing the prototype at the lab in Purdue University prior to shipping in August 2017 (Vicén 2017).

Figure 60 The prototype after arrival at the Hyperloop Pod Competition (20th August 2017, Los Angeles, California) (Vicén 2017).

5.1.8 Testing and evaluation

The last step, testing and evaluation, took place on the week from the 20th to 27th August at SpaceX's headquarters in Hawthorne, California. The team prepared several checklists for that purpose, in order to be ready and have an efficient procedure. Below an example of procedure to do the unboxing:

The pod is fixed inside a Wood box that includes two wood pallets. This wood box is fixed with straps to a dolly, allowing us to move the box around the testing lot. Once the box is in our testing area, the procedure will be as follow:

- Lock the dolly's wheel, this will not allow the dolly to move around.
- Unlock and remove the straps that keep together the pod box and the dolly.
- Unlock and remove the top part of the box and analyze possible issues produced during the transportation.
- Unlock and remove the rest of the parts of the box.
- Remove the boxes around the pod that contain tools, extra parts, extra materials etc.
- Remove the wedges and straps that fix the pod to the box.
- With the help of 8 people (3 on each side, 1 on the front and 1 on the back) unload the pod and leave it over the stands in order to be ready to work on the pod.
- Remove the box from the dolly with the help of 6 people or with a forklift to prepare the dolly for next steps.

Figure 61 Procedure to unbox the Hyperloop prototype (Vicén 2017).

More examples of Checklists can also be seen in 111.

During the testing week, the team was able to pass almost all test, except from the last one. Below can be seen a picture from the pressure chamber test:

Figure 62 Pressure chamber test at SpaceX headquarters (Vicén 2017).

The feedback received from SpaceX was very fruitful, because there were experts in several fields, such as aerospace, power electronics, low-pressure environments as well as mechanics.

Finally, the last test went wrong due to a failure in the communications system and the team wasn’t able to achieve its ultimate goal: to enter the Hyperloop test track, achieving the 8th position in the global ranking.

After the competition, the team held a Reflexion meeting in which the team management (Daniel, David and Juan) gave a speech congratulating the team about the results and motivating them to keep working for the next competitions. During the meeting there was also place for comments for improvement, and each team members was able to talk about their experiences in order to have a general view of the situation.

5.1.9 Prototypes

Different types of prototypes during the innovation process are:

5.1.9.1 Conceptual prototype

As can be seen in the figures below, the conceptual prototypes were pictures, similar to the idea of final product, that the team used to raise funds at the early stage of the project (months 1-3). In the first case, the product refers to the competition pod, and in the second case, to the futuristic Hyperloop system.

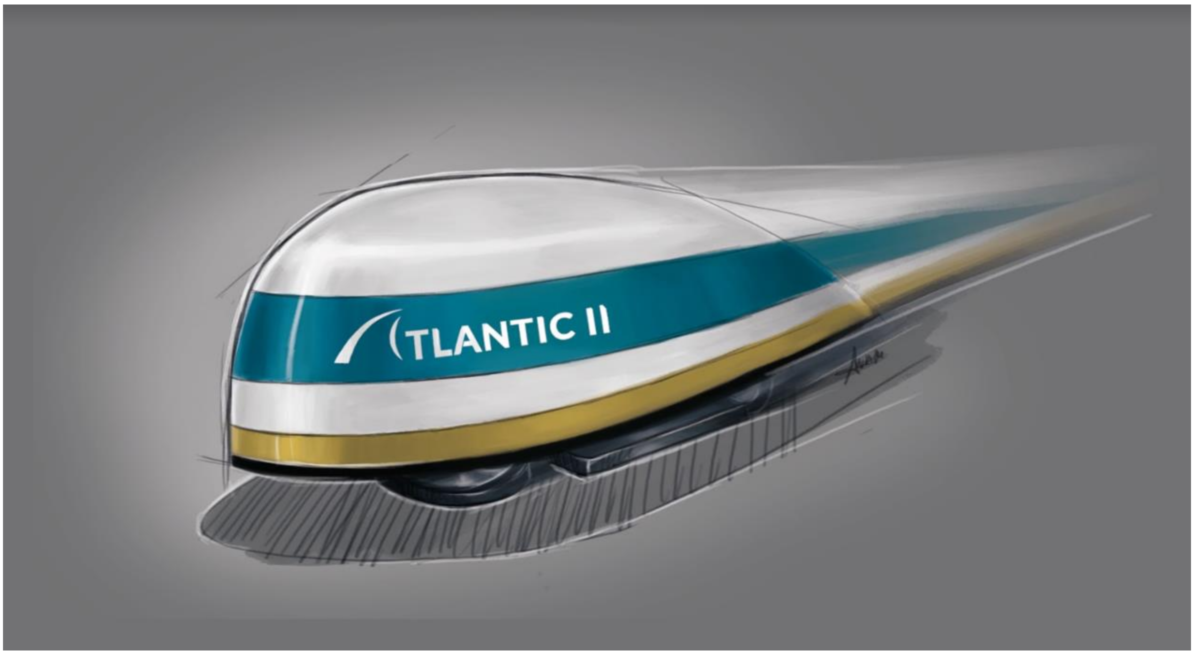

Figure 63 Illustration of the Atlantic II prototype (Ana Sarrión, 2016)

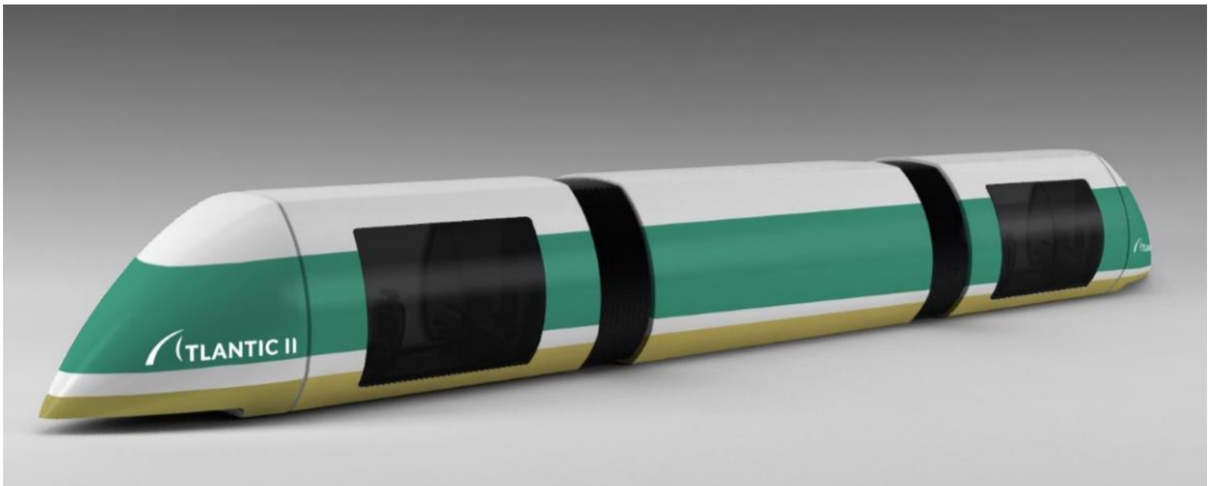

Figure 64 : Illustration of the future Hyperloop system (Alfonso Reyes, 2016)

5.1.9.2 Geometrical prototype

In order to test several models of propulsion, several sketches were drawn in order to check all possible solutions and select the most appropriate one.

During the project, and due to the high uncertainty, other ideas appeared such as the ones below, exploring propulsion mechanisms:

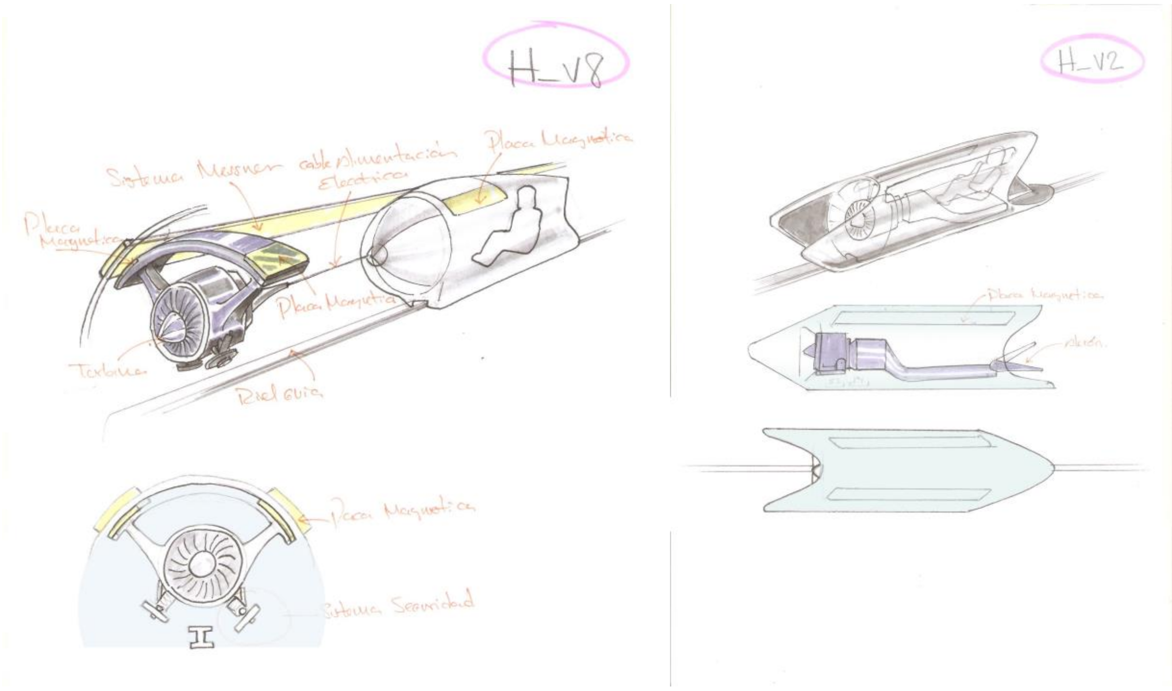

Figure 65 Sketches of several propulsion mechanisms (Alfonso Reyes, 2016)

These sketches, provided by researcher and industrial designer Alfonso Reyes, one of the members of the team, were essential to provide feedback from the other team members, because the methods of propulsion were understood very easily.

5.1.9.3 Functional prototype

For example, during the process of creating the propulsion system, and in order to test the motors, the team had to create a functional prototype, in which information could be obtained, but without having the final product yet. In this case the motors were not proven with the final batteries, but with an external power source, and instead of having the wheel rolling with a big test track (as in the real competition), this was exchanged by another motor which provided the necessary torque.

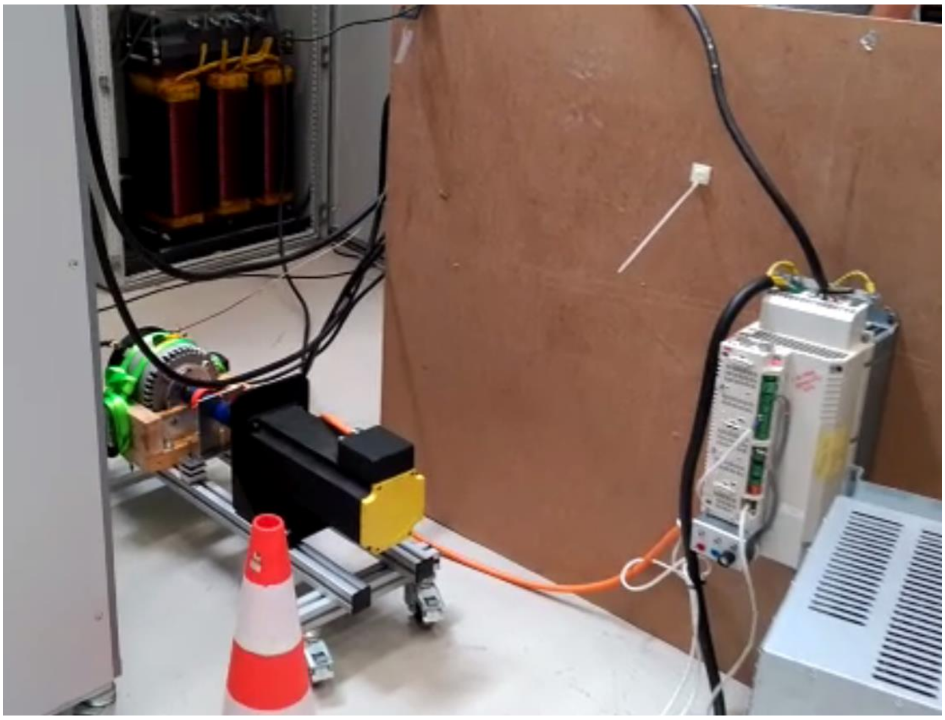

Figure 66 Propulsion subsystem: electric motor test bench (Vicén 2017).

5.1.9.4 Technical prototype

This technical prototype is the final product, used to validate that the Hyperloop can achieve high speeds inside the low-pressure tube due to the low air friction. It was also used to gather feedback from investors, that were walking around during the competition.

Figure 67 The Atlantic II prototype, by Hyperloop UPV team (Vicén 2017).

5.1.9.5 Others

Other artefacts were used during the innovation process, such us the following one.

Table 6 Decision-making table defining the two possibilities (Vicén 2017).

	Initial idea	Final idea
Levitation	Superior active levitation	Inferior passive levitation
Propulsion	Aircraft compressor (aerodynamic)	Electric motors (mechanic)
Wheels	Only for take-off / landing	Always in touch with rail
Braking	Aerodynamic and friction	Friction and magnetic
Chassis	Welded aluminum tubes in a cylindrical shape	Aluminum honeycomb composite, planar shape
Fairing	Monocoque made by third party	Monocoque do-it-yourself
Energy supply	Lithium batteries	Lithium batteries
Avionics	Master-slave Teensy architecture	Master-slave Teensy architecture

This was a table used for decision making. After several talks with the American university team, it was January and the team needed to take a decision: to participate with the American university or to follow its own path. In order to choose, two proposals were analyzed. The team had been able to find several parts of the initial concept and adapt them for the competition but some of them were really difficult to find, such as the aircraft compressor, and the team was stuck. Furthermore, the complexity of the levitation system was high for the small time-frame of the project. Finally, the team decided to **pivot** and opt for a more practical design adapted to the final goals of the competition: to create the fastest vehicle.

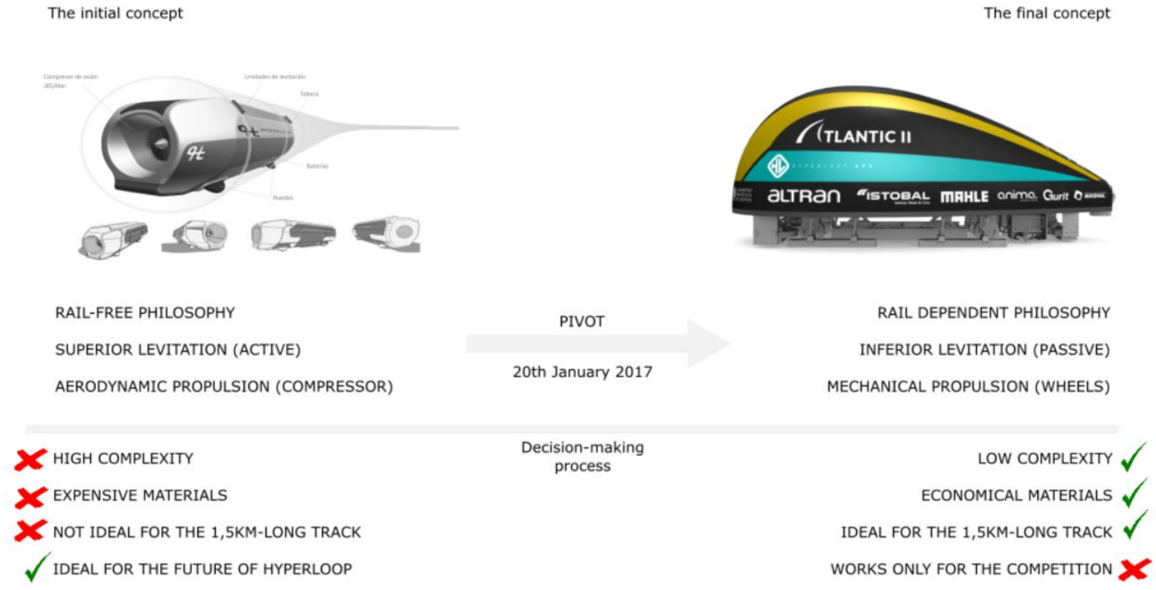

Figure 68 Summary of the before-and-after products to be built (Vicén 2017).

5.2 Chronological arrangement

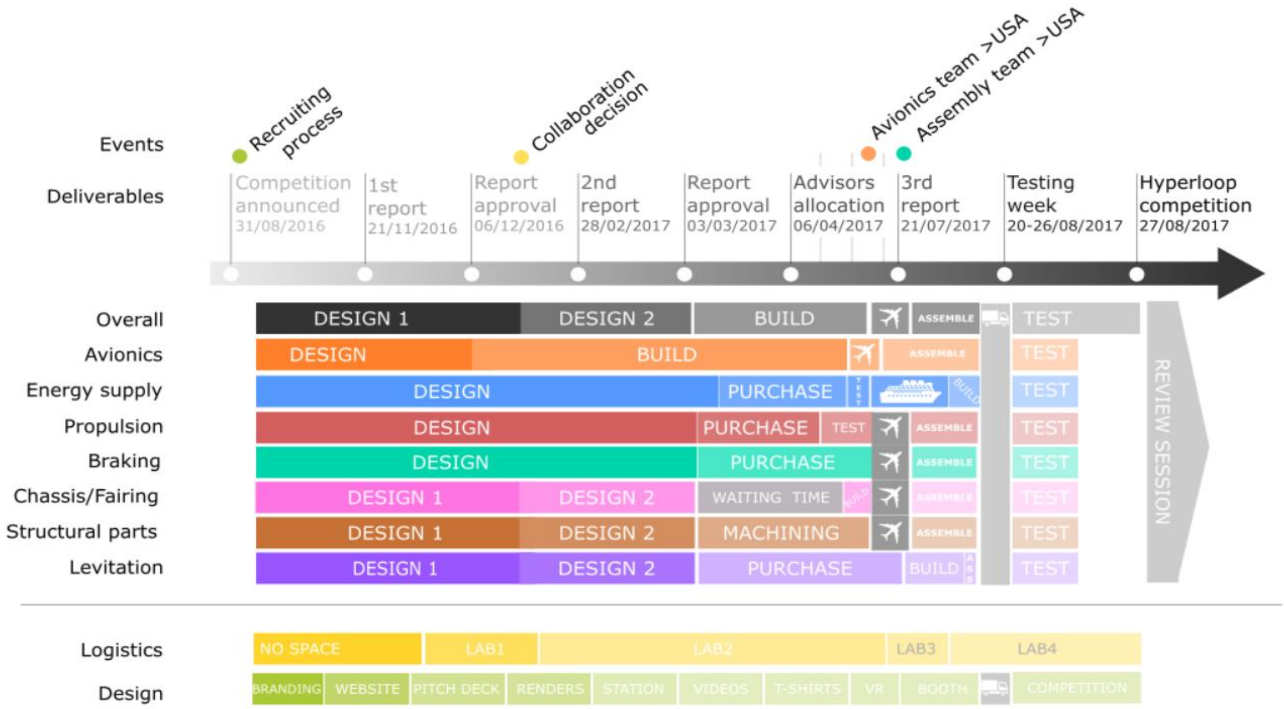

Figure 69 Chronological arrangement of the design phases in relation with the several subsystems of the team during the innovation process of the Hyperloop UPV team (Vicén 2017).

In the chart above the entire product development process is represented and ordered in a chronological way, from start to finish. As can be seen, everything starts with the announcement of the competition, then there is a design phase. The design phase took three different paths: first path, the fastest, was the avionics system, because it was independent from all other subsystems and from Purdue.

Then, the structural and levitation parts were clear for the first requirements, but then they needed to be redesigned with the new specifications for the prototype created in collaboration with Purdue. Finally, energy, propulsion and braking took more time because they were the most complex systems.In the building phase, there was also a difference between parts that needed to be just purchased (fixed arrival dates, easier to plan) to that parts that needed to be machined or fabricated (dependent on external factors, more difficult to plan).

Also, some dead time was spent in the development of the fairing and chassis, because they were expected to be manufactured in Purdue but in the end they need to be manufactured in Spain. Although most of the systems were easy to assemble, the final assembly took place after all parts arrived at Purdue University, so the team had to deal with both plane and boat shipping, this last one during more than 30 days, something that delayed a lot the assembly process.

Finally, everything was assembled at Purdue University and shipped to Los Angeles for the competition.

5.3 Conclusions

During this study, the objective has been to try to apply the concepts learned from the research in Agile product development methods into the real world. Usually, traditional product development methods are very complex and their application is only appropriate for big companies with low degrees of uncertainty and high degrees of stability. However, with the rise of the Agile approaches, a niche has been found for the application in smaller organizations like startups, with high degree of uncertainty during their first phases.

Although Agile was born to provide IT and programmers with useful tools, with these works an emphasis is tried to be put in the application to the development of other kinds of products, for example hardware.

In order to apply these Agile approaches, first an analysis was carried out, to check the State-of-the-Art. After that, there was a selection of the most appropriate methods to apply in the project taking into account its characteristics. The methods selected were: Design Thinking, Lean Startup and Scrum. Design Thinking was used in the first phases of the project, especially ideation and design. The Lean Startup was used as a method to create several Minimum Viable Products obtaining feedback from the team prior to Competition. And finally, Scrum, was ideal during the development and assembly processes to structure the day to day work, delivering on time prototypes that could be later used to assemble the final prototype.

It must be said that, in this case, the most useful method was Scrum. The application was simple and easy to understand by the team. There were a lot of tools available such as Trello, Excel Sheets, and Presentations, that allowed the team to implement easily the iterative procedures.

This, together with an exhaustive use of communication methods and the weekly meetings was the key aspects to align the philosophy of the team leaders with the rest of the team, allowing for a fluid and Agile Product Development. The flexibility of the method also allowed the team to take a customized version of it that fully fitted the characteristics of the project.

For that purpose, the author of this thesis would recommend applying Agile, and especially Scrum methods to Product Development projects that have similar characteristics than the one examined.

5.4 Future Works

Currently there are not many works in the direction of applying Agile in hardware and physical products. This is why, if there should be mentioned points for future research, it would be interesting to have a wider variety of projects in order to determine the real efficiency of Agile approaches in Product Development.

When these works are published, the results of this work should be compared in the future to draw even more conclusions.

As well as Scrum, Design Thinking and Lean Startup, that are more well-known due to media exposure, more research should be carried out in new methods that arise and that can lead to better performance or more agile/flexible product development.

Also, the Munich Procedure Model (MVM) and the VDI 2221 models should be applied to similar products in order to be able to compare.

Finally, the application of new communication technologies has completely changed the way this project was managed in comparison with traditional product development. Thanks to constant contact between the members of the team, it was possible to react very fast to changes and to be more efficient as a team.

Although this fact has been only briefly commented in this work, the communication platforms can play an important role in future product development and would be another field of study.

6. Recommendations

6 Recommendations

During the process of writing this work, the author of this thesis has collected some recommendations that would hopefully help new project managers and entrepreneurs to develop products faster and more efficiently:

1. The Scrum methodology has proven to be an appropriate method to use in the development of an hyperloop prototype, a project with a high degree of uncertainty in budget, short time availability of team members (5-10h/week), timeframe of 1 year and team size of 30.

2. The most important point in the application Scrum method has been choosing the appropriate cycle lengths and their relationship with time availability of team members, achieving a constant way of working during the whole timeframe.

3. Also of importance in the implementation of Scrum has been to make it easy for the team members and managers to follow the process: the creation of tools such as simple presentation templates for the use by team members or the creation of the weekly meetings were key for the progress of the project.

4. The creation of priority buffers in order to manage complexity has been successfully implemented and has enabled a proper collection and distribution of tasks.

5. The use of web-based tools has been a key enabler for communication and co-work, allowing co-located teams to work together living at both sides of the ocean.

6. Recommended tools for the application of the Agile approaches are: Trello, Google Drive (Excel Sheets), Whatsapp and Slack.

7. The key when applying Scrum is also the distribution of the Sprints and the definition of the people needed for the Sprint. In the work, the design process was carried out individually by the team while in the assembly process the Sprint team was composed of members of all areas.

8. The exhaustive collection of data has been extremely useful for the later organization of the events chronologically and the analysis of the results obtained.

9. While organization in Excel sheets was useful, for similar projects a special software for economic management would be more efficient.

10. When the budget is very limited and uncertain, the use of creativity in the conceptualization phase can be very useful to attract the first supporters, after which more supporters will follow.

7. Literature

7 Literature

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8 List of figures

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10. List of abbreviations	*64*

10 Abbreviations

APS	Agile Project Management for Systems in the regulatory field
FMEA	Failure Mode and Effects Analysis
GfSE	Gesellschaft für Systems Engineering e.V.
GUI	Graphical User Interface
MVM	Munich Procedure Model (Münchner Vorgehensmodell)
MVP	Minimum Viable Product
OMG	Object Management Group
TBD	To Be Decided
UML	Unified Modeling Language
VDI	Verein Deutscher Ingenieure

Annex *A-1*

Annex

A1 Checklists for the competition *A-1*

A1 Checklists for the competition

Pod Navigation Test

1. POD Power ON
    a. Check that all connections from and to the batteries are correctly seated.
    b. Activate master switch, 3V switch, 5V switch, pneumatic switch and motor switch sequentially. Every one of this switches has a LED which will turn on once the switch is activated.
    c. Check at the GUI that the voltage, current and temperature on the batteries are at **nominal values.**

2. Place pod in a safe and mobile state and initiated to the same Software State as in an actual run.
3. Team shows telemetry values of position and velocity via its GUI.
4. Pod is left stationary for five minutes, and the navigation drift, if any, is observed.
5. Pod is manually moved a distance of 200 feet and brought to a rest.
6. Team shows resultant telemetry values of position and velocity via its GUI.
7. Test variations can be repeated as necessary, for example:
    - Repeat test with unplugged (failed) encoder sensor and ensure that the pod only increments the distance based of the remaining healthy sensors.
    - Repeat the test with unplugged (failed) tape reader and use the optical tape to see sensitivity of the Pod.

Software State Diagram Test

1. POD Power ON
    a. Check that all connections from and to the batteries are correctly seated.
    b. Activate master switch, 3V switch, 5V switch, pneumatic switch and motor switch sequentially. Every one of this switches has a LED which will turn on once the switch is activated.
    c. Check at the GUI that the voltage, current and temperature on the batteries are at **nominal values.**
2. Activate READY state from GUI after confirmation from adviser to continue. Check for new state value in GUI indicating the Pod received ready state.
3. Pod will run through state diagram.
4. At all times, team will monitor with advisor states of actuators through GUI while also looking at relevant data.
5. After running through first iteration, team will cause an exit condition. Check exit conditions. Team will run through all exit conditions.
6. After running through test, team will power off pod.

Exit conditions :

A - Navigation Fail Test:

As with the procedure above, the ready state will be sent to the pod. While in COAST, which is powered mode, we will remove connection from the GUI either by disconnecting the computer from the switch or powering off switch.

B- Emergency Brake from the GUI

As with the procedure above, the ready state will be sent to the pod. While in coast the EM BRAKE will be activated through the GUI. This will cause the pod to go into BLFT state (emergency brake). When done it will maintain this state until reset command is sent from GUI.

C- End track conditions:

GUI will upload value for motor coast in seconds. If the stripe count of 27 is not reached and pod reaches time value it will automatically brake. If stripe count reaches 27 pod will also break. When braking is activated and acceleration is 0 for a certain amount of time pod will release breaks and go into idle.

Test 3. External Subtrack

TRANSPORT

1. 9-10 people lift the pod into the dolly
2. Fix the pod properly
3. Move the dolly to the External Subtrack
4. 9-10 people lift the pod from the dolly to the External Subtrack

POD POWER ON

1. Check that all connections from and to the batteries are correctly seated.
2. Activate master switch, 3V switch, 5V switch, pneumatic switch and motor switch sequentially. Every one of this switches has a LED which will turn on once the switch is activated.
3. Check at the GUI that the voltage, current and temperature on the batteries are at **nominal values.**

TESTING

1. Navigate to GUI and activate TEST button in motor/pneumatic control panel
2. This test executes the following:
    1. Turn manifold On
    2. Turn wheel actuator On
    3. Turn battery switch On

4. Turn motor switch On
5. Turn motor speed to 10% (this value can be configurable by easily changing the command in the call on the GUI)
6. Wait 1 second.
7. Turn motor speed to 0%
8. Turn motor switch to Off
9. Turn eddy brake actuator to On
10. Turn friction brake actuator to On
11. Wait 10 seconds.
12. Reset pod state. Turns off all systems.

4. This test can be run several times changing the parameters of motor speed and braking time.

5. After testing system will be shut down with the power off procedure.

POWER OFF

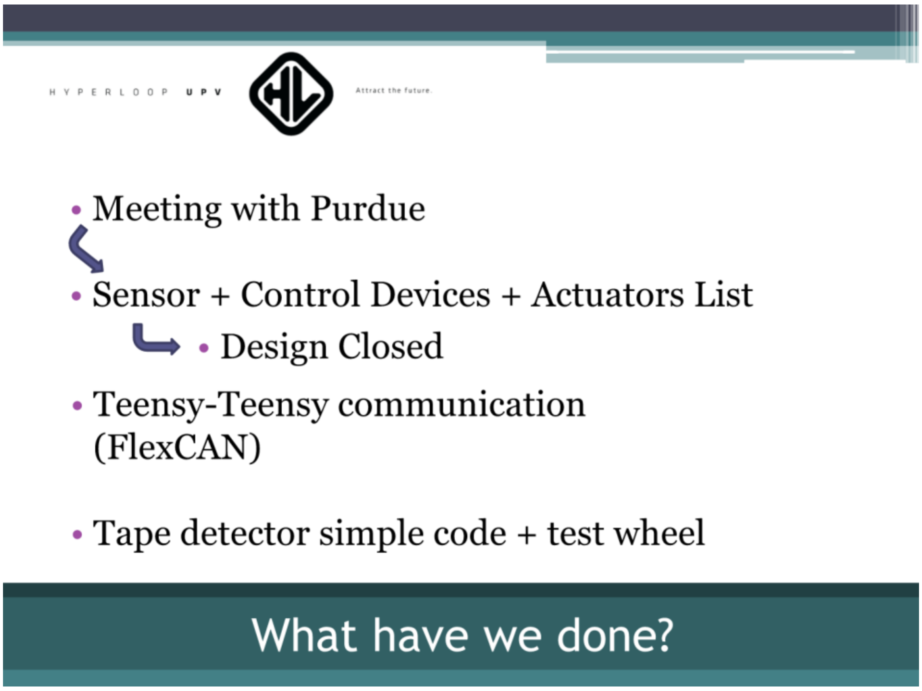
1- Confirm contactors are open

2- Pneumatics retraction position. Open valves. Nominal pressure.

3- Turn off motor switch, pneumatic switch, 5V switch, 3V switch and master switch.

A2 Subsystem Weekly Presentation Example in General Meeting

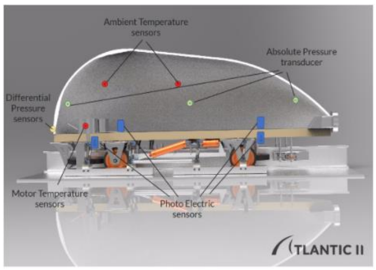
1. Slides



HYPERLOOP UPV

Attract the future.

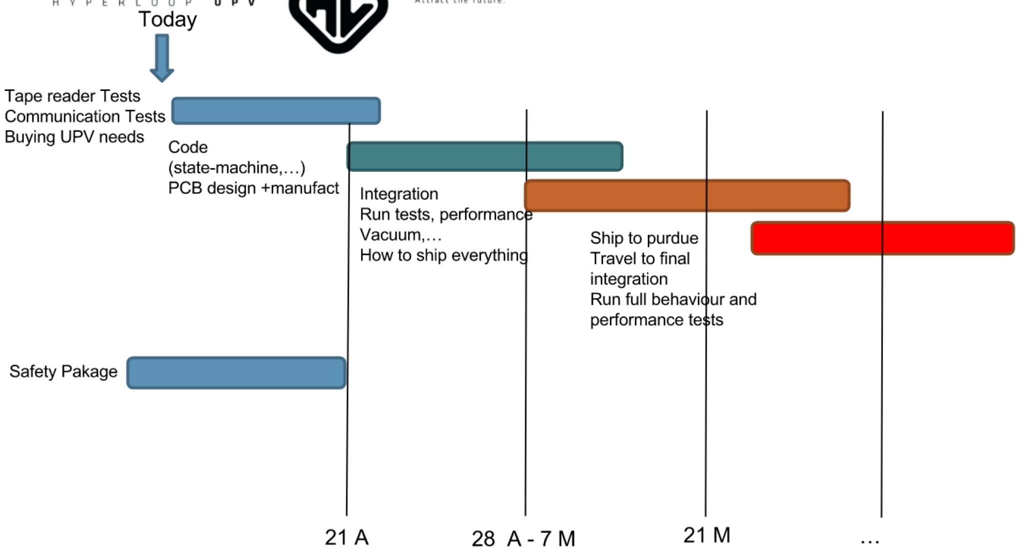
- Tape detector improvement ->Multi Interruption
- Ethernet + comm
- GUI integration
- Sensor and PCB distribution



What are we working on?

HYPERLOOP UPV

Attract the future.



Which will be the next steps?

H Y P E R L O O P U P V

Attract the future.

- Pedro'll arrive Spain 7 May carring some sensor electrovalves, relays,…

- Need to design the wiring and harness

- Looking for a way to send it all

- Need to travel to Purdue to final integration (Avionics+Energy guys)

Which will be the next steps?

A3 Use of Product Backlog buffers to improve efficiency

1. Buffer table

^^^^^^ Add a new row above the other ones everytime you need to buy something ^^^^						11.057,52 €	Process flow 1 >>>>	2 >>>>>	3 >>>>	Other information		
Subsystem	Item	Brand	Link(s)	Cost/unit (€)	Units	Total cost aprox(€)	Accepted?	Paid?	Received?	How to buy it?	Promoting person	Other comments
Propulsion	Item 9	Brand A	https://www...	500,00€	1	500,00€	Asking for quote			Own funds	Francisco	Comment1
Propulsion	Item 8	Brand B	https://www...	600,00€	1	600,00€	Asking for quote			Own funds	Juan	Comment1
Energy	Item 7	Brand C	https://www...	10,00€	2	20,00€	Purchase stopped			Sponsor found	Francisco	Comment1
Energy	Item 6	Brand D	https://www...	15,00 €	1	15,00 €	Purchase stopped			University supports	Francisco	Comment1
Avionics	Item 5	Brand E	https://www...	25,00€	8	200,00€	Further studies needed			Sponsor found	Francisco	Comment1
Propulsion	Item 4	Brand F	https://www...	23,54€	1	23,54€	Accepted	Waiting for invoice		Sponsor found	Francisco	Comment1
Energy	Item 3	Brand G	https://www...	1.000,00€	2	2.000,00€	Accepted	Waiting for invoice		Own funds	Juan	Comment1
Structures	Item 2	Brand H	https://www...	20,00 €	2	40,00 €	Accepted	Paid by UPV	Coming: link->	Sponsor found	Francisco	Comment1
Structures	Item 1	Brand I	https://www...	13€	1	13€	Accepted	Paid by UPV	Received	University supports	Francisco	

A4 Budget

This section of the project will cover the economic análisis of the project. For that purpose, first an analysis of the different phases will be carried out, with a visual Gantt chart to observe the timelines. Second, the detail of the budget of the different phases will be presented and finally a summary of the total cost of the project will be presented.

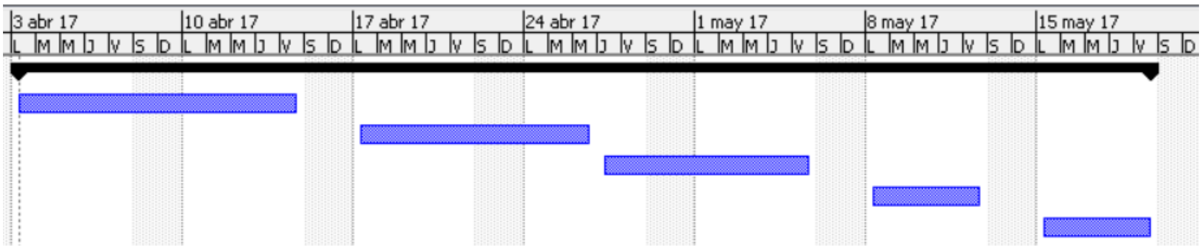
A4 – 1. Project phases and Gantt Chart

The project started on the 3rd of April of 2017 and was submitted in Munich the 2nd of October of 2017. Since it is a Double Degree work, it was presented both at the Technical University of Munich and at the Universitat Politècnica de València. This is the reason why this work had to be adapted to the Spanish format adding the Budget section found on this Annex 4. For the purposes of the Gantt Chart, the day of the presentation at Technical University of Munich will be considered as the ending day of the project, with a total of about 30 ECTS. The project was divided in the following phases:

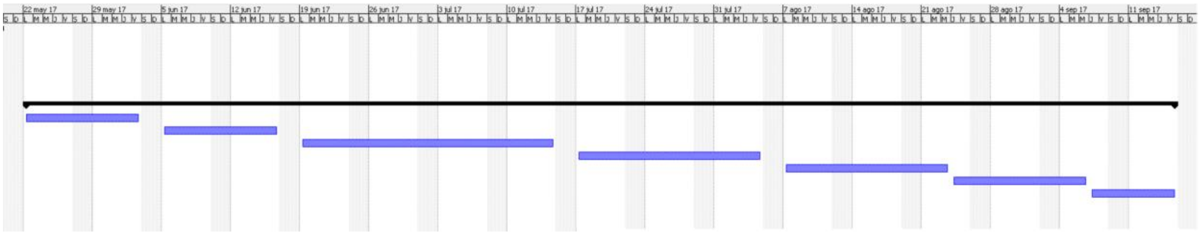
Name of the task	Duration(days)	Started on	Finished on
Phase I: Project Planning	35	03/04/17 08:00	**19/05/17 17:00**
Definition of the project	4	03/04/17 08:00	**14/04/17 17:00**
Definition of the topics and related literature	5	17/04/17 08:00	**26/04/17 17:00**
Definition of the objectives and actions	6	27/04/17 08:00	**05/05/17 17:00**
Definition of the research methodology	5	08/05/17 08:00	**12/05/17 17:00**
Project scheduling and Gantt Chart	5	15/05/17 08:00	**19/05/17 17:00**
End of Phase I	-	19/05/17 17:00	**19/05/17 17:00**
Phase II: Thesis development and writing	85	22/05/17 08:00	**15/09/17 17:00**
Introduction	15	22/05/17 08:00	**02/06/17 17:00**
Research Methodology	12	05/06/17 08:00	**16/06/17 17:00**
State-of-the-art	38	19/06/17 08:00	**14/07/17 17:00**
Application of Agile in Product Development	25	17/07/17 08:00	**04/08/17 17:00**
Results of data collection	11	07/08/17 08:00	**23/08/17 17:00**
Recommendations and conclusions	11	24/08/17 08:00	**06/09/17 17:00**
References	4	07/09/17 08:00	**15/09/17 17:00**
End of Phase II	-	15/09/17 17:00	**15/09/17 17:00**
Phase III: Preparation of the presentation	11	18/09/17 08:00	**02/10/17 17:00**
Revision	5	18/09/17 08:00	**22/09/17 17:00**
Correction	5	25/09/17 08:00	**29/09/17 17:00**
Printing and documentation submission	1	02/10/17 08:00	**02/10/17 17:00**
End of Phase III	**-**	**02/10/17 17:00**	**02/10/17 17:00**

The Gantt Chart of the project can be observed in the figure above:

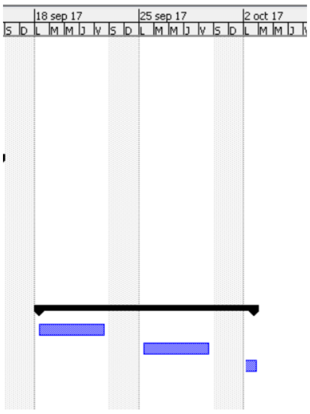
Phase I:



Phase II:



Phase III:



A4 – 2. Budget

In the final part the total cost is calculated. The following costs have been taken into account:

- Junior engineer rate 20,00 €/hour
- Advisor rate 60,00 €/hour

	Working Days	Hours student	Student costs (€)	Hours advisor	Advisor costs (€)	Total costs (€)
Phase I: Project Planning	**35**	**280**	**5.600,00 €**	**28**	**1.680,00 €**	**7.280,00 €**
Definition of the project	10	80	1.600,00 €	8	480,00 €	2.080,00 €
Definition of the topics and related literature	8	64	1.280,00 €	6,4	384,00 €	1.664,00 €
Definition of the objectives and actions	7	56	1.120,00 €	5,6	336,00 €	1.456,00 €
Definition of the research methodology	5	40	800,00 €	4	240,00 €	1.040,00 €
Project scheduling and Gantt Chart	5	40	800,00 €	4	240,00 €	1.040,00 €
Phase II: Thesis development and writing	**85**	**680**	**13.600,00 €**	**68**	**4.080,00 €**	**17.680,00 €**
Introduction	10	80	1.600,00 €	8	480,00 €	2.080,00 €
Research Methodology	10	80	1.600,00 €	8	480,00 €	2.080,00 €
State-of-the-art	20	160	3.200,00 €	16	960,00 €	4.160,00 €
Application of Agile in Product Development	15	120	2.400,00 €	12	720,00 €	3.120,00 €
Results of data collection	13	104	2.080,00 €	10,4	624,00 €	2.704,00 €
Recommendations and conclusions	10	80	1.600,00 €	8	480,00 €	2.080,00 €
References	7	56	1.120,00 €	5,6	336,00 €	1.456,00 €
Phase III: Preparation of the presentation	**11**	**88**	**1.760,00 €**	**8,8**	**528,00 €**	**2.288,00 €**
Revision	5	40	800,00 €	4	240,00 €	1.040,00 €
Correction	5	40	800,00 €	4	240,00 €	1.040,00 €
Printing	1	8	160,00 €	0,8	48,00 €	208,00 €
Total costs	131	1048	**20.960,00 €**	104,8	**6.288,00 €**	**27.248,00 €**

Finally, the total cost of the project is 27.248,00€.