FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO

Development and implementation of industrial methodology and processes for the production of Next-Cross products

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In partial fulfillment of the requirements for the degree of
Master of Science in the subject of
Mechanical Engineering

July 25, 2022

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Abstract

Urbanization, the increasing number of cars, and the lack of attention to traffic rules by drivers and pedestrians have led to an increase in traffic accidents involving pedestrians in recent years. According to World Health Organization, road traffic is the 8^{th} leading cause of death for all age groups, and it is also the leading cause of death for children and young adults aged 5-29 years. In this context, Pavnext, a technology startup that offers solutions to promote safer, smarter, and more sustainable cities, has been developing Next-Cross products, a set of solutions to promote greater pedestrian safety in cities, as well as real-time data monitoring for traffic management.

Next-Cross products are innovative solutions for road and crosswalk applications to make urban crossings safer. Starting with the Pedestrian Sensor, a component applied to the crosswalk that detects the presence of pedestrians and then controls a light application on the crosswalk, the LED Marker, which differently signals the presence of pedestrians near the crosswalk, effectively promoting their safety. Finally, there is a third component for vertical signs that improve their visibility at night, the LED Signal.

The Next-Cross *v.1* products, prototyped and tested in a pilot project in Matosinhos-Portugal, are highly dependent on post-processing and consist of a large number of components, which is not feasible for mass production. Therefore, several studies were conducted on the main parameters to be developed, based on theoretical principles (manufacturing process, industrial design, and material selection). The main objective of the project is the industrial development of solutions that can be manufactured on an industrial scale. To achieve this goal, several alternative solutions were developed in an iterative process, of which only the final solutions approved by the company are described in this dissertation. After the development of the final solutions, denominated Next-Cross *v.2*, a budgeting was performed. It is worth mentioning that the development of the industrial versions of the Next-Cross *v.2* products in this dissertation does not include the electronic part of the product.

With the development of Next-Cross *v.2* was possible to develop functional products by adopting new manufacturing processes that lead to components reduction, and lower unit cost of each product. In addition to the development, quality control methods have been defined for the Next-Cross *v.2* products and also for Pavnext. The expected product life cycle is shown, and the maintenance and end-of-life strategy for the products is explained.

Keywords: Road safety; Crosswalks; Next-Cross; Product development; Manufacturing processes; Sustainability.

Resumo

Urbanização, o número crescente de carros e a falta de atenção dos condutores e peões às regras de trânsito, tem levado à um aumento dos acidentes de trânsito envolvendo peões nos últimos anos. Segundo a Organização Mundial de Saúde, o tráfego rodoviário é a 8^a causa principal de morte para todas as idades, e é também a principal causa de morte de crianças e jovens adultos dos 5 aos 29 anos de idade. Neste contexto, a Pavnext, uma startup tecnológica que oferece soluções para promover cidades mais seguras, inteligentes e mais sustentáveis, tem vindo a desenvolver os produtos Next-Cross, um conjunto de soluções para promover uma maior segurança dos peões nas cidades, bem como a monitorização de dados em tempo real para a gestão do tráfego.

Os produtos Next-Cross são soluções inovadoras para aplicações em estradas e passadeiras para fazer as travessias urbanas mais seguras. Começando com o Sensor de Pedestres, um componente aplicado na passadeira que detecta a presença de peões e depois controla uma aplicação luminosa na faixa de pedestres, o Marcador LED, que assinala de forma diferenciada a presença de peões na faixa de pedestres, promovendo a sua segurança. Finalmente, existe um terceiro componente para melhorar a visibilidade da sinalização vertical à noite, o Sinal LED.

Os produtos Next-Cross *v.1*, prototipados e testados num projecto-piloto em Matosinhos-Portugal, são altamente dependentes do pós-processamento e consistem num grande número de componentes, o que não é viável para a produção em massa. Por conseguinte, foram realizados vários estudos sobre os principais parâmetros a desenvolver, com base em princípios teóricos (processo de fabrico, desenho industrial, e selecção de materiais). O principal objetivo do projeto é o desenvolvimento industrial de soluções que podem ser fabricadas à escala industrial. Para atingir este objetivo, foram desenvolvidas várias soluções alternativas em um processo iterativo, das quais apenas as soluções finais aprovadas pela empresa são descritas na presente dissertação. Após o desenvolvimento das soluções finais, denominadas Next-Cross *v.2*, foram efetuadas orçamentações. Vale a pena mencionar que o desenvolvimento das versões industriais dos produtos Next-Cross *v.2* nesta dissertação não inclui a parte electrónica do produto.

Com o desenvolvimento do Next-Cross *v.2* foi possível desenvolver produtos funcionais através da adoção de novos processos de fabrico que levam à redução de componentes e a um custo unitário mais baixo de cada produto. Para além do desenvolvimento, foram definidos métodos de controlo de qualidade para os produtos Next-Cross *v.2* e também para a Pavnext. O ciclo de vida esperado do produto é mostrado, e a estratégia de manutenção e de fim de vida dos produtos é explicada.

Palavras-chave: Segurança rodoviária; Passadeiras; Desenvolvimento de produto; Processos de fabrico; Sustentabilidade.

Dedicated to my parents,
Gisele and Aluísio

“Let the future tell the truth and evaluate each one according to
his work and accomplishments. The present is theirs;
the future, for which I really worked, is mine”

Nikola Tesla

Acknowledgments

The work developed for this dissertation could not been accomplished and concluded without the support of several people, to which I would like to express my gratitude.

First of all, I would like to express my gratitude to my supervisor Dr. Francisco Duarte. His experience, availability, creativity and empathy are some words I can highlight from his orientation. I will always be grateful for the opportunity to develop this project together with Pavnext.

I would like to express my gratitude to my supervisor Dr. Teresa Duarte, for all the availability, advice, and proposals suggested for the realization of this work. I would also like to thank for all the orientation during these years at FEUP.

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I would like to thank all the professors at FEUP, for all the teaching, availability and help during my academic journey. In the same manner, many thanks to my friends at FEUP, for all their help and support.

To my girlfriend Isadora, for sharing my enthusiasm with the realization of this project and for all the love, support and patience.

Finally, I would like to express gratitude to my family, for always being there and for the continuous motivation during all these years. I also express my profound and sincere gratitude to my parents Aluísio and Gisele, for the opportunity to pursue higher education abroad, but most of all for their, dedication, guidance and unconditional love.

For all, my sincere acknowledgments.
Júlio Varandas Pancracio

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Acronyms

3DP	3D printing
AM	Additive manufacturing
ASNR	*Autoridade Nacional de Segurança Rodoviária*
CAD	Computer-Aided Design
DFM	Design for Manufacturability
EMS	Environmental Management System
EOL	End-of-Life
EU	Europe Union
FFF	Fused Filament Fabrication
ID	Industrial Design
IMT	*Instituto da Mobilidade e dos Transportes*
IP	Ingress Protection
IK	Impact Rating
LCA	Life Cycle Analysis
LM	LED Marker
LM_p	LED Marker Profile
LM_{mf}	LED Marker Mounting Frame
LS	LED Signal
MRP	Material Resource Planning
NASA	National Aeronautics and Space Administration
PCB	Printed Circuit Board
PDCA	Plan-Do-Check-Act
PS	Pedestrian Sensor
PS_b	Pedestrian Sensor Box
PS_{mf}	Pedestrian Sensor Mounting Frame
QMS	Quality Management System
TOC	Theory of Constraints
TRL	Technology Readiness Levels
UN	United Nations
UPTEC	*Parque de Ciência e Tecnologia da Universidade do Porto*
WHO	World Health Organization

Chapter 1

Introduction

1.1 Contextualization

Urbanization, the increasing number of cars, and the lack of attention to traffic rules by drivers and pedestrians has led to an increase in traffic accidents involving pedestrians in recent years. According to WHO (World Health Organization), road traffic is the 8^{th} leading cause of death for all age groups, and it is also the leading cause of death for children and young adults aged 5-29 years (WHO, 2018). In 2007, urban and rural populations were almost exactly the same, with 3.33 billion people each. According to estimates from UN (United Nations), 55% of people live in urban areas today and this number is projected to increase to nearly 68% by 2050 (Ritchie and Roser, 2018), leading to a global urbanization, which will conduct to a further increase in pedestrian accidents if cities do not change.

Urban development has led to a paradigm shift in the 21^{st} century, and research activities for smarter cities have become a priority task, directly involving industrial and political institutions, experts, and the scientific community. Although information technology and communications have advanced exponentially, and smart cities become a reality, this concept is still under development. A city's intelligence is derived from the set of physical and legal infrastructures that support economic development, ensure social inclusion, safety and provide environmental protection (Eremia et al., 2017). Figure 1.1 illustrates the key characteristics of a city and the tools available to transform a city into a smart city.

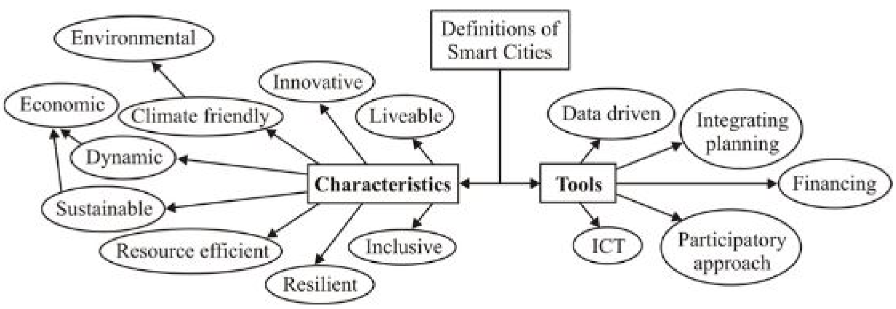


Figure 1.1: Characteristics and tools used to define the Smart City (Eremia et al., 2017)

1.2 Pavnext

Pavnext is a technological startup based at UPTEC - *Parque de Ciência e Tecnologia da Universidade do Porto* that offers solutions to promote safer, smarter and more sustainable cities. Pavnext's main goal is to develop innovative solutions (products and services) that contribute to the improvement of human health and environmental quality.

Currently, the company has two main products:

- **Next-Road** — a device installed on the road surface capable of extracting kinetic energy from vehicles and converting it into electrical energy for various applications, and real-time traffic monitoring;
- **Next-Cross** — devices installed at crosswalks that can warn drivers, illuminate the crossing, and monitor crosswalk use in real time.

After this brief introduction of the company, the next section aims to explain in detail the state of the art of the Next-Cross products.

1.3 Next-Cross Products

Next-Cross products, represented in Figure 1.2, are innovative solutions for application in urban crosswalks, in order to make the crossing safer. This is achieved by sensors installed at the beginning of each side of the crosswalk, the Pedestrian Sensor (**A**). They detect the presence of pedestrians and activate a crossing protocol that controls a light application on the roadway, the LED Marker (**B**), that differentially signals the presence of pedestrians in the crosswalk, effectively promoting their safety. It also consists of a third device, called LED Signal (**C**), that is attached to traffic signs to increase their visibility and monitor the movement in real time.

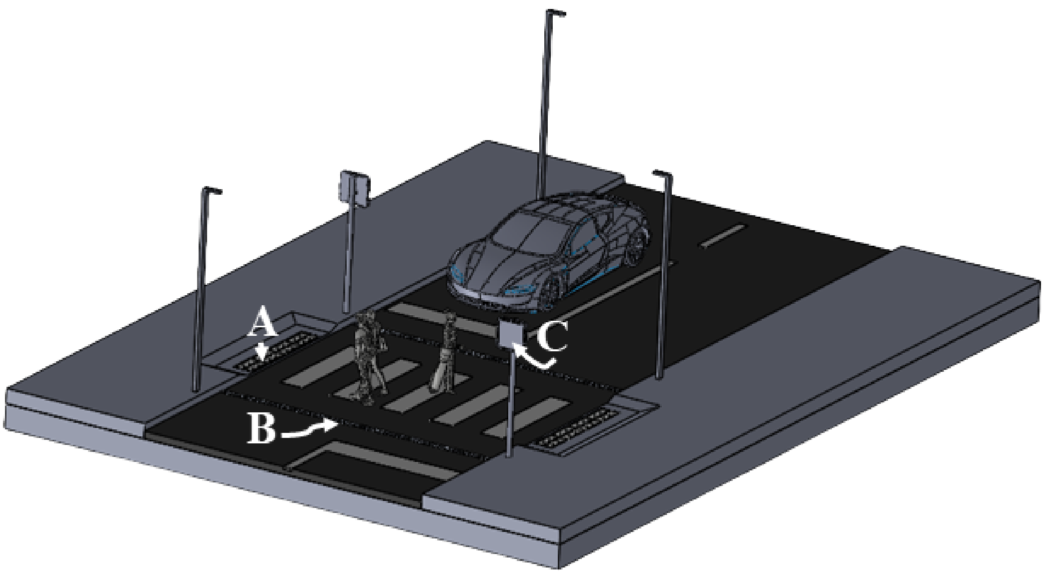


Figure 1.2: Next-Cross products

The following subsection intends to explain the TRL (Technology Readiness Level) scale of product evaluation to clarify the reader about the state-of-the-art maturity of Next-Cross products.

1.3.1 TRL scale

Originally developed by NASA (National Aeronautics and Space Administration) in the 90s for space technologies, TRL scale are a type of measurement system used to assess the maturity level of a particular technology. TRL are based on a scale from 1 to 9, being TRL 9 the most mature technology.

Over time, many organizations such as the EU (European Union) have made adaptations to facilitate the application of the TRL scale in other industrial sectors. In Figure 1.3 the NASA (NASA, 2012) and EU (EU, 2014) definitions for the TRL scale can be analyzed.

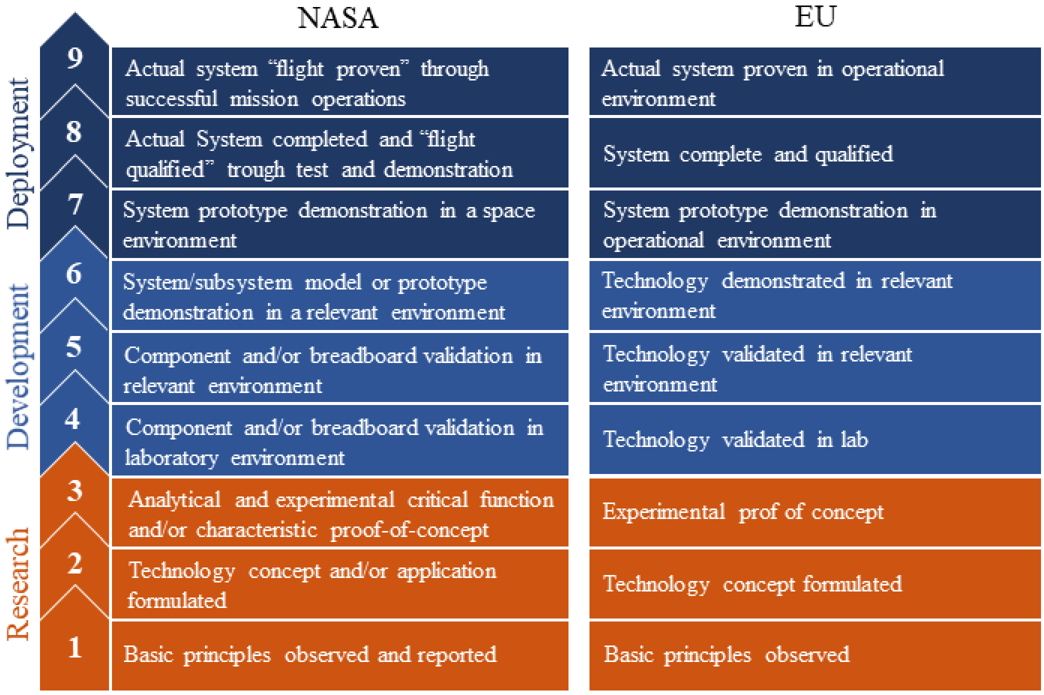


Figure 1.3: TRL scale from NASA and EU. Adapted from: (NASA, 2012), (EU, 2014)

1.3.2 Pedestrian sensor

The PS (Pedestrian Sensor) is installed at the entrances of crosswalks and aims to detect a pedestrian and initiate a safety protocol for crossing. The sensor also collects information such as quantity, speed, and direction of travel to support public agencies in urban planning.

The state-of-the-art, PS *v.1* is at level 7 on the TRL scale, having been tested in an operational environment in Matosinhos. The prototype tested was built from laser cutting, machining and 3D printing. Figure 1.4 shows the pedestrian sensor *v.1*, this component is 600 mm long, 400 mm wide and 35 mm high.

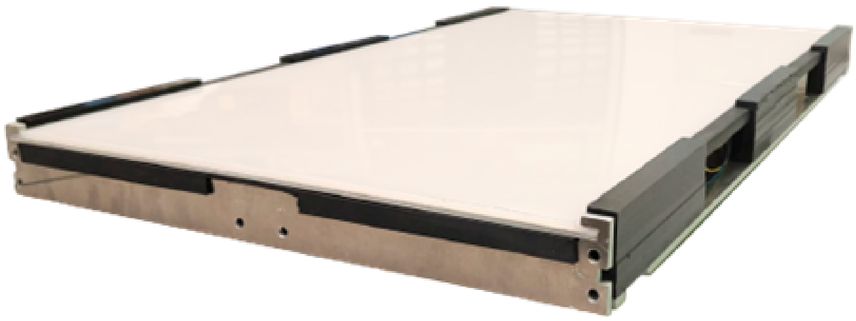


Figure 1.4: Isometric view of PS *v.1*

This component must meet the following requirements:

- **A** — Water resistance;
- **B** — Impact resistant;
- **C** — Support successive pedestrian crossings (1.000 N).
- **D** — Support rare passages of a vehicle wheel (10.000 N).

1.3.3 LED Marker

The LM (LED marker) is installed along the road surface. Its function is to signal more efficiently the presence of a pedestrian in the crosswalk. It also collects data about the number of vehicles in the area.

The state-of-the-art, named LM *v.1* is at level 7 on the TRL scale, having been tested in an operational environment. The prototype tested was built by extrusion. Figure 1.5 shows the LM *v.1*, this component installed on city streets is 485 mm long, 140 mm wide, and 85 mm high.

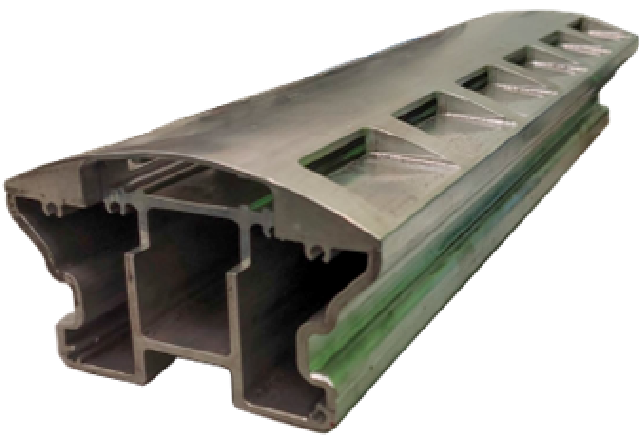


Figure 1.5: Isometric view of LM *v.1*

This component must meet the following requirements:

- **A** — Water resistance;
- **B** — Impact resistant;
- **C** — Support successive vehicle passages (20.000 N);
- **D** — Support occasional heavy vehicles passages (300.000 N).

1.3.4 LED Signal

The LS (LED Signal) is installed in traffic signs and aims to illuminate the sign in the presence of a pedestrian in the crosswalk and also to collect data of the movement.

The state-of-the-art, named LS *v.1* is at level 2 on the TRL scale, having only developed the concept of the technology in SolidWorks. Figure 1.6 shows the LS *v.1*. This component is 80 mm long, 605 mm wide, and 600 mm high.

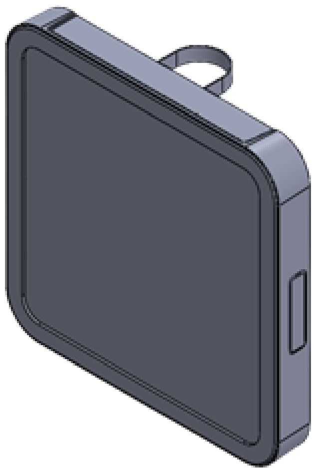


Figure 1.6: Isometric view of LS *v.1*

This component must meet the following requirements:

- **A** — Water resistance.

1.4 Objectives

In order to increase pedestrian safety and reduce the number of accidents in cities, this dissertation aims the industrial development of Next-Cross products by the Portuguese startup Pavnext, following the principles of Smart Cities.

The main objectives of the project include:

1. Literature review of the different existing solutions;

2. Study of materials and industrial processes with potential practical application in the components of the NEXT-Cross products;
3. The state of the art of Next-Cross products and study of the Pavnext pilot project;
4. Development of methodology and industrial processes for the production of Next-Cross products, including material selection;
5. Economic study of the developed solution, with a view to mass production of the NEXT-Cross product;
6. Study and definition of methods for product quality control, as well as product life cycle, end-of-life and recycling, including a product sustainability analysis.

1.5 Work plan

The work planning was structured in the following phases:

- **1st task** — Characterization of the Next-Cross design, with identification and definition of all mechanical design elements, materials, and expected performance of the elements individually and in assembly;
- **2nd task** — Study of materials and industrial processes with potential practical application in the components of the Next-Cross project;
- **3th task** — Development of methodology and industrial processes for the production of Next-Cross products, including material selection;
- **4th task** — Economic study of the developed solution, with a view to mass production of the Next-Cross product;
- **5th task** — Study and definition of methods for product quality control, as well as product life cycle, end-of-life and recycling, including a product sustainability analysis;
- **6th task** — Writing of the master's dissertation.

1.6 Dissertation Structure

In addition to the introduction, this dissertation contains another 6 chapters. Chapter 2 describes the bibliographic study of potential industrial processes for application in Next-Cross products, as well as an analysis of existing solutions. Chapter 3 perform the state of the art of each product, in conjunction with an analysis of the Pavnext pilot project. Chapter 4 describes in detail the development of each Next-Cross product. Chapter 5 expose the overall economic analysis of the developed solutions. Chapter 6 pose the methods used to control product quality, along with the product life cycle, end of life, and recycling. Finally, Chapter 7 presents the conclusions and future works of this dissertation.

Chapter 2

Literature review

This chapter presents the bibliographic research that served as basis for the development of this dissertation.

2.1 Introduction

The industrial development process of a product is the sequence of steps that must be followed to design, develop, and market a product. Accordingly, the next subsections address the relevant issues in the development of Next-Cross products, namely industrial design, standards, manufacturing processes, material selection, and product sustainability.

2.2 Industrial design

The design concept involves the implementation of an idea in the form of projects or models that, through construction and configuration, result in an industrial product that can be mass produced (Löbah, 2001).

In other hand, ID (Industrial Design) can be defined as the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer (Ulrich and Eppinger, 2015).

The outcome of an industrial product is primarily determined by the properties of the raw materials, the associated manufacturing processes and environmental issues, as well as organizational aspects and the behavior of competitors.

The benefits of using ID include increased product appeal and customer satisfaction through additional or better features, strong brand identity, and product differentiation. These benefits typically translate into a price premium and/or increased market share (Ulrich and Eppinger, 2015).

2.2.1 Industrial products classification

All industrial products are consumer goods, they become the property of the user at a certain point in time, are used and then discarded, thus creating a cycle of consumption. All industrial products are also capital goods, because each product requires a certain amount of capital to be acquired (Lӧbah, 2001).

A fundamental starting point for the classification of industrial products is the fact that these products have a function to perform in their consumption cycle. Therefore, it is important to study the intensity and nature of interactions between users and industrial products, especially during use (Lӧbah, 2001).

Therefore, according to (Lӧbah, 2001), it is important to observe how the product is used, what meaning and value it has for the user, how many people use it, and whether the product is used as private or collective property. Considering the types of relationships established by the author, it is possible to classify the products into:

A — Direct consumption;

B — Indirect consumption;

C — Individual products;

D — Collective products.

In this way, Next-Cross products stands in the category of indirect consumption products, i.e., they are products that remain hidden, such as ball bearings, turbines for power generation, motor rotors, etc. There is no direct use by the consumer. These products initially have useful functions and are often part of larger projects. The configuration of these elements is determined by their practical purpose and attention is paid to their design (Lӧbah, 2001).

2.2.2 Concept development

The concept development phase is an iterative process of identifying the customer, competing products, target specifications, creating product concepts, selecting the final concept(s), establishing final specifications, testing the concept(s), performing an economic analysis, and planning the remaining project activities (Ulrich and Eppinger, 2015).

According to (Lӧbah, 2001), the creative process of concept development can be divided into four phases, namely:

1. Problem analysis;
2. Generation of alternative concept;
3. Concept evaluation;
4. Solution materialization.

2.2.3 Process Planning

Process planning aims to select manufacturing processes and sequences to convert an object from its initial shape to its final form, based on a predefined engineering drawing, as is summarized in Figure 2.1.

Process plans for manufacturing a complex part may include several feasible alternatives. Therefore, it is critical to evaluate the quality of a process plan from both a technological and economic perspective. A valid plan not only ensures the required quality of the manufactured parts, but also reduces production costs (Zijm et al., 2018).

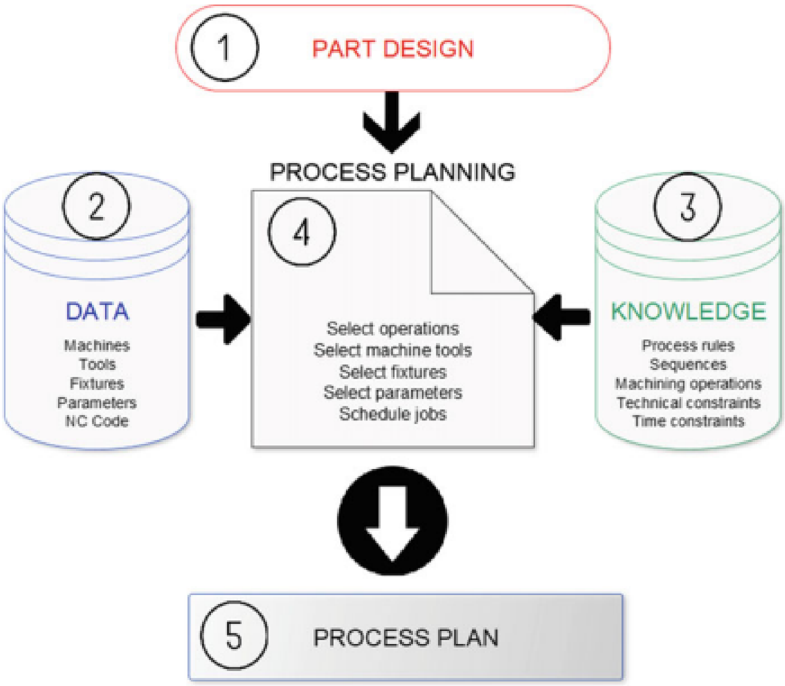


Figure 2.1: Process planning (Zijm et al., 2018)

2.3 Product Standards

In order to establish the requirements for Next-Cross products, it was sought to understand what standards such products must meet.

2.3.1 Ingress Protection Code

The IP code (Ingress Protection Code) is a coding system used to indicate the degree of protection that an enclosure provides against access to hazardous parts, ingress of solid objects, and/or ingress of water according to the IEC 60529 standard (IEC, 2013).

The code is characterized by the letters IP followed by two numbers and two letters (optional) according to Table 2.1.

Table 2.1: Elements of IP code and their meanings (IEC, 2013)

Element	Numerals or letters	Meaning for the protection of equipment	Meaning for the protection of persons
Code letters	IP	–	–
First characteristic numeral		Against ingress of solid foreign objects	Against access to hazardous parts
	0	non-protected	non-protected
	1	≥ 50 mm diameter	back of hand
	2	≥ 12,5 mm diameter	finger
	3	≥ 2,5 mm diameter	tool
	4	≥ 1,0 mm diameter	wire
	5	dust-protected	wire
	6	dust-tight	wire
Second characteristic numeral		Against ingress of water with harmful effects	–
	0	non-protected	
	1	vertically dripping	
	2	dripping (15" tilted)	
	3	spraying	
	4	splashing	
	5	jetting	
	6	powerful jetting	
	7	temporary immersion	
	8	continuous immersion	
	9	high pressure and temperature water jet	
Additional letter (optional)		–	Against access to hazardous parts with:
	A		back of hand
	B		finger
	C		tool
	D		wire
Supplementary letter (optional)		Supplementary information specific to:	–
	H	high voltage apparatus	
	M	motion during water jet	
	S	stationary during water test	
	W	weather conditions	

2.3.2 Impact Protection Rating

The IK Code (Impact Rating Code) is an international numerical classification for the degree of protection that electrical equipment enclosures provide against external mechanical impact according to the IEC 62262 (2002) standards (Schnautz, nd).

The code is characterized by the letters IK followed by two numbers, ranging from 00 to 10. Each value represents a certain resistance to mechanical impact in joules [J], as can be seen in Table 2.2.

Table 2.2: Classification of impact energy (Schnautz, nd)

IK code	IK00	IK01	IK02	IK03	IK04	IK05	IK06	IK07	IK08	IK09	IK10
Impact energy, J	a)	0.14	0.2	0.35	0.5	0.7	1	2	5	10	20
a) Not protected under this standard											

2.3.3 Crosswalk standards

According to ASNR (*Autoridade Nacional de Segurança Rodoviária*), urban crosswalks have two designations. The first one, designated M11, consists of longitudinal bars running parallel to the track axis and alternating at regular intervals, or two continuous transverse lines indicating where pedestrians should cross the tracks. The second, designated M11a, is an extension and may be used eventually and only if the crossing is controlled by light signals (ANSR, 2019).

On (ANSR, 2019), it is also possible to analyze the standard dimensions at the crosswalks, as can be seen in Figure 2.2.

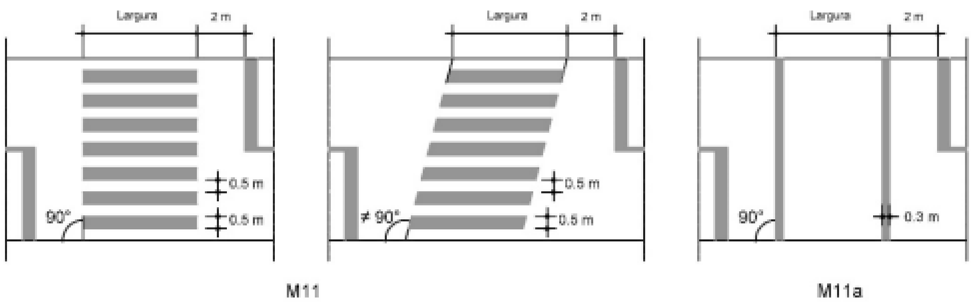


Figure 2.2: Crosswalks dimensions (ANSR, 2019)

2.3.4 Speed Bump standards

Although LM *v.1*, does not have the same functionality as a speed bump, it has a similar shape. Therefore, the technical standards for this element have been analyzed.

The ASNR defines a speed bump as a non-temporary elevation built across the full width of the roadway. It is intended to cause inconvenience to vehicle occupants when they cross the roadway at speeds higher than the recommended speed, but should not cause major inconvenience or damage to the vehicle at speeds equal to or lower than the recommended speed (ANSR, 2007).

Moreover, ASNR establishes some technical data for speed bumps in (ANSR, 2007). This element must have a minimum length of 900 mm, their height must not be less than 25 mm or exceed 75 mm, a vertical surface of the speed bump must not be more than 6 mm high, and the ramps of the speed bump profile must have a maximum slope that depends on the road on which they are installed.

In Figure 2.3, can be analyzed the dimensions for the speed bump similar to the LM *v.1*.

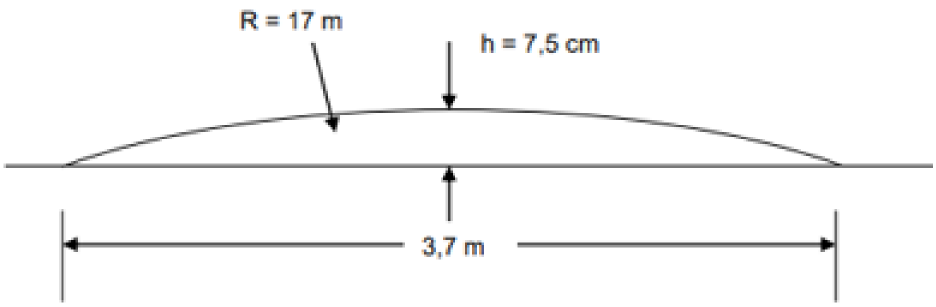


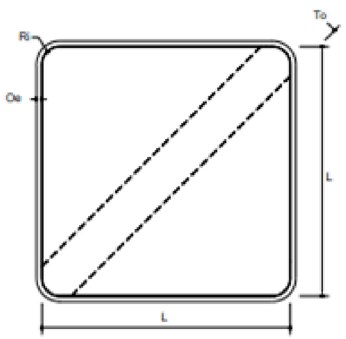
Figure 2.3: Speed bump dimensions (ANSR, 2007)

2.3.5 Vertical Signaling Standards

Since the LED Signal is installed on traffic signs, it was studied which standards apply to traffic signs regarding their dimensions.

According to IMT (*Instituto da Mobilidade e dos Transportes*), vertical signs are signs that, by virtue of their location, shape, color, type, and also through symbols and/or alphanumeric characters, convey a visual message with a specific meaning to drivers (IMT, 2018).

In the document (IMT, 2018) it was possible to analyze the available dimensions for the vertical signal H7 (pedestrian crossing) represented in Figure 2.4



Signals B6, H1a a H8b, H33, H36, H37 e H40

Dim.	Small	Normal		Big
L	600,0	700,0	900,0	1150,0
Oe	10,0	20,0	20,0	50,0
To	100,0	116,7	150,0	191,7
Ri	42,9	50,0	64,3	82,1

Figure 2.4: Dimensions for the vertical signal H7 (IMT, 2018)

2.4 Market Analysis

To better understand the signaling systems currently employed at urban crosswalks, a market analysis was conducted.

2.4.1 Pelican crossing

Pelican crossing are often used on streets with high traffic volumes, high approach speeds, or very high pedestrian flow. This type of crosswalk has a signal request button on the traffic signal pole, as shown in Figure 2.5. When pressed by a pedestrian, displays the message "wait", the red signal on the other side of the crosswalk changes to a green signal to indicate to the pedestrian that it is safe to cross the street, and a red light is shown to traffic (Martin, 2006).

Figure 2.5: Pelican crossing. Adapted from: (Startrescue, 2021)

2.4.2 Puffin Crossing

Puffin crossing aims to reduce vehicle delays and improve pedestrians' sense of security while crossing the road. At a Puffin crossing, the light indicator is located above the push button on the upstream signal pole (rather than across the street as on a Pelican), as can be seen in Figure 2.6. Puffin detects pedestrians in the crosswalk and adjusts the length of the red phase for vehicles (Martin, 2006).

Figure 2.6: Puffin crossing. Adapted from: (Wikipedia, 2022)

2.4.3 Countdown Devices

The idea of the countdown device is to improve crossing by providing information to pedestrians at crosswalks by displaying the remaining time of the pedestrian crossing phase, as shown in Figure 2.7 a). In this type of device the pedestrian also indicates his presence from a device fixed on the pole opposite to the countdown device, Figure 2.7 b) (Martin, 2006).

Figure 2.7: Countdown device

2.4.4 Light Warning Devices

These devices are installed along the crosswalk or even in the traffic signs to alert drivers of the existence of the crosswalk. Also, they can include a solar energy generation component, contributing to the sustainability of the site.

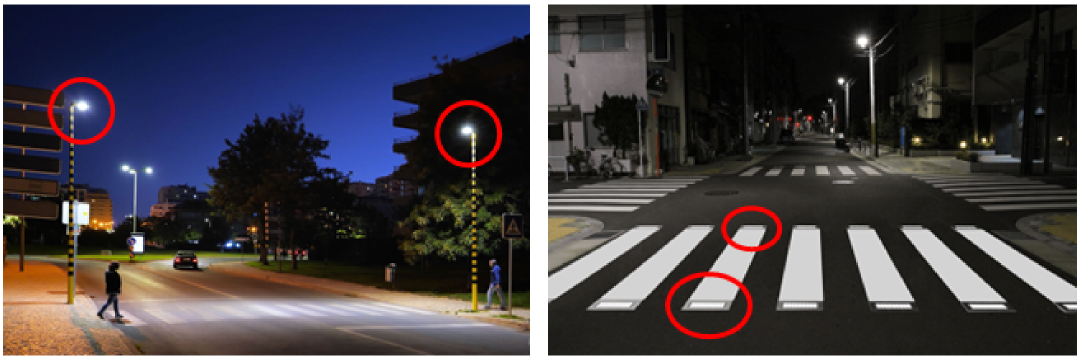
In Portugal, the use of such technologies can be observed as, for example, in small LED markers placed interspersed along the roadway, or in LED warning signs. These two technologies can be seen in Figure 2.8.

Figure 2.8: Light warning devices

2.4.5 Constant Light Devices

These devices are designed to increase the visibility of the location and/or the crossing path. To this end, they use constant LED's instead of flashing, as in subsection 2.4.4.

Figure 2.9 shows in a) the NEOS LED intelligent lighting system for crosswalks installed in Portimão. The system consists of a column painted with yellow and black stripes and a LED spotlight at the top (Schreder, 2021). In b) can be seen the SR-CROSSLED-S marker with pilot project installed in Braga (Arminas, 2021).



a) b)

Figure 2.9: Constant light devices. a) NEOS LED; b) Sernis SR-CROSSLED-S. Adapted from: (Schreder, 2021), (Arminas, 2021)

2.4.6 Presence Sensing Devices

These devices use sensors to detect the presence of pedestrians at the entrance to crosswalks and send the signal to the on-site warning light system. In Figure 2.10 can be seen a device that detects pedestrians by the company Soltráfego in Portugal.

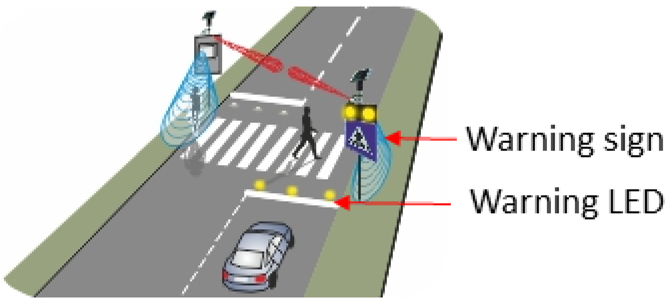


Figure 2.10: Presence sensing device. Adapted from: (Soltráfego, 2019)

2.5 Manufacturing processes

2.5.1 Extrusion

Extrusion is a compression process in which the working material is forced to flow through a die in order to produce a desired cross-sectional shape. A wide variety of shapes with fairly close tolerances can be obtained by this manufacturing process, and little or no material is wasted. However, this process requires the cross-section of the extruded part to be uniform along its entire length (Groover, 2010). Figure 2.11 shows the direct (forward) and indirect (backward) extrusion process. This process was used to obtain the LED Marker *v.1* profile.

Although extrusion is commonly considered a high production process, it is surprisingly advantageous and should not be ruled out for small batch or even prototype production (Bralla, 1998).

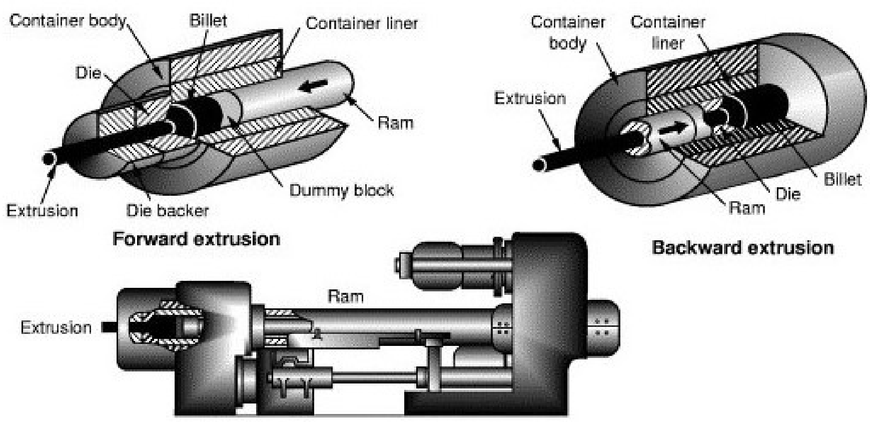


Figure 2.11: Extrusion process. Adapted from: (Swift and Booker, 2003)

2.5.2 Machining

Machining is the most versatile and accurate of all manufacturing processes in its capability to produce a diversity of part geometries and geometric features. Machining processes are characterized by material removal processes. The basic principle of all their variants is to start from a block of raw material and remove material to produce the desired final geometry. This processes can be divided into conventional (e.g. milling, turning, and drilling) and unconventional (e.g. electrical discharge machining, laser cutting, and beam cutting) (Groover, 2010). Figure 2.12 shows one of the conventional types of machining, the milling process used in the Next-Cross prototypes.

Machined parts are universally used in industrial and consumer products. They are found in applications where precision is required. When high dimensional accuracy is not required, stamping or casting are more economical processes. However, when surface finish, flatness, roundness, circularity, parallelism or accuracy of fit are required, machining of the part is virtually always necessary (Bralla, 1998).

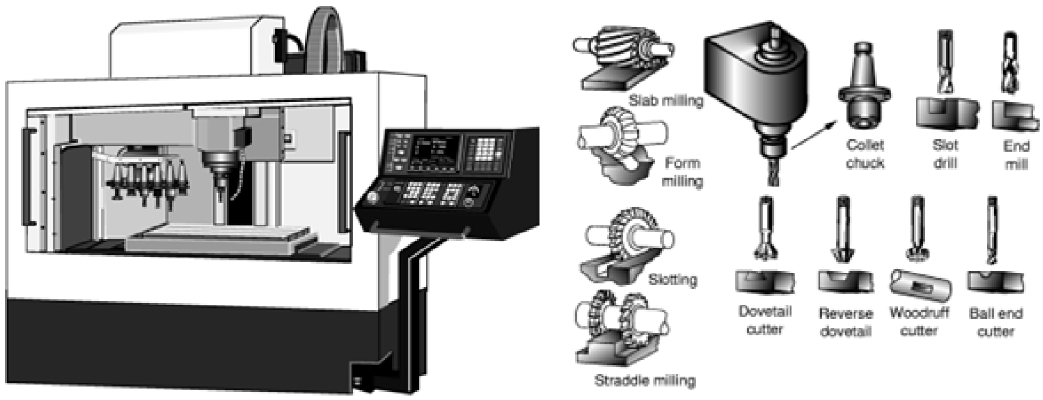


Figure 2.12: Milling process. Adapted from: (Swift and Booker, 2003)

2.5.3 Casting

Casting is a process in which molten metal flows by gravity or other force into a mold where it solidifies in the shape of the mold cavity. This process can be used to produce parts with complex geometries *net shape* or *near net shape*. Very large parts can be made by this process, and any metal that can be heated to a liquid state can be used. Also, some casting processes are well suited for mass production (Groover, 2010). Today, there are various casting processes such as sand casting, gravity die casting, pressure die casting, investment casting, etc. Figure 2.13 illustrates a pressure die casting process.

This process was not used in the production of the prototypes of the Next-Cross products. However, it could be interesting to use this process, such as in the Pedestrian Sensor or LED Marker.

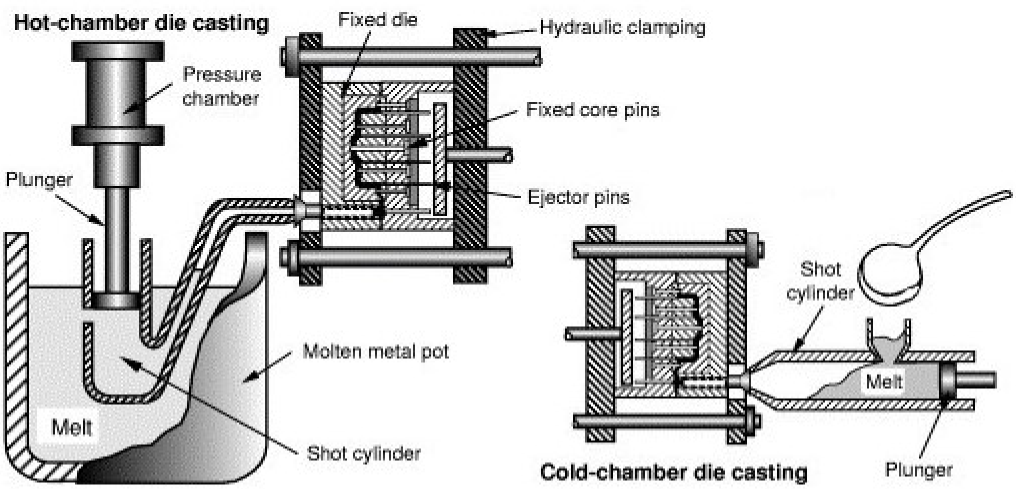


Figure 2.13: Pressure die process. Adapted from: (Swift and Booker, 2003)

2.5.4 Injection Molding

Injection molding is a process in which a polymer is heated to a highly plastic state and flows under high pressure into a mold cavity, where it solidifies and produces discrete components that almost always have a net shape (Groover, 2010).

Most injection molding processes includes plastification, injection, packing, cooling, and ejection stages. Cycle time are usually in the range of 10 to 30 seconds, although cycles of 1 minute or more are not uncommon for large parts (Kazmer, 2016).

Figure 2.14 shows the process of injection molding. This process could be interesting for manufacturing the components of the Pedestrian Sensor and the LED Signal.

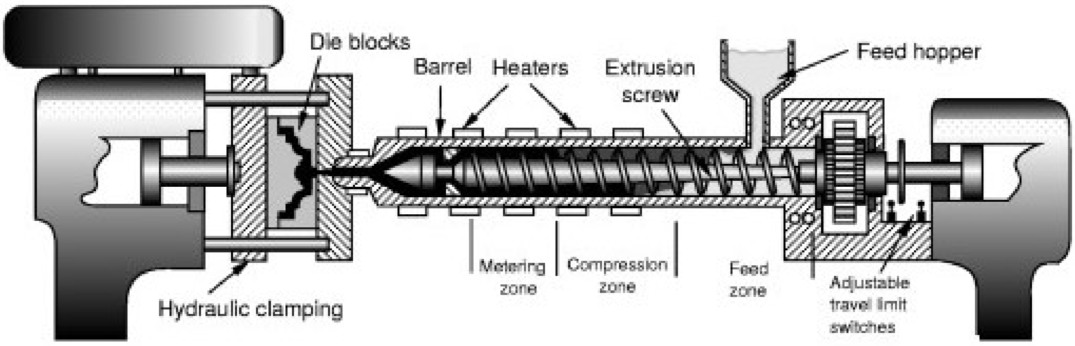


Figure 2.14: Injection molding process. Adapted from: (Swift and Booker, 2003)

2.5.5 Additive Manufacturing

Additive manufacturing (AM), broadly known as 3DP, is the construction of a three-dimensional object from a digital model. The term *3D printing* can refer to a variety of processes in which material is deposited under computer control to create a three-dimensional object, using for the formation of each layer, materials such as plastics, liquids, or melted powdered grains. AM allows the fabrication of very complex geometries and has been widely applied in different industries, including construction, prototyping and biomechanical (Ngo et al., 2018).

The Figure 2.15 represents the AM process. Next-Cross products have used FFF (Fused Filament Fabrication) technology for prototyping, and this technology may still be of interest for making small components for the final solution.

Figure 2.15: Additive manufacturing process. Adapted from: (Ambrosi and Pumera, 2016)

2.5.6 Welding

Welding is a material joining process in which two or more parts are coalesced at their contact surfaces by an appropriate application of heat and/or pressure. In some welding processes a filler material is also added to facilitate coalescence (Groover, 2010).

This process is usually the most economical way to join components when it comes to material consumption and fabrication costs, creating a permanent joint where the parts become one unit. The welded joint can be stronger than the parent materials if a filler metal is used whose strength properties exceed those of the parent materials and if proper welding techniques are used (Groover, 2010).

According to (Groover, 2010), the welding process can be divided in fusion welding and solid-state welding. In fusion welding, base metals are melted by heat. In many fusion welding processes, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint. Conversely, solid-state welding refers to joining processes in which no filler metal is used and coalescence results from application of pressure or a combination of heat and pressure.

This process can be useful for example for the Pedestrian Sensor. Figure 2.16 shows an example of welding, the metal inert gas (MIG) arc welding process (fusion welding).

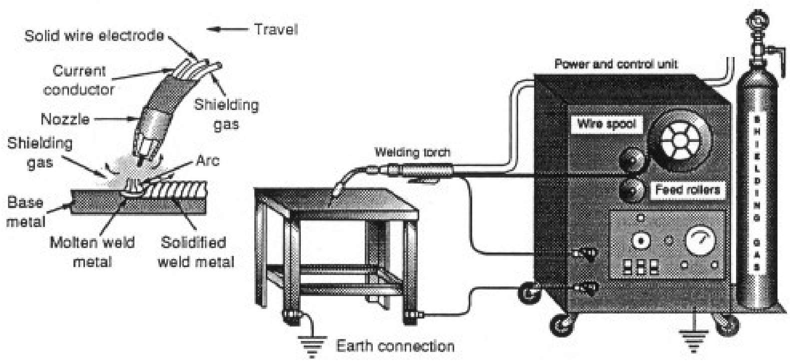


Figure 2.16: Metal inert-gas welding process. Adapted from: (Swift and Booker, 2003)

2.6 Material selection

Materials affect both the appearance and mechanical properties of a product. Therefore, one of the most important stages in the development of a product is the proper selection of materials.

Currently, there are more than 160,000 materials available to engineers. Although standardization is attempting to reduce this number, the constant emergence of other materials with new and usable properties is expanding the possibilities even further. As can be seen in Figure 2.17, the material selection process involves an interaction between function, material, form, and process. (Ashby, 2010).

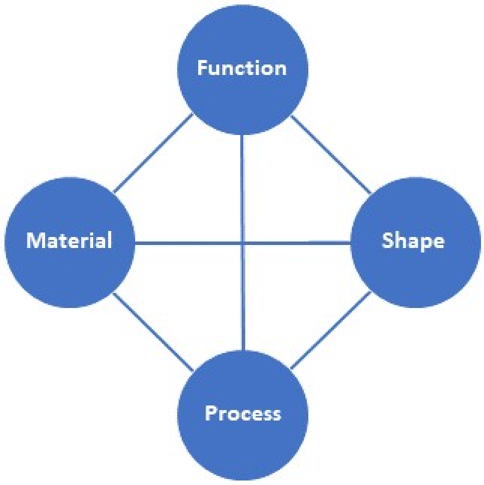


Figure 2.17: Material selection interaction. Adapted from: (Ashby, 2010)

Materials used in engineering can be divided into six categories, as represented in Figure 2.18 . Members of a category share certain characteristics, such as similar properties, similar manufacturing processes, and often similar applications (Ashby, 2010).

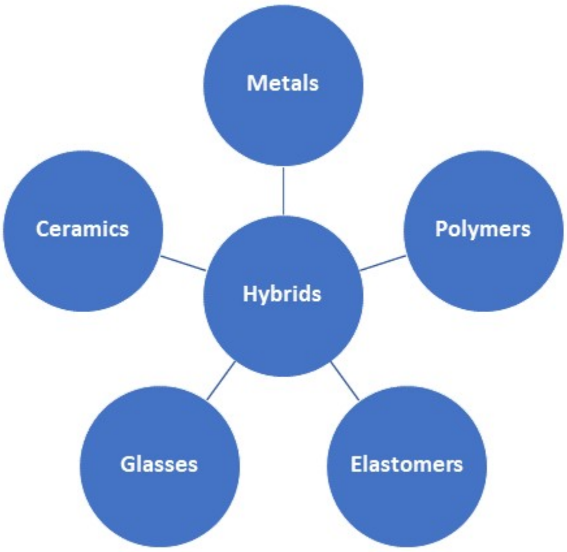


Figure 2.18: Categories of engineering materials. Adapted from: (Ashby, 2010)

In order to meet the expected requirements, materials must be selected according to their properties. Correspondingly, the properties studied for material selection in this dissertation are physical, mechanical, chemical, electrical and thermal.

For the evaluation and selection of the materials, the Ansys (CES) Granta Edupack 2022 software was used. This software contains an extensive database with information about the materials, their properties, and their costs.

2.7 Assembly Line

The production line is the step-by-step development from the conception of a product. In this process may occur various steps, such as assembly, quality control, packaging and others. The goal of a production line is to produce a particular product as efficiently and cost-effectively as possible without compromising the quality of the product. A production line can take different forms depending on different aspects, such as (Jacobs et al., 2011):

- Batch size;
- Custom manufacturing;
- Production order;
- Production planning and demand.

Several studies and methodologies have been developed on this subject, among which it can be a highlight, for example, MRP (Material Resource Planning), TOC (Theory of Constraints), Six Sigma, Lean Manufacturing, etc. However, these studies will not be addressed, as they do not fit the core development of this dissertation.

2.8 Product Sustainability

All human activities have some impact on the environment, which has a limited capacity to cope with it. It is clear that current human activities are crossing this threshold, reducing the quality of the world and threatening the well-being of future generations (Ashby, 2010).

The manufacture and use of products and their associated consumption of materials and energy are among the culprits (Ashby, 2010). In such manner, engineers and designers have been trying to create alternatives for product development in order to achieve greater sustainability as:

- **Design for the environment** — Interpreted as an effort to adapt our current design methods to correct known, measurable environmental damage, with a time scale of 10 years average product life;
- **Design for sustainability** — It meets present needs without compromising the needs of future generations. The time scale is measured in decades or centuries. Apart from the fact that adaptation takes much longer, reaching such a level requires social and political changes in addition to product development.

Life-cycle engineering design has emerged as an extension of DFM (Design for Manufacturability), covering not only manufacturability but also issues related to the entire product life-cycle represented in Figure 2.19 (Y.Asiedu and Gu, 1998).

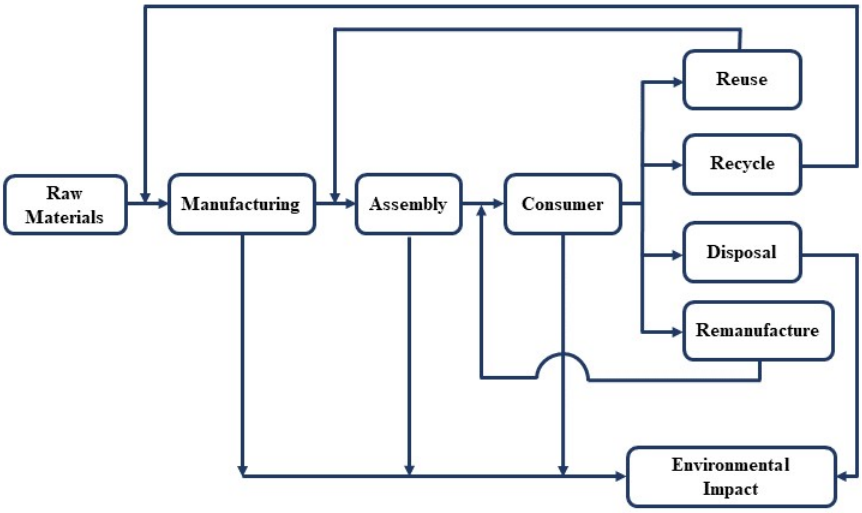


Figure 2.19: Product life cycle and recycling. Adapted from: (Y.Asiedu and Gu, 1998)

Life-cycle engineering aims to maximize a product's contribution to society while minimizing costs to the manufacturer, the user, and the environment (Y.Asiedu and Gu, 1998).

LCA (Life Cycle Analysis), also known as life cycle assessment, is a comprehensive method for evaluating all direct and indirect environmental impacts over the entire life cycle of a product system, from material procurement through manufacturing and use to final disposal (disposal or reuse) (Hill, 2013).

In this way, the development of Next-Cross products will take into account the overall sustainability of the components, so that it will be possible to reuse the products at the end of their life and create a cycle similar to that represented in Figure 2.20.

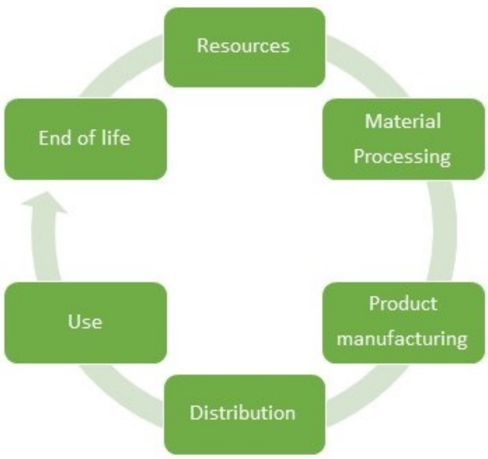


Figure 2.20: Product sustainability. Adapted from (Hill, 2013)

Chapter 3

Next-Cross *v.1* – Review

The objectives of this chapter are the functional and economic analysis of the Next-Cross *v.1* products and the observation and study of the pilot project for the purpose of product optimization.

It is worth mentioning that the economic analysis was based on the BOM (Bill of Materials) of the Pavnext pilot project in Matosinhos, Portugal. The BOM of the PS *v.1* and LM *v.1* can be found in Appendix A.

In the analysis of the three Next-Cross products, the components were divided into two categories, these being:

- **Standard** — components purchased from suppliers;
- **Manufactured** — custom-made components by manufacturing processes.

3.1 Pedestrian Sensor *v.1*

As mentioned in subsection 1.3.2, the Pedestrian Sensor is installed at the entrances of crosswalks and aims to detect a pedestrian and initiate a safety protocol for crossing. For better understanding, a new nomenclature will be adopted for the PS *v.1*. The unit has been divided into two components, the PS_b (Pedestrian Sensor Box) and the PS_{mf} (Pedestrian Sensor Mounting Frame). The product unit assembly consists of 3 PSb and 1 PSmf, as shown in Figure 3.1.

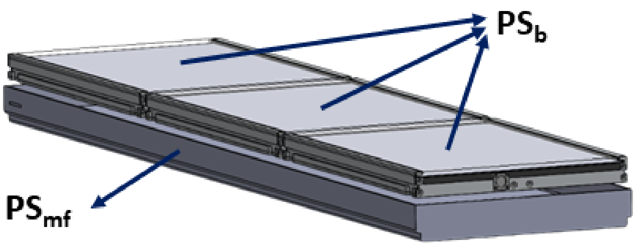


Figure 3.1: Pedestrian Sensor *v.1* $(3 \times PS_b + 1 \times PS_{mf})$

Looking at Figure 3.2, in a) can be seen the exterior design of the product, while in b) it is possible to observe the interior components of the PS_b *v.1*.

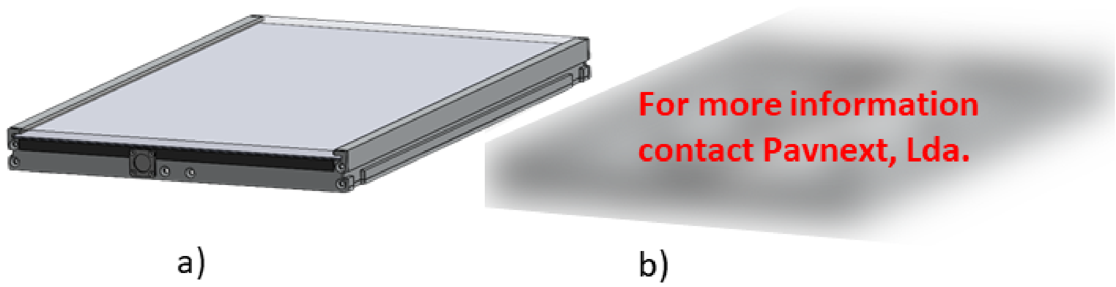


Figure 3.2: Pedestrian Sensor box (PS_b): a) External view; b) Internal view

In the exploded view shown in the Figure 3.3, it is possible to analyze all the components in the PS_b *v.1*. This version contains a total of 17 references, which add up to a total of 64 components.

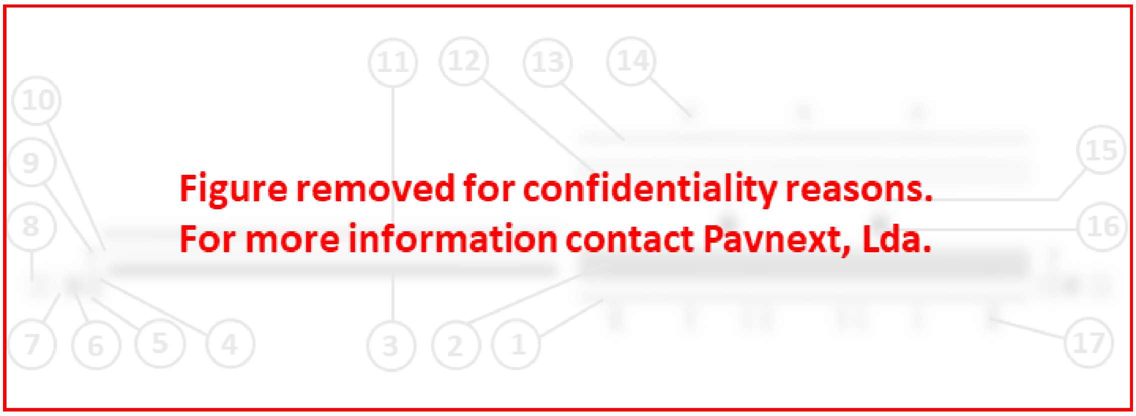


Figure 3.3: Exploded view of PS_b *v.1*. 1) Base; 2) Lateral; 3) Lateral rubber; 4) Sponge seal ring; 5) Side cover; 6) Higo connector; 7) M3x5 Screw; 8) M5x12 Screw; 9) Side cover rubber; 10) Aluminum plate; 11) Acrylic plate; 12) Central support; 13) Central rubber; 14) Spring; 15) Top sensor rubber; 16) Base sensor rubber; 17) M6x20 Screw

In Figure 3.4, the six manufactured components of the PS_b *v.1* can be analyzed. Components 1, 2, 5,10 are made of 6063-T1 aluminum alloy, component 12 of PLA, and component 11 of acrylic.

Figure 3.4: Manufactured components of $\mathrm{PS_b}$ *v.1*. 1) Base; 2) Lateral; 5) Side cover; 10) Aluminum plate; 11) Acrylic plate; 12) Central support;

Regarding the standards components of $\mathrm{PS_b}$ *v.1* as springs, rubbers and screws will not be covered in this chapter.

In the PS *v.1* BOM (see Appendix A.1), the costs for the production of $\mathrm{PS_b}$ *v.1* and $\mathrm{PS_{mf}}$ *v.1* for the pilot project can be analyzed. In this sense, the percentage of $\mathrm{PS_b}$ costs associated with standard and manufactured components can be analyzed in Figure 3.5 a). It is noteworthy that the value of the manufactured components for the $\mathrm{PS_b}$ *v.1* is 4 times higher than the value of the standard components. Thus, from Figure 3.5 b), it can be seen that the cost of the $\mathrm{PS_b}$ represents approximately 2/3 of the product unit, making it necessary to develop a new approach to its manufacture, in an attempt to equalize the price of the two components.

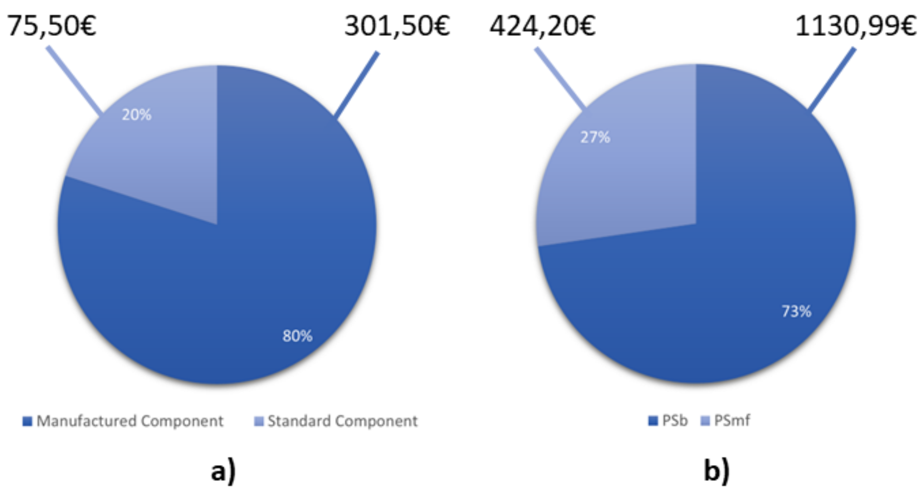


Figure 3.5: PS *v.1* analysis. a) Manufactured components vs. standards components costs for one $\mathrm{PS_b}$; b) Product unit costs $(3 \times PS_\mathrm{b} + 1 \times PS_\mathrm{mf})$

3.2 LED Marker *v.1*

As stated in subsection 1.3.3, the LED Marker is installed on both sides of crosswalks along the roadway and is intended to alert drivers of the proximity of a crosswalk and illuminate the crossing for pedestrians. For better understanding, a new nomenclature will be adopted for the LM *v.1*. The unit has been divided into two components, the $\mathrm{LM_p}$ (LED Marker Profile) and the $\mathrm{LM_{mf}}$ (LED Marker Mounting Frame). The product unit assembly consists of 6 $\mathrm{LM_p}$ and 1 $\mathrm{LM_{mf}}$ as can be seen in Figure 3.6.

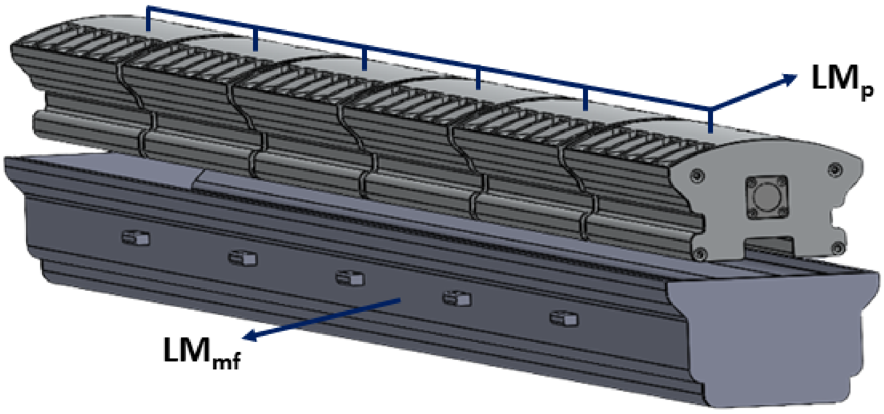


Figure 3.6: LED Marker *v.1* $(6 \times LM_p + 1 \times LM_{mf})$

In Figure 3.7 a) is observable the exterior design of the LM_p *v.1*. Also, can be seen the geometry of the extruded profile in b).

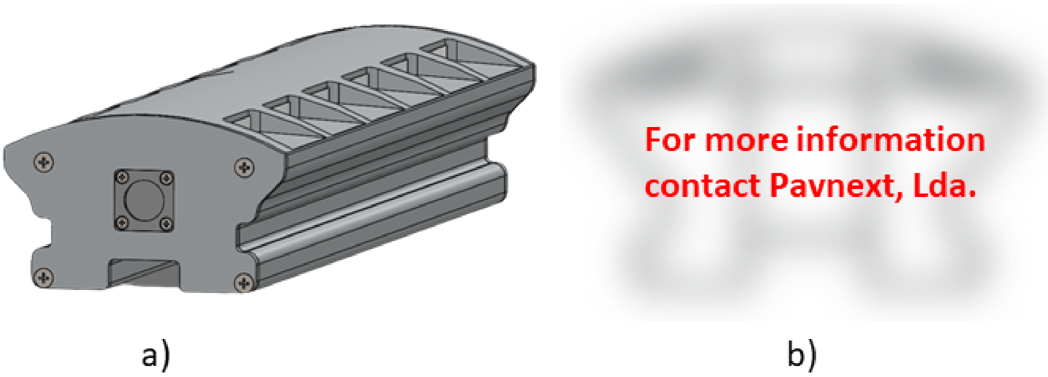


Figure 3.7: LED Marker *v.1*. a) LM_p; b) Extruded profile

In the exploded view of LM *v.1* represented in Figure 3.8, can be analyzed all the components in the LM_p *v.1*. This version contains a total of 6 references, which add up to a total of 23 components.

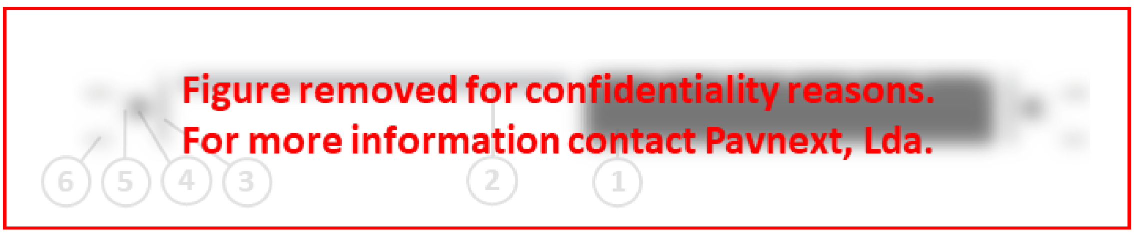


Figure 3.8: Exploded view of LM_p *v.1*. 1) Profile; 2) Acrylic; 3) Lateral cover; 4) Connector; 5) M3x5 Screw; 6) M5x20 Screw

In Figure 3.9 the two manufactured components of the LM_p can be observed. Both components are manufactured from 6063-T1 aluminum alloy.

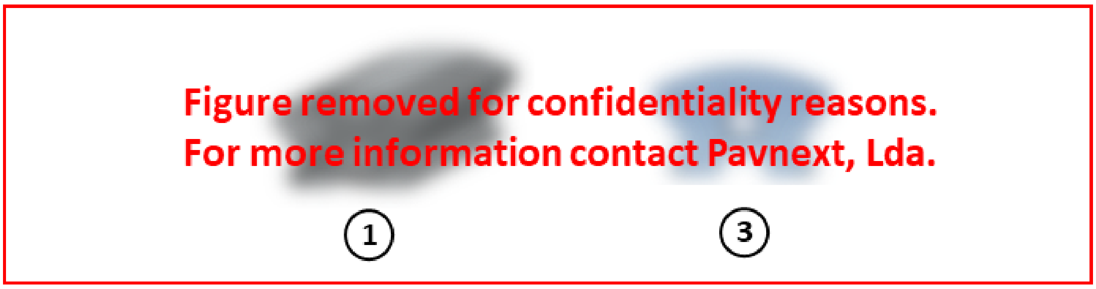


Figure 3.9: Manufactured components of $\mathrm{LM_p}$ *v.1*. 1) Profile; 3) Lateral cover

In the LM *v.1* BOM (see Appendix A.2), the costs for the production of $\mathrm{LM_P}$ and $\mathrm{LM_{mf}}$ for the pilot project can be analyzed. The percentage of $\mathrm{LM_P}$ costs associated with standard and manufactured components can be viewed in Figure 3.10 a). It is notable that the value of the manufactured components for the $\mathrm{LM_p}$ *v.1* is 2.2 times higher than the value of the standard components. Thus, from Figure 3.10 b), it can be seen tha t the cost of the $\mathrm{LM_{mf}}$ corresponds to 1/3 of the cost of a unit composed of 6 $\mathrm{LM_p}$ and 1 $\mathrm{LM_{mf}}$.

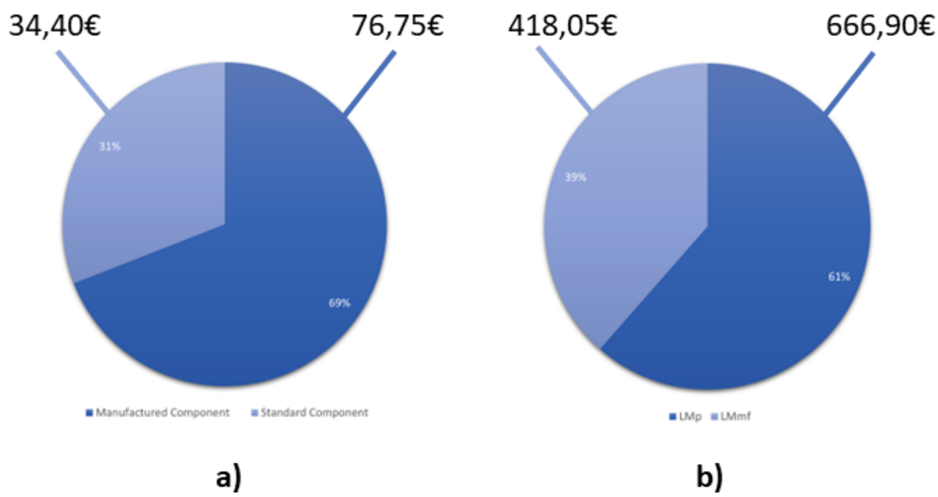


Figure 3.10: LM *v.1* analysis. a) Manufactured components vs. standards components costs for one $\mathrm{LM_p}$; b) LM *v.1* costs $(6 \times LM_P + 1 \times LM_{\mathrm{mf}})$

3.3 LED Signal *v.1*

As mentioned in subsection 1.3.4, the LED Signal aims to illuminate the traffic signs at crosswalks, providing better visualization for the driver. In Figure 3.11 can be better observed the state of the art called LED signal *v.1* in SolidWorks. Thus, this product was never prototyped and did not participate in the pilot project.

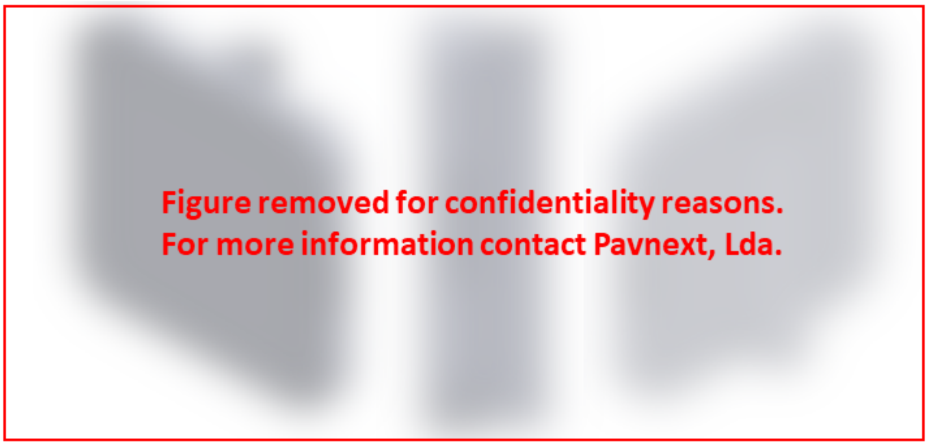


Figure 3.11: LED Signal *v.1*

From a market and legislation analysis, it was noticed that the concept version could present implementation barriers that impact sales. Thus, alternative designs were sought for the illumination of the traffic signs.

3.3.1 LED Signal prototyping

The initial concept for the solution called LED Signal concept *v.1* would be a module attached to the existing traffic signals and manufactured primarily by extrusion and injection molding. Figure 3.12 shows the concept at CAD, namely (a) a side profile made by extrusion and (b) the corners made by injection molding.

In this concept, a LED strip would run across the profile, illuminating the traffic signal from all sides. The modules would wrap around the entire perimeter of the traffic sign and would be fixed by a steel plate attached to the pole at the back.

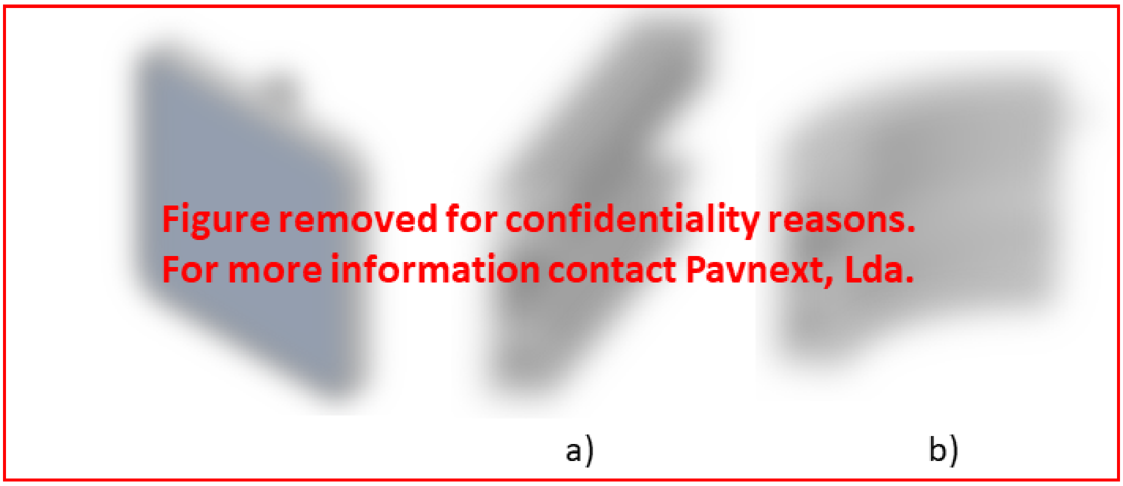


Figure 3.12: LED Signal concept *v.1*

To validate the concept, a Creality Ender-3Pro 3D printer was used to materialize the first prototype in PLA, shown in Figure 3.13. After some tests and design changes, this model was discarded because, even if standardized, there are slight differences in dimensions between the manufacturers of traffic signs, besides the fact that the proximity of the LED does not provide the intended illumination.

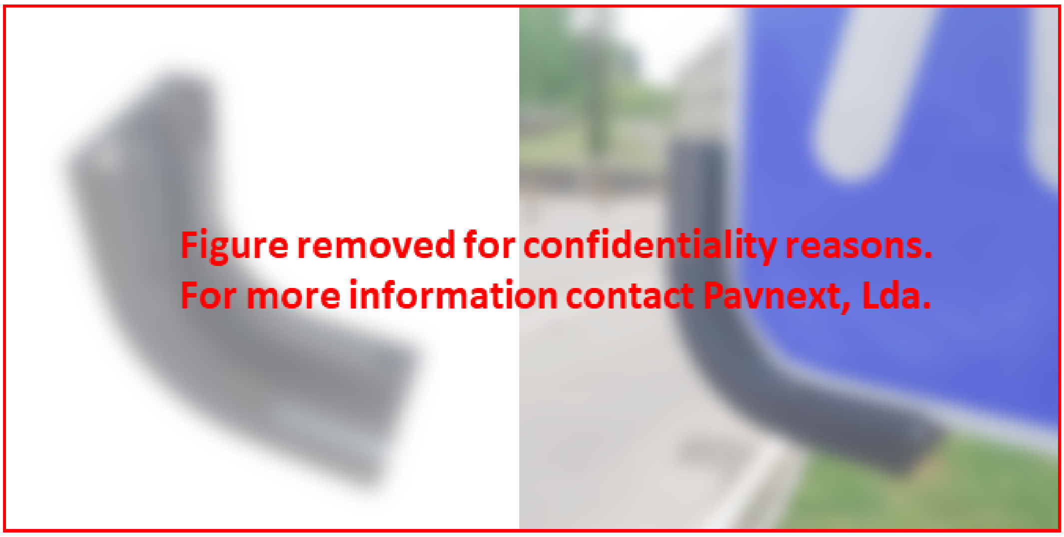


Figure 3.13: LED Signal concept *v.1*, PLA prototype

After brainstorming, the approach was changed and a new, simpler model was developed. This model, called LED Signal concept *v.2*, would be mounted on top of the traffic sign, using the same screws that attach the sign to the pole. This version would consist of three pieces joined together in a sandwich format, as shown in the CAD version in Figure 3.14.

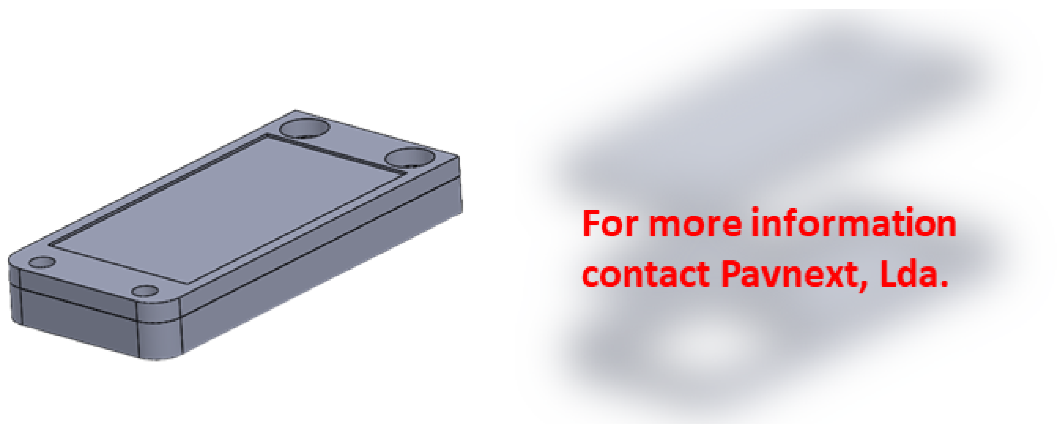


Figure 3.14: LED Signal concept *v.2*

Figure 3.15 shows the second prototype in PLA. This version proved to be simpler and provided the illumination that Pavnext desired.

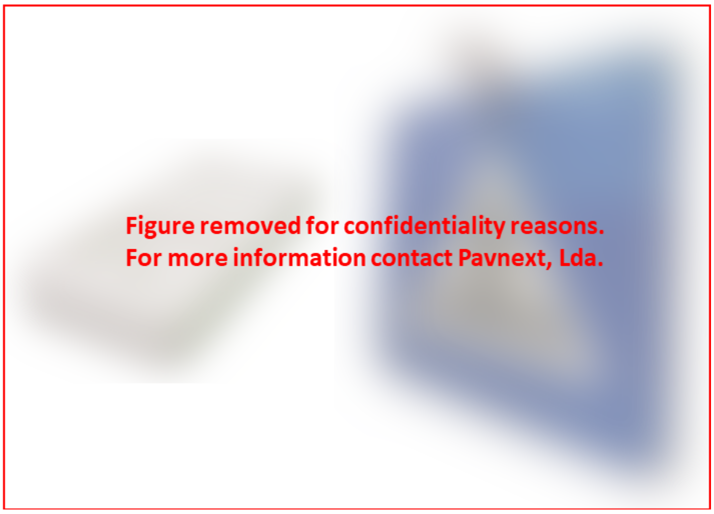


Figure 3.15: LED Signal concept *v.2*, PLA prototype

3.4 Pilot Project

A pilot project is a small-scale preliminary study conducted to evaluate the feasibility, durability, cost, and side effects of a product. Also, to make improvements to the design/materials prior to large-scale production (Lewis et al., 2021).

Pavnext has built its first pilot project in Matosinhos to validate its two products, Next-Road and Next-Cross. Figure 3.16 shows the layout of the Next-Cross products. In this figure, can be also seen the PS *v.1* the entrance of the crosswalk, and the LM *v.1* along the road. It is worth noting that the LM *v.1* were placed only halfway along the road on one side.

Figure 3.16: Pavnext pilot project in Matosinhos, Portugal

In Table 3.1 can be seen the cost analysis of the pilot project BOM.

Table 3.1: Implementation costs of Pavnext's Next-Cross pilot project

Product	Units	Cost	Percentage
Pedestrian Sensor box (PS_b)	6	2.261,98€	35,5%
Pedestrian Sensor mounting frame (PS_{mf})	2	848,40€	13,3%
LED Marker profile (LM_p)	18	2.000,70€	31,4%
LED Marker mounting frame (LM_{mf})	3	1.254,15€	19,8%
	Total:	6.365,23€	100%

3.5 Analysis and Optimization

Based on the observation of the pilot project, an attempt was made to identify weaknesses in Next-Cross *v.1* in order to improve it for the development of new industrial solutions.

3.5.1 Pedestrian Sensor *v.1*

The PS *v.1* did not show any broken parts. However, it was found that the top cover of some units was a little bent, and that the sealing of the system needed to be improved.

Another major drawback of the current version is the high number of manufactured components, which not only increase the cost of the product, but also lead to a longer assembly time.

As for assembly, the current system of fastening the top cover by rails should be revised, as it causes great difficulties during assembly.

In Figure 3.17, the PS *v.1* installed in Matosinhos can be closely observed.

Figure 3.17: Pedestrian Sensor *v.1* in the pilot project

3.5.2 LED Marker *v.1*

Regarding the LM *v.1*, it showed visible defects such as fissures on the top and even broken parts. It is also worth mentioning that an accumulation of dirt was noticed on the openings of the LED's. It was also noted that passing vehicles at high speeds generated a loud impact noise.

The assembly of the acrylic on the extruded profile proved to be a difficulty and it was also noted that the sealing of the system needs to be improved.

In Figure 3.18 can be seen the main problems encountered in the current version of the LED marker in Pavnext's pilot project.

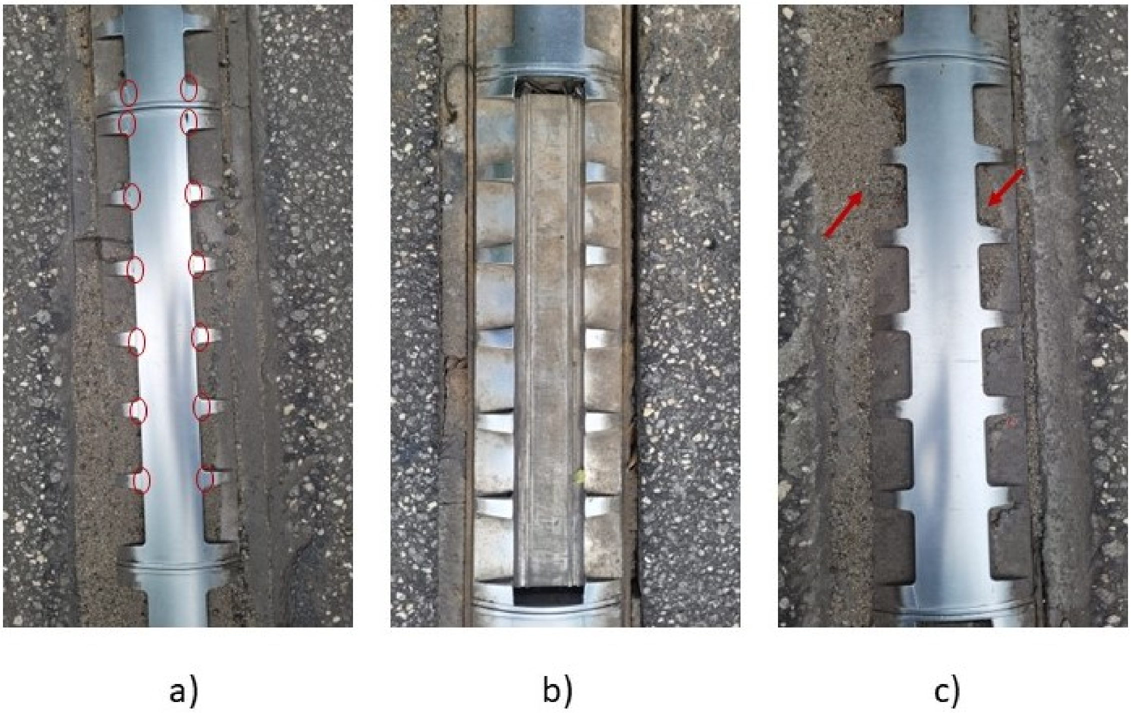


Figure 3.18: LED Marker *v.1* in the pilot project. a) Apparent cracks; b) Broken unit; c) Dirt accumulation

3.6 Conclusion

It can be concluded that the PS_b *v.1* has many components that increase its cost, so it is necessary to develop new manufacturing routes to reduce this number and eventually its price.

As for the LM_p *v.1*, its design needs to be changed to avoid cracks and support the loads. It is also necessary to develop a new approach to avoid impact noise.

Chapter 4

Next-Cross *v.2* – Product Development

This chapter aims to present the new construction solution developed during this dissertation, designated Next-Cross *v.2*.

4.1 Initial Assumptions

Figure 4.1 highlights the key aspects of development that lead to the best product cost.

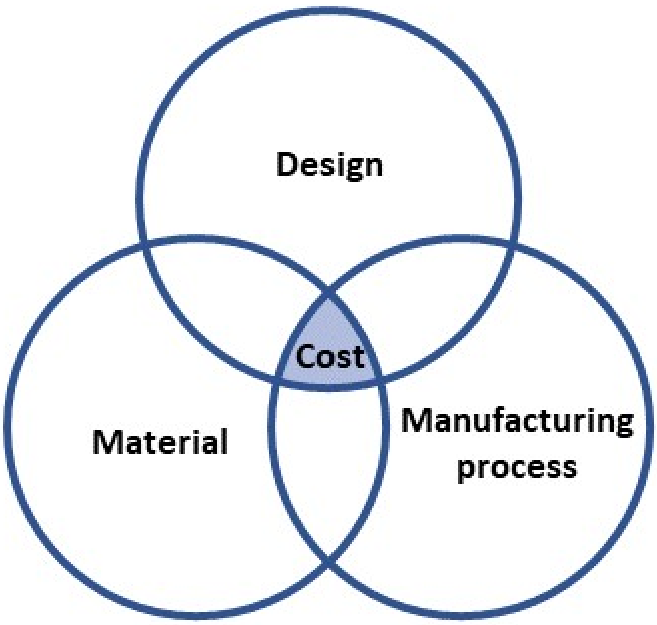


Figure 4.1: Pillars of Next-Cross *v.2* product development

4.1.1 Design

Design is a crucial aspect in cost optimization. Taking as a starting point the Next-Cross *v.1*, it was sought:

- Redesign to reduce the number of components;
- Design with easy assembly and maintenance;
- Redesign to mass reduction.

4.1.2 Manufacturing Process

Based on the analysis of version *v.1* and the findings from the literature review, it is concluded that for Next-Cross *v.2*, the processes should be selected for economic and sustainable production in such a way that the manufacture of the components and the conditions are such that the use of post-processing can be minimized.

Considering the need for industrial production, extrusion and injection molding will be the highlighted manufacturing processes, since a die is used that allows a high production cadence, whose initial investment is amortized by mass production. As for machining, it is avoided whenever possible and used only in necessaries cases.

For the development of the three products, a study was conducted in which the main manufacturing processes were selected, being them: extrusion, injection molding, bending and casting. Followed by secondary processes, such as: machining, and welding.

4.1.3 Material

The selection of materials was made based on the following objectives/restrictions:

- Mass reduction;
- Cost reduction;
- Mechanical properties;
- Compatibility with manufacturing processes.

4.2 Development Process

Based on the analysis in the previous chapter, a logical and iterative sequence of steps was structured for the validation of the new solutions, as shown in Figure 4.2.

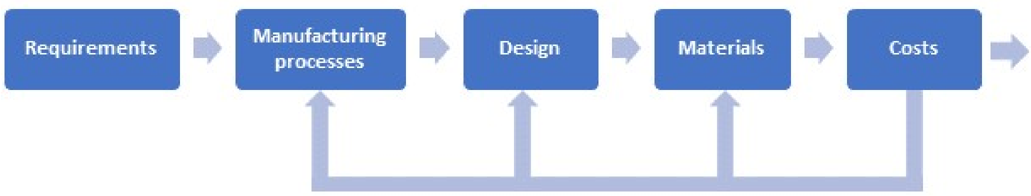


Figure 4.2: Next-Cross *v.2* product development process

In summary, based on the configuration of the existing component(s) in Next-Cross *v.1*, the requirements of the systems, and the feedback from the pilot project, a selection was made of the best technological processes to be adopted in each product. New solutions were then designed based on the defined processes. Once the solutions were validated, material studies were carried out and, once this phase was completed, a budget was sought for each product (this phase was carried out based on Pavnext's expertise and through the contact with the industry).

The development process shown in Figure 4.2 was based on an iterative method. Once a step did not meet the Pavnext criteria, the steps were repeated until approval.

Once all initial assumptions and the method of the development process have been determined, the construction of Next-Cross *v.2* will be addressed.

4.3 Next-Cross *v.2*

The development of the Next-Cross *v.2* products started with the Pedestrian Sensor, then the LED Marker, and finally the LED Signal.

4.3.1 Pedestrian Sensor *v.2*

As mentioned in Section 3.1 , the PS *v.1* had many components, which increased its cost. Therefore, new manufacturing routes were sought to reduce these costs. In this regard, three PS_b were developed using different manufacturing processes to manufacture the PS_b *v.2*, these processes being:

- Extrusion;
- Injection molding;
- Bending.

In the next sub-sections the final versions of each constructive design are described. It is worth mentioning that no changes will be made to PS_{mf}.

A. PS_b *v.2* extrusion version

In the final version, obtained after 7 iterations, the main body (base) is designed to be manufactured using the extrusion process followed by the machining of the spring house and holes. Therefore, compared to the previous version (PS_b *v.1*), the 3D printed central support, the machined laterals, 8 M3 screws, and 4 M6 screws are avoided.

In Figure 4.3 is visible in a) the CAD of the assembly of PS_b *v.2* by extrusion. In b) can be seen the isometric view of the extruded base profile.

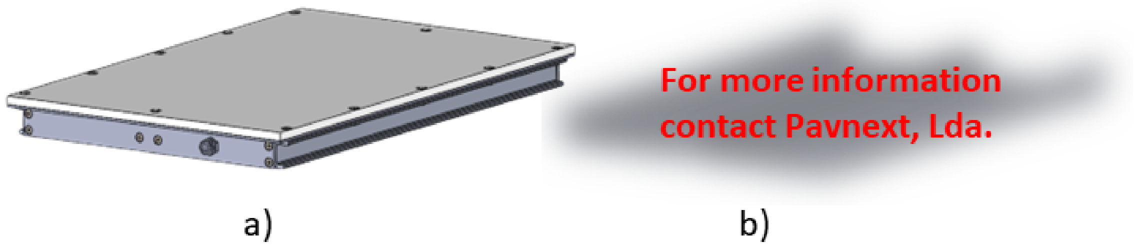


Figure 4.3: Extruded version. a) PS_b; b) Extruded base

In Figure 4.4, the geometry of the extrusion profile can be better analyzed. This profile was obtained respecting the industries' best practices for the process.

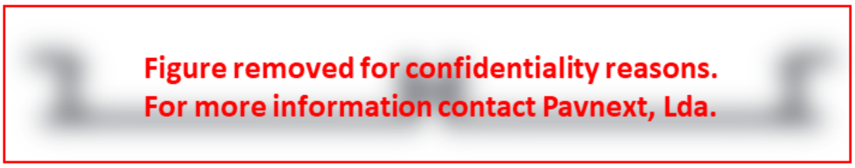


Figure 4.4: Extrusion profile geometry

In the exploded view in Figure 4.5, can be analyzed all the components in the PS_b *v.2* by extrusion. This version contains a total of 13 references, which add up to a total of 45 components. In Appendix B.1 can be seen more of the PS_b *v.2* by extrusion drawings.

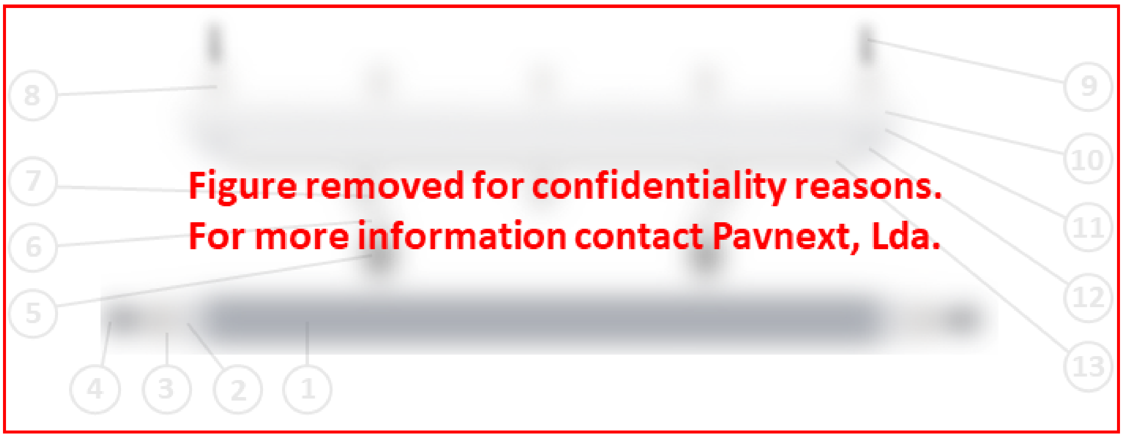


Figure 4.5: PS_b *v.2* by extrusion exploded view. 1) Base; 2) Side cover; 3) M5x5 screw; 4) PG-9 cable gland connector; 5) Base sensor rubber; 6) Top sensor rubber; 7) Spring; 8) M6x20 Screw; 9) M6x35 Screw 10) Acrylic plate; 11) Aluminum plate; 12) Central Screw base; 13) Central rubber

According to CES Edupack, extrusion of metals is limited to ductile materials with melting points below 1700°C, usually aluminum, copper, magnesium, low and medium carbon steels, low alloy steels and stainless steels. In relation to this process, aluminum alloy 6063-T1 was chosen due to its good cost-benefit ratio and local availability. Table 4.1 shows the main properties of this material.

Table 4.1: 6063-T1 (CES Edupack)

Price	1,73€/Kg
Density	2685 Kg/m^3
Young's Modulus	69 GPa
Yield strength	65 MPa
Tensile strength	125 MPa
Compressive strength	65 MPa

After the material selection of the PS_b *v.2* by extrusion, a static simulation was performed for this material using the finite element method with PrePoMax software to verify that the material meets the requirements. Appendix C.1 shows the result of displacement, Von Mises stress and Tresca stress, when a force of 10.000 N, corresponding to the weight distribution on the wheels of a light vehicle, is applied to the base. From the analysis of the data summarized in Table 4.2, it can be concluded that the material meets the requirements.

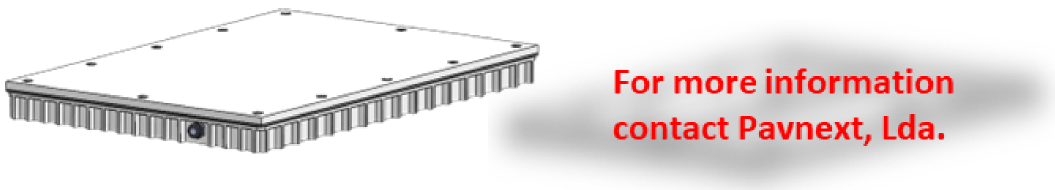
Table 4.2: PS_b *v.2* by extrusion simulation (PreProMax)

Applied force	10000 N
Displacement	0,00 mm
Von Mises stress	1,89 MPa
Tresca stress	2,14 MPa
6063 – T1 Yield strength	65,00 MPa

B. PS_b *v.2* injection molding version

In the final version, obtained after 4 iterations, the main body (base) is designed to be injection molded. Therefore, compared to the PS *v.1*, the central support, the laterals, the side covers, 8 M3 screws, 12 M5 screws, and 4 M6 screws are avoided.

Figure 4.6 shows the assembly of PS_b *v.2* by injection molding and the injected base.



a) b)

Figure 4.6: Injected version. a) PS_b; b) Injected base

Can be seen in Figure 4.7 the geometry and details of the injected base.

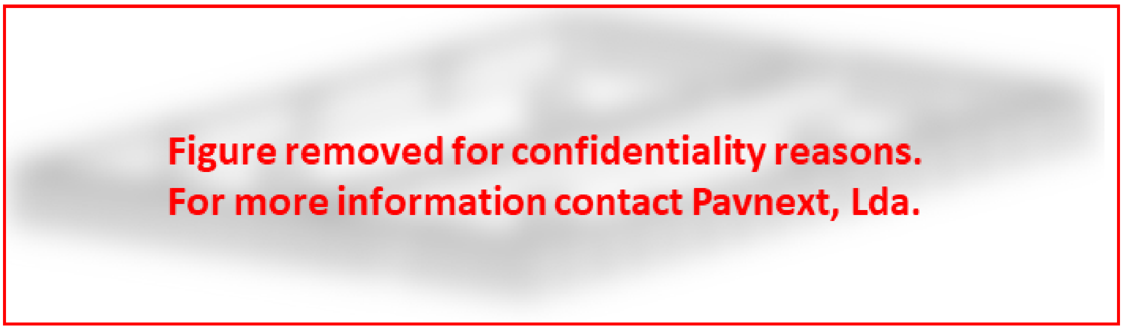


Figure 4.7: Injected base

In the exploded view in Figure 4.8, can be analyzed all the components in the PS_b *v.2* by injection molding. This version contains a total of 12 references, which add up to a total of 38 components. In Appendix B.2 can be seen more of the PS_b *v.2* by injection molding drawings.

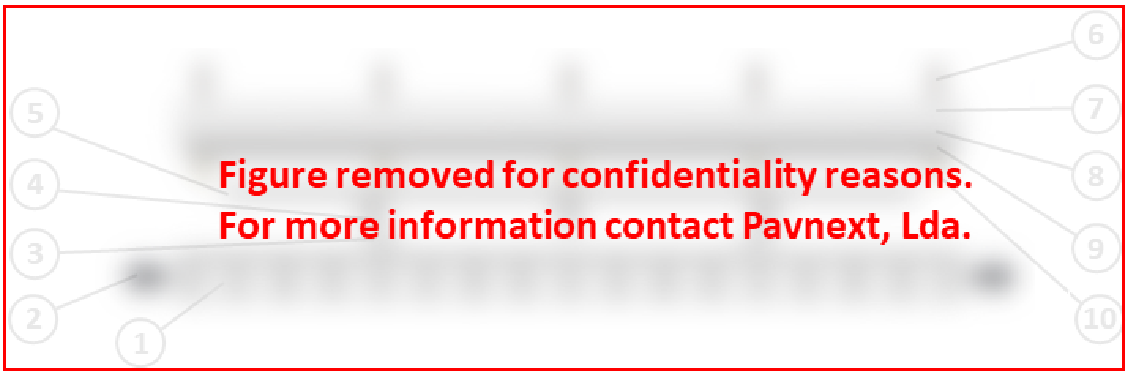


Figure 4.8: PS_b *v.2* by injection molding assembly. 1) Base; 2) PG-9 cable gland connector; 3) Top sensor rubber; 4) Spring; 5) Central rubber; 6) M6x25 Screw; 7) Acrylic plate; 8) Aluminum plate; 9) Sponge sealing ring; 10) Threaded insert

According to CES Edupack, most thermoplastics can be injection molded. Among the possible candidates, ABS was selected for this process, and its main properties are listed in Table 4.3.

Table 4.3: ABS (CES Edupack)

Price	1,58€/Kg
Density	1030 Kg/m^3
Young's Modulus	2,4 GPa
Yield strength	42 MPa
Tensile strength	45 MPa
Compressive strength	62 MPa

In Appendix C.2, can be observed the results of displacement, Von Mises stress, and Tresca stress when the same force of 10.000 N is applied. From the analysis of the data summarized in Table 4.4, it can be concluded that the material meets the requirements.

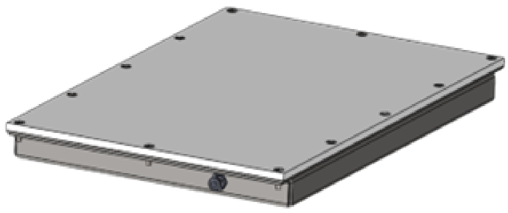
Table 4.4: PS_b *v.2* by injection molding simulation (PreProMax)

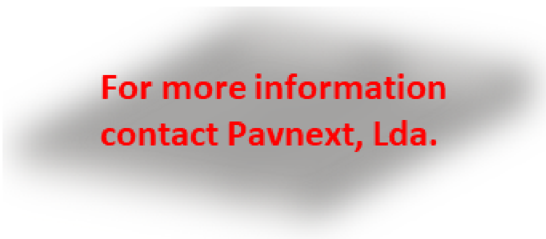
Applied force	10000 N
Displacement	0,00 mm
Von Mises stress	1,46 MPa
Tresca stress	1.61 MPa
ABS Yield strength	42,00 MPa

C. PS_b *v.2* bending version

The final version, obtained after 2 iterations, the main body (base) is designed for bending. Therefore, compared to the PS *v.1*, the laterals, the side covers, 8 M3 screws, 12 M5 screws, and 4 M6 screws are avoided.

Figure 4.9 shows the assembly of PS_b *v.2* by bending and the bended base.





a) b)

Figure 4.9: Bended version. a) PS_b; b) Bended base

The bended base is obtained by joining two bent sheets. The first in the shape of the outer box and a smaller one that gives shape to the central support as can be seen in Figure 4.10. They would be assembled by welding points.

Figure 4.10: Bended base components

In the exploded view in Figure 4.11, can be analyzed all the components in the PS$_b$ *v.2* by bending. This version contains a total of 10 references, which add up to a total of 26 components. In Appendix B.3 can be seen more of the PS$_b$ *v.2* by bending drawings.

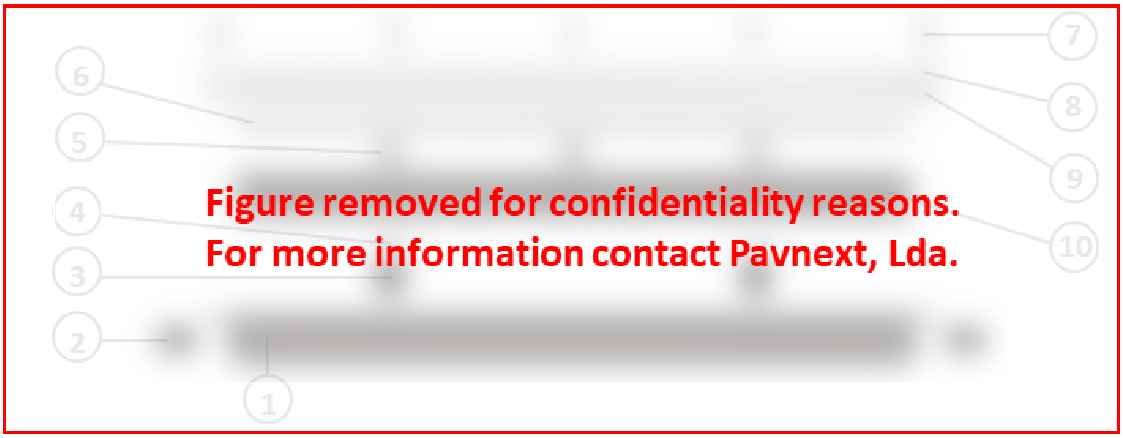


Figure 4.11: PS$_b$ *v.2* by bending assembly. 1) Base; 2) PG-9 cable gland connector; 3) Base sensor rubber; 4) Top sensor rubber; 5) Spring; 6) Central rubber; 7) M6x25 Screw; 8) Acrylic plate; 9) Aluminum plate; 10) Central support

According to CES Edupack, bending is most commonly used for metals, especially steels. However, Al, Cu, Ni, Zn, Mg and Ti alloys can also be processed. AISI 304 stainless steel was selected for this process, and its main properties are listed in Table 4.5.

Table 4.5: AISI 304 (CES Edupack)

Price	3,37€/Kg
Density	7955 Kg/m^3
Young's Modulus	197 GPa
Yield strength	245 MPa
Tensile strength	592 MPa

In Appendix C.3, can be seen the results of displacement, Von Mises stress, and Tresca stress when a force of 10.000 N is applied. From the analysis of the data summarized in Table 4.6, it can be concluded that the material meets the requirements.

Table 4.6: PS$_b$ *v.2* by bending simulation (PreProMax)

Applied force	10000 N
Displacement	0,00 mm
Von Mises stress	15,14 MPa
Tresca stress	17,4 MPa
AISI 304 Yield strength	245,00 MPa

4.3.2 LED Marker *v.2*

It was seen in subsection 3.5.2 that the LED Marker presented some problems in the pilot project. Therefore, new designs were sought to address these problems. In this regard, after 8 interactions, only one LM *v.2* will be presented using the same method as the initial prototype, the extrusion process.

Compared to the previous version, there were some changes such as a new 150 mm width, some sections with a greater thickness of 5 mm, a larger radius, less curvature at the top, and the addition of a center pillar for the top.

In Figure 4.12 a) is observable the exterior design of the LM_p *v.2*. Also can be seen the geometry of the new extruded profile in b).

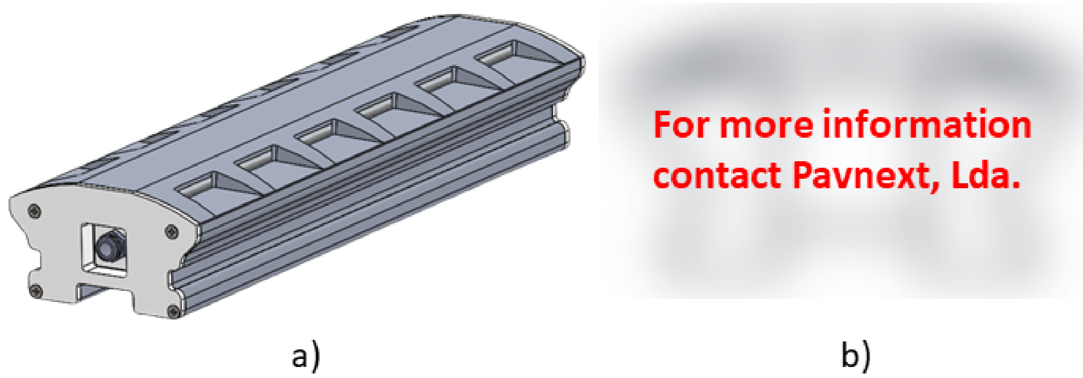


Figure 4.12: LED Marker *v.2*. a) LM_p; b) Extruded profile

In the exploded view in Figure 4.13, can be analyzed all the components in the LM_p *v.2*. This version contains a total of 5 references, which add up to a total of 15 components. In Appendix B.4 can be seen more of the LM_p *v.2* drawings.

Figure 4.13: Exploded view of LM_p *v.2*. 1) Profile; 2) Acrylic; 3) Lateral cover; 4) PG-9 cable gland connector; 5) M5x20 Screw

The material selected for the LED Marker was aluminum alloy 6063-T1 with the properties previously listed in Table 4.1. Appendix C.4 shows the displacement, Von Mises stress and Tresca stress when a force representing the weight distribution on the wheels of a heavy vehicle of 100.000 N is applied to the base. From the analysis of the data summarized in Table 4.7, it can be concluded that the material meets the requirements. For the lateral covers ABS was chosen.

Table 4.7: LM_p *v.2* simulation (PreProMax)

Applied force	100000 N
Displacement	0,02 mm
Von Mises stress	44,74 MPa
Tresca stress	46,48 MPa
6063 – T1 Yield strength	65,00 MPa

4.3.3 LED Signal *v.2*

As seen in subsection 3.3.1, the LED Signal has undergone some changes since the state of art. Pavnext decided to proceed with the LED Signal concept *v.2*.

In summary, this concept represented in Figure 4.14 would reduce the complexity and number of state-of-the-art components and could be easily connected to traffic signals at crosswalks. It is worth mentioning that the development to this version took 5 iterations.

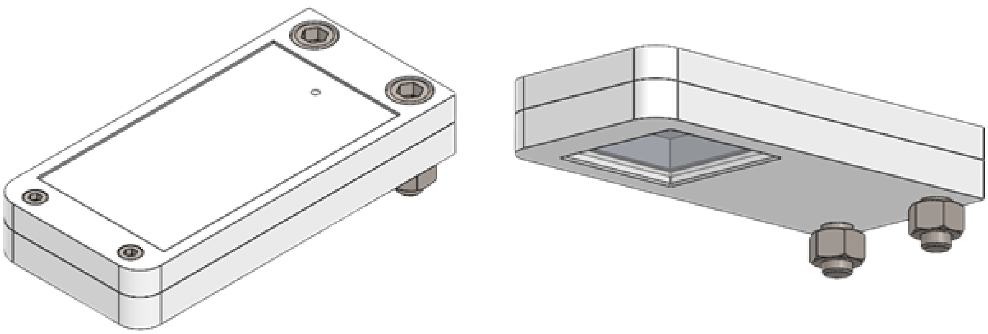


Figure 4.14: LED Signal

In the exploded view in Figure 4.15, can be analyzed all the components in the LS. This version contains a total of 7 references, which add up to a total of 15 components. In Appendix B.5 can be seen more of the LS *v.2* drawings.

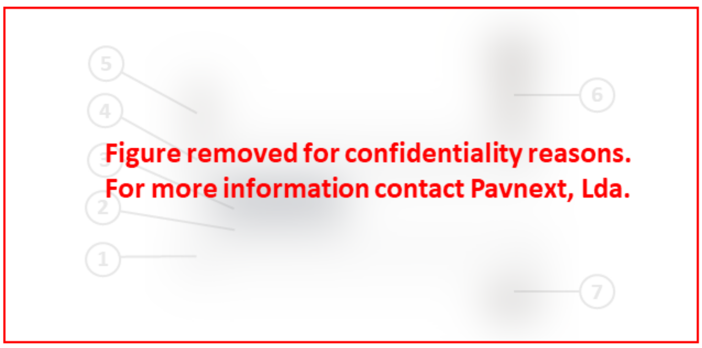


Figure 4.15: Exploded view of LS *v.2*. 1) Base; 2) Acrylic; 3) LED support; 4) Top cover; 5) M5x16 Screw; 6) M10x30 Screw; 7) M10 nut

This material is not subjected to great stresses, only to environmental conditions. Therefore, a cost-effective material was sought that is resistant to UV radiation and temperature fluctuations. Thus, the thermoplastic ABS was chosen for the base and the top cover. For the LED support, Pavnext sought a material with good thermal conductivity that could withstand the temperatures of the LED. Therefore, the aluminum alloy EN AC 46000 was chosen, with its main properties listed in Table 4.8.

Table 4.8: EN AC 46000 (CES Edupack)

Price	1,88 €/Kg
Density	2760 Kg/m^3
Young's Modulus	76 GPa
Yield strength	140 MPa
Tensile strength	240 MPa

4.4 Connectors

The exchange of the Higo connector for the PG-9 cable gland made it possible to reduce not only 4 M3 screws per connector, but also to save the machining of the cover recess to fit the connector to the Pedestrian Sensor and LED Marker.

In Figure 4.16 can be observed the comparison between the two connections. Another important factor in the decision was the IP68 warranty and the fact that such a connection allows any device to follow the curvature of the road in case of a future version.

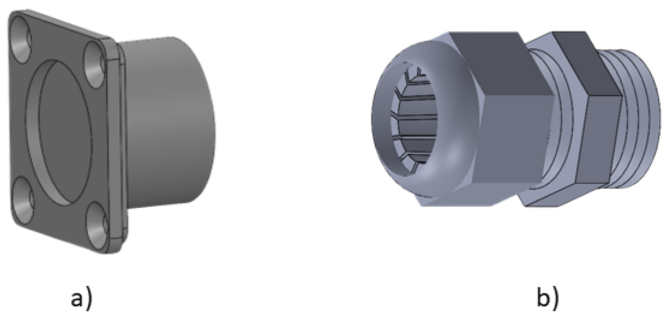
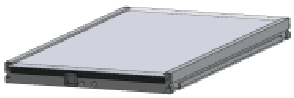
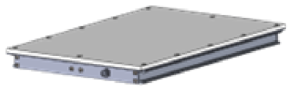
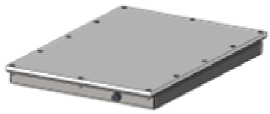
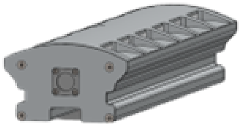
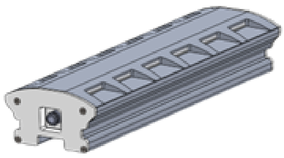
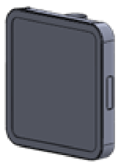
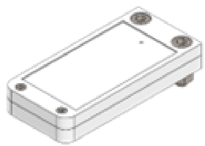


Figure 4.16: Comparison between pre-industrial and industrial version connectors. a) Higo connector; b) PG-9 cable gland connector

4.5 Conclusion

In Table 4.9, can be observed a brief summary of the development of the new versions of the Next-Cross *v.2* products. It is remarkable that by aligning design with different manufacturing routes, a good reduction of components has been achieved in all three products. It is worth mentioning that this analysis will be discussed in Chapter 5.

Table 4.9: Next-Cross product development summary

	v.1	**v.2**
PS	 17 references 64 components	Extrusion 7 interactions 13 references 45 components 
		Injection molding 4 interactions 10 references 38 components 
		Extrusion 2 interactions 10 references 26 components 
LM	 6 references 23 components	 8 interactions 5 references 15 components
LS	 10 references 34 components	 5 interactions 7 references 15 components

Chapter 5

Technical and economic analysis

This chapter consists of a comparison between the pre-industrial and industrial Next-Cross versions, as well as an economic analysis of the new solutions developed.

It is worth noting that the economic analyzes were performed based on the budgets of external companies for the specific manufactured component.

5.1 Initial assumptions

The prices adopted for raw materials in the economic analysis are those that the companies passed on in the budgeting phase of the Next-Cross products. They are shown in Table 5.1, along with the density of each material taken from CES Edupack.

Table 5.1: Data from adopted materials

Material	Density [Kg/m^3]	Price [€/Kg]
6063 – T1	2685	4,50
ABS	1030	2,50
AISI 304	7955	3,37* (* CES Edupack)
EN AC 46000	2760	1,88* (* CES Edupack)

The components that were not priced, had their prices calculated based on Equation 5.1.

$$UnitCost = Volume[m^3] \times Density[kg/m^3] \times Price[Euro/kg] \tag{5.1}$$

5.2 Analysis of components

One of the cost reduction goals was to reduce the number of existing elements in the products. This goal was pursued throughout the design phase. Therefore, Figure 5.1 compares the quantities present in the pre-industrial and industrial versions of the Pedestrian Sensor, Figure 5.2 compares the components of the LED Marker, and Figure 5.3 compares the difference between the versions of the LED Signal.

The analysis of Figure 5.1 shows that the three industrial versions of the Pedestrian Sensor have a reduction of components compared to the pre-industrial version. The reduction between PS_b *v.1* and PS_b *v.2* by extrusion was 30%, for PS_b *v.2* by injection molding 42% and finally for PS_b *v.2* by bending 59%.

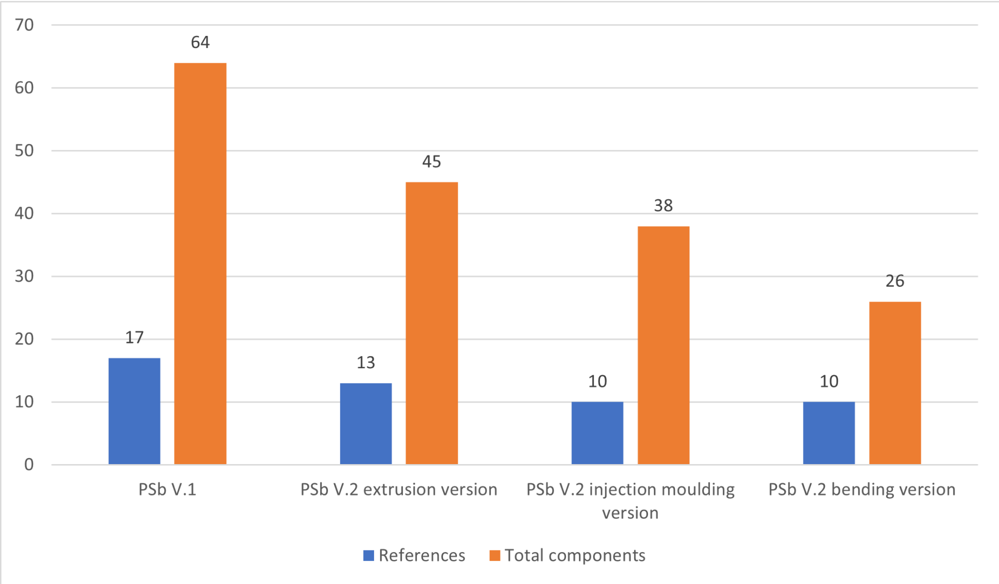


Figure 5.1: Reduction of Components in the Pedestrian Sensor

Analyzing the comparison between the pre-industrial and industrial version of the LED Marker in Figure 5.2, can be noted that the reduction of components was 35%.

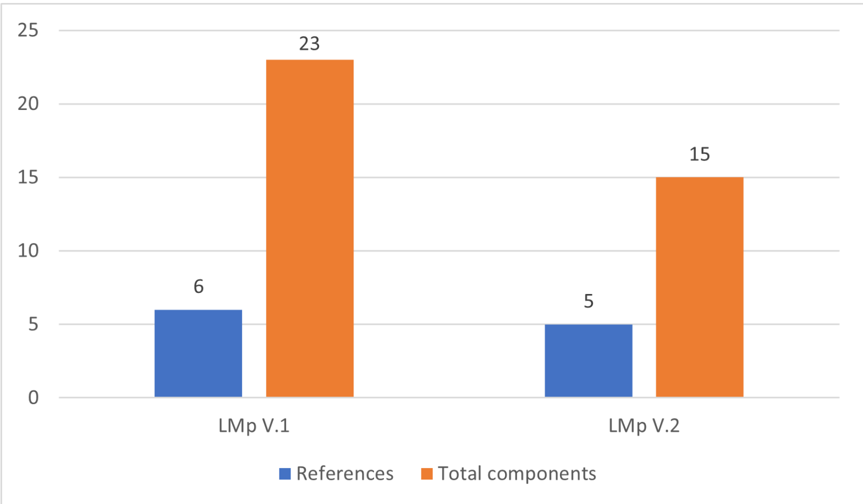


Figure 5.2: Reduction of Components in the LED Marker

Finally, from the analysis of Figure 5.3, it can be concluded that the reduction of components between the pre-industrial and industrial versions of the LS was 56%.

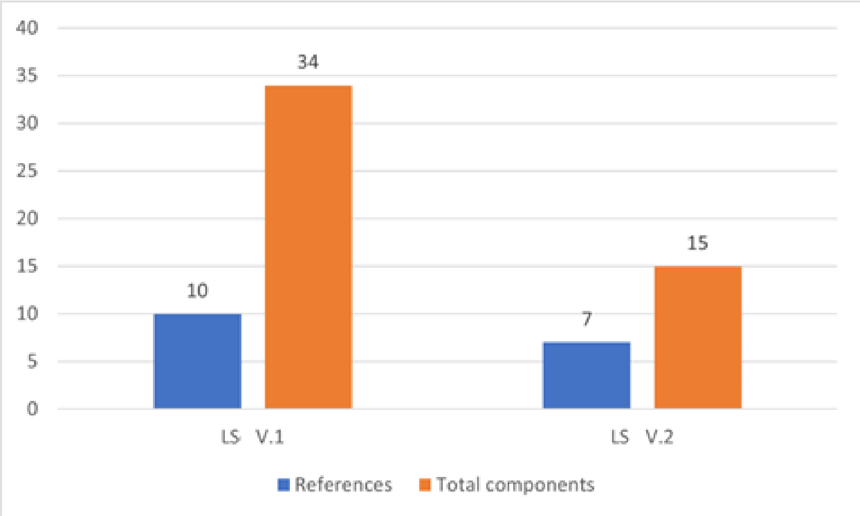


Figure 5.3: Reduction of Components in the LED Signal

5.3 Economic analysis

Chapter 3 presented the review of Next-Cross *v.1* products as well as an economic analysis of each product.

This section aims to present the data obtained by the Next-Cross *v.2* product budgeting, as well as to compare the pre-industrial and the industrial versions in a mass production volume.

5.3.1 Pedestrian Sensor *v.2*

After budgeting, Table 5.2 shows the comparison of investment prices for extrusion and injection dies and the cost per unit. It should be noted that it was not possible to obtain the budgeting for PS *v.2* by bending in time, so it will be out of the analysis. The BOM for PS *v.2* by extrusion and injection molding can be found in Appendix B.6

Table 5.2: Pedestrian Sensor unit price comparison

Product	Die cost [€]	Unit price [€]
PS *v.1*	0	377,00
PS *v.2 extrusion*	3.350	200,70
PS *v.2 injection*	48.000	120,48
PS *v.2 bending*	---	---

As expected, the capital required for the production of the Pedestrian Sensor *v.2* is much higher than *v.1*. However, despite this difference, by inserting suitable manufacturing processes, the cost per unit of the product has been reduced.

Considering the costs associated with all the process variants, it is then necessary to determine the moment when it becomes advantageous to produce model *v.2*. Thus, it is necessary to find the break-even-point.

In this way, using Equations 5.2, 5.3 and 5.4, the cost of each product was calculated in relation to the production volume.

$$PSv.1 = 377x \tag{5.2}$$

$$PSv.2 - Extrusion = 3.350 + 200,72x \tag{5.3}$$

$$PSv.2 - Injection = 48.000 + 120,48x \tag{5.4}$$

Looking at the graph in Figure 5.4, can be conclude that compared to PS *v.1*, the PS *v.2* extrusion model becomes advantageous with a volume greater than 20 units, while the PS *v.2* injection molding model needs a volume greater than 188 units to become advantageous. As for the two developed versions of the PS *v.2*, can be seen that the higher investment in injection mold is only valid for a higher production volume of 557 units.

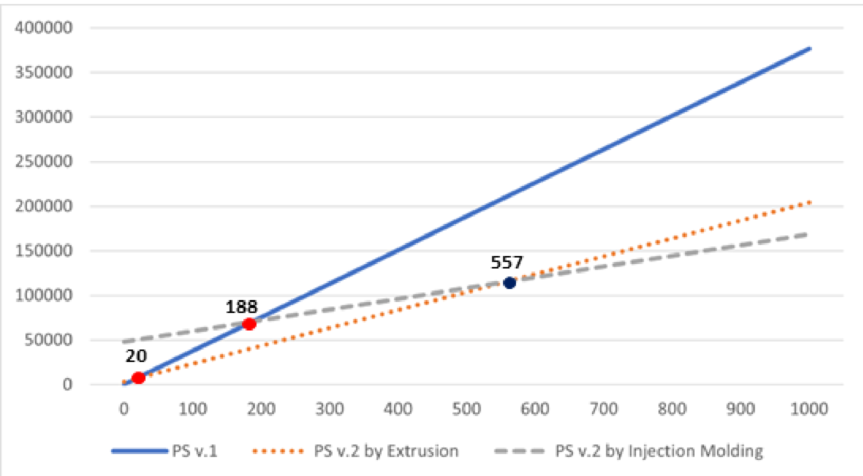


Figure 5.4: Break-even-points of PS versions

By comparing the values in Table 5.3, it can be seen that in addition to the cost reduction of the manufactured components, a cost reduction of the standard components has been also achieved.

Table 5.3: Comparison between manufactured and standard components in PS versions

Product	Manufactured components [€]	Standard components [€]
PS *v.1*	301,50	75,50
PS *v.2 extrusion*	146,50	54,22
PS *v.2 injection*	64,50	55,98
PS *v.2 bending*	---	---

5.3.2 LED Marker *v.2*

Table 5.4 shows the comparison of investment prices for extrusion and injection dies and the cost per unit. The BOM for LM *v.2* can be found in Appendix B.6. It is worth mentioning that in the LM *v.1* model the investment of 3.000 euros refers only to an extrusion die, while in the LM *v.2* version the investment of 23.500 euros refers to 3.500 euros of the extrusion die and 23.000 euros of the injection die.

Table 5.4: LED Marker unit price comparison

Product	Die cost [€]	Unit price [€]
LM *v.1*	3.000	111,15
LM *v.2*	23.500	69,91

As expected, the capital required to produce the LED Marker v2 is much higher than v1 since the lateral covers are designed for injection molding.

To calculate the break-even point, Equations 5.5 and 5.6 were used and the result can be seen in the graph in Figure 5.5.

$$LMv.1 = 3.000 + 111,15x \tag{5.5}$$

$$LMv.2 = 23.500 + 69,91x \tag{5.6}$$

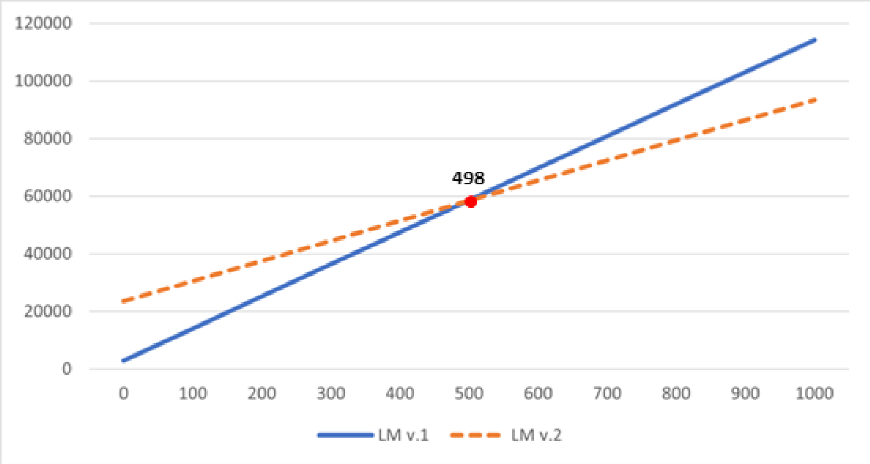


Figure 5.5: Break-even-points of LM versions

Looking at the graph, it can be concluded that the LM *v.2* becomes advantageous than version *v.1* with a production volume of more than 498 units.

When analyzing Table 5.5, similarly to the Pedestrian Sensor *v.2*, the LED Marker *v.2* shows a reduction in the cost of the standard components.

Table 5.5: Comparison between manufactured and standard components in LM versions

Product	Manufactured components [€]	Standard components [€]
LM *v.1*	76,75	34,40
LM *v.2*	47,15	22,76

5.3.3 LED Signal *v.2*

Regarding the LED Signal *v.2*, can be observed in Table 5.6 the costs of the dies and price per unit. It is worth mentioning that it was not possible to obtain in time the budget for the LED support by casting. The BOM for LS *v.2* can be found in Appendix B.6.

Table 5.6: LED Signal unit price comparison

Product	Die cost [€]	Unit price [€]
LS *v.2*	38.000 + LED sup.	18,34

In any case, this component has a high investment cost. However, due to the size of the product, its cost per unit is low, which for large production volumes would be very beneficial to the company.

In Table 5.7, can be seen the cost comparison between manufactured and standard components. Unlike the other models, in this model the cost of manufactured components was lower than standard components, due to the manufacturing route and materials selection.

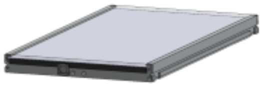
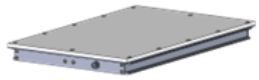
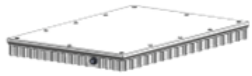
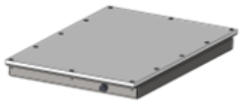
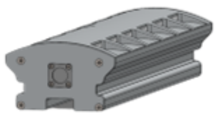
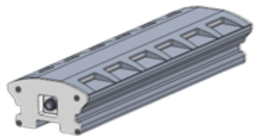
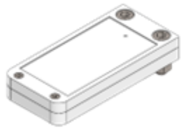
Table 5.7: Comparison between manufactured and standard components in LS versions

Product	Manufactured components [€]	Standard components [€]
LS *v.1*	2,00	16,34

5.4 Conclusion

Table 5.8 briefly summarizes the economic analysis of the Next-Cross *v.2* products.

Table 5.8: Next-Cross economic analysis summary

	v.1	***v.2***
PS	 Unit cost: 377 € Investment: 0 €	Extrusion Unit cost: 200,72€ Investment: 3.350 € 
		Injection molding Unit cost: 120,48€ Investment: 48.000 € 
		Extrusion no data 
LM	 Unit cost: 111,15 € Investment: 3.000 €	 Unit cost: 69,91 € Investment: 23.500 €
LS	 Not produced	 Unit cost: 18,34 € Investment: 38.000 + LED sup.

Chapter 6

Quality control and sustainability

This chapter is about defining methods to control product quality as well as product life cycle, end-of-life, and recycling.

6.1 Quality control

Quality control in industry is considered essential because it enables standardization of production from start to finish. When a defective item appears, it is called a nonconformity because it does not meet the required specifications.

Quality control in Pavnext's processes can bring benefits such as:

1. Efficient use of resources;
2. Reduce costs;
3. Improves production methods;
4. Quality culture within the team;
5. Standardize products and services.

Implementing improvement-focused methods depends on the efforts and understanding of all stakeholders, because new technologies are not enough to make projects sustainable. In addition, it is essential to use quality tools to reduce or even eliminate waste in order to maintain control and quality in processes.

6.1.1 Frameworks

In order to continuously improve Pavnext's products and services, and thus their quality, the author of this thesis indicates the two following frameworks to help achieve the company's goals.

A. PDCA

The PDCA (Plan-Do-Check-Act) cycle represented in Figure 6.1 is a four-step, iterative approach to continuously improving processes, products or services and solving problems. It involves systematically testing possible solutions, evaluating the results, and implementing those solutions that have proven effective (ASQ, 2022).

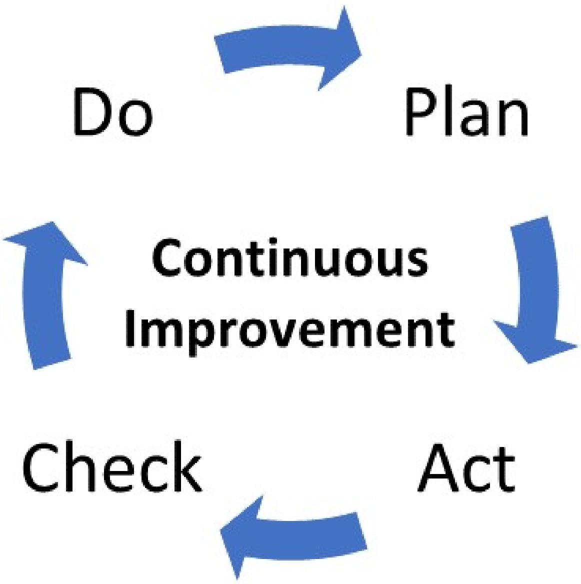


Figure 6.1: PDCA iterative four steps

The four phases of the cycle are:

- **Plan** — Identify and analyze the problem or opportunity, develop hypotheses and decide which ones to test, and formulate an action plan;
- **Act** — Test the potential solution and measure the results;
- **Check** — Investigate the result, measure the effectiveness and decide whether the hypothesis is viable or not;
- **Do** — If the solution is successful, carry out its implementation, standardization, and finally draw conclusions.

Preventive and continuous use of this method can avoid impulsive team decisions and waste of resources, identify potential process improvements, and prioritize the quantification of data and results that are essential for a better management.

B. 5s

The 5S program was developed by Kaoru Ishikawa in the 1950s, during the country's recovery period after the end of World War II. It includes the five Japanese words seiri (sort), seiton (put in order), seiso (shine), seiketsu (standardize), and shitsuke (preserve). The 5S philosophy focuses on simplifying the work environment, organizing the workplace effectively, and reducing waste while improving safety and quality (Patel and Thakkar, 2014).

Originally, the 5S program was applied to achieve a just-in-time production rhythm. Today it is a tool used within the framework of the Lean philosophy. Each of these words reveals a principle to be applied in the day-to-day operations of the business. In short, it can be said that:

- **Seiri** — Seiri (sense of use) allows organizations to have a good sense of keeping only what works and what they use most in the work environment. With this practice, companies can have more open spaces, facilitate the movement of people and products, increase employee comfort and safety, speed up environmental cleaning, reduce waste and promote productivity;

- **Seiton** — Seiton (sense of organization) ensures that companies organize their work environment and know where to store each document or material they need. Each item must have its place, according to the role it plays in the company's processes, and must be returned to that place after use. In this way, companies can reduce the time spent searching for materials, speed up processes, improve inventory management, make it easier to clean the environment and reduce losses;

- **Seiso** — Seiso (sense of cleanliness) develops awareness that cleanliness is everyone's responsibility. This step encompasses everything from the individual spectrum (the cleanliness of each workplace) to the collective spectrum (the cleanliness of areas such as restrooms and the company cafeteria). It should be noted that cleanliness is important for both the quality of the product and the quality of health and safety conditions in the workplace. In this way, companies can improve their quality of life, reduce the risk of contamination by biological agents, create a more pleasant environment for everyone, and increase safety in the workplace;

- **Seiketsu** — Seiketsu (sense of normalization) brings us the concept of normalization, which makes commonplace and systematized the new values and standards imposed by Seiri, Seiton, and Seiso. Standardization is fundamental to quality control and brings countless benefits to companies, such as better control of processes, higher quality in general, streamlining production processes, reducing errors and increasing efficiency and productivity;

- **Shitsuke** — Shitsuke (sense of discipline and self-discipline), that is, making the new standard a habit, a lifestyle. This step is essential so that such changes are not intermittent or temporary, but become a true philosophy of work. It is the sense of discipline that enables companies to develop continuous improvement cycles.

6.1.2 ISO 9000

The ISO 9000 (ISO9000, nd) family of standards was developed with the aim of promoting guidelines that can be implemented by companies and institutions around to ensure quality in the performance of their internal and external processes.

The ISO 9000 guarantees credibility, solidity, responsibility, and facilities in the company's business relations. In addition, users of the company's products or services can have greater security in the consumption or use of these products.

Therefore, according to the author it is highly beneficial for Pavnext to focus on obtaining this certification, in particular ISO 9001. This certification is obtained after an audit by an accredited certification institution.

ISO 9001:2015 (ISO9001, nd) is defined as an international standard that specifies the requirements for a QMS (Quality Management System). Organizations use the standard to demonstrate that their products and services meet customer and regulatory requirements.

It is worth noting that the frameworks presented above work together with the requirements that must be met for ISO 9001:2015 certification, such as process mapping, quality policy, and management system planning.

6.1.3 Maintenance

Next-Cross products will operate in a variety of conditions, such as:

- Variable loads due to the passage of vehicles or pedestrians with different weights;
- Variable loads associated with non-constant vehicle and pedestrian speeds;
- Subject to a high rate of passages;
- Exposed to weather condition;
- Exposed to citizen vandalism.

In this way, once any unit presents a defect, the author recommends Pavnext to replace it with a new or reconditioned unit, thus effectively responding to the problem presented by the cities. Once replaced, the defective unit will be taken to the workshop to be evaluated and reconditioned. When reconditioning is not possible, the functional components will be reused, and the rest taken for recycling.

6.2 Sustainability

This sub-chapter aims to summarize the concern taken in the selection of materials, product life cycle, end of life, and recycling. In addition, it is worth noting that Pavnext strives to develop its assembly line with maximum energy efficiency and minimum waste.

6.2.1 Material selection

The material selection was considered as one of the main factors for the sustainability of the product. Thus, the selected materials are recyclable and can already be used non-virgin for the manufacturing of the units.

In addition to careful material selection, design and manufacturing processes can also be optimized, not only to minimize material losses but also to save energy for manufacturing, transportation and storage.

6.2.2 Life cycle

Regarding the life cycle of each Next-Cross product, the next subsections detail the information and fatigue simulations performed in SolidWorks (see Appendix C) for the Pedestrian Sensor and LED Marker versions *v.2*. It is worth noting that the fatigue analysis was not extensive and did not consider factors such as impacts or vehicle speed. Also, the LED Signal was not considered in this analysis because it is not subjected to mechanical loads.

I. Pedestrian Sensor *v.2*

For the Pedestrian Sensor a daily frequency of 2.000 people was stipulated. In Equation 6.1 can be seen that at the end of 1 year a frequency of 730.000 cycles is expected.

$$2.000 \times 365 = 730.000 \tag{6.1}$$

Thus, being that Pavnext wants its products to have a useful life of at least 10 years, in Equation 6.2 can be seen that it is expected a number of 7.300.000 cycles in 10 years for the Pedestrian Sensor *v.2*

$$730.000 \times 10 = 7.300.000 \tag{6.2}$$

Performing a simplified fatigue analysis in Solidworks, considering only a center force of 1.000 N showed that the structure is not damaged after this number of cycles. In Appendix C on section C.1, C.2 and C.3 the results for the bases of the three PS *v.2* models can be analyzed.

II. LED Marker *v.2*

For the LED Marker, a daily frequency of 10.000 vehicles was considered. For a light vehicle with four wheels, this frequency would be multiplied by 2. Thus, as can be seen in Equation 6.3, 7.300.000 cycles are expected after 1 year.

$$10.000 \times 2 \times 365 = 7.300.000 \tag{6.3}$$

In Equation 6.4 can be seen that 73.000.000 cycles are expected at the end of 10 years.

$$7.300.000 \times 10 = 73.000.000 \tag{6.4}$$

With this data, a fatigue analysis was performed, considering a center force of 10.000 N. Since the alternating stress in the model is below the minimum value of the S-N curve, there was no damage to the model. The result for the LM *v.2* can be seen in Appendix C in section C.4. It is worth reiterating that the analysis was not very extensive and there was not much refinement of the study due to limited computing power, but that this data serves as a good indicator of the life expectancy of the product.

6.2.3 End-of-life

EOL (End-of-Life), in the context of product life cycle, refers to the final stages of a product's existence. The particular concerns of EOL depend on the perspective of the manufacturer or the user. For the manufacturer, EOL is not only about ceasing production, but also about continuing to meet the market needs that the product fulfills, which may lead to the development of a new product. For the user, EOL is about responsibly disposing of the existing product, switching to another product, and ensuring minimal disruption.

In Table 6.1, the EOL options for a product can be seen.

Table 6.1: End-of-life options (CES Edupack)

End of life option	Description	Environmental burden
Reuse	Extension of product life	Lowest
Re-engineer	Incorporation of re-engineered part into new product	⇩
Recycle	Reprocessing of material into primary supply chain	
Combustion	Recovery of the calorific content of the material	
Landfill	Disposal of material	Highest

At the end of each Next-Cross product's life, the components that cannot be reused will be destined for recycling.

6.2.4 ISO 14000

ISO 14000 (ISO14000, nd) is a set of international standards for environmental management. These standards, also referred to as EMS (Environmental Management Systems), summarize a set of guidelines for environmental audits, environmental performance evaluations, and product life cycle analyzes.

The main objective of ISO 14000 is to ensure that certified corporations are constantly seeking to improve environmental protection and mitigate problems that their production chain could bring to stakeholders and society. For companies, the implementation of these standards allows them to enhance their brand, gaining more prestige and respect for their sustainability.

In this sense, and in accordance with one of Pavnext's philosophies, the author believes that obtaining the certification ISO 14001 would be of great importance.

ISO 14001:2015 (ISO14001, nd) specifies the requirements for an EMS that an organization can use to improve its environmental performance. This standard is used by organizations that want to systematically manage their environmental responsibilities and thus contribute to the environmental pillar of sustainability.

6.3 Conclusion

In the development of Next Cross products, attention was always paid to sustainability. For example, processes and materials were chosen to minimize waste and have the most appropriate end-of-life possible.

Next-Cross products are also in line with the UN Sustainable Development Goals. This is because they are infrastructure solutions that can increase pedestrian safety and thus reduce accidents. Also, because they go hand in hand with the concept of Smart Cities and, in addition to promoting safety, collect important data for more efficient traffic management.

Chapter 7

Conclusions and future works

This chapter presents the conclusions of this dissertation and outlines the prospect of future work that is believed to be of interest in enhancing the Next-Cross product capabilities.

7.1 Conclusions

The main objective of the project was the industrial development of Next Cross products by introducing new manufacturing routes related to industrial mass production. This objective was achieved by designing Next-Cross v.2, a more economical version than the current one. The alternatives development phase was a long and iterative process, combining industrial design with new manufacturing processes to reduce costs and the number of components.

As mentioned in Chapter 4 the pillars of the industrial development of the Next-Cross products had cost per unit as the main factor. Thus, by combining design, material selection and manufacturing processes it was possible for the Pedestrian Sensor *v.2* not only to reduce its weight and number of components, but to achieve a large reduction in the cost per unit.

The LED Marker *v.2* was promising because its greater thickness and profile guarantee the absorption of mechanical loads. As for the post-processing by machining, it was not possible to avoid it in this product, but it was tried to reduce the machined area to decrease costs in a mass-production scale. Also with new manufacturing approaches, it was possible to reduce the number of components as well as the cost per unit.

Regarding the LED Signal *v.2*, not only a great reduction in components was achieved, but also a new design that guarantees the installation on any vertical sign on the crosswalks, whether new or existing. This ensures that Pavnext has less bureaucracy compared to the old solution, as well as a much more simplified version.

It is worth noting that, as seen in the economic analysis in Chapter 5, depending on the manufacturing process, the investment is only valid when producing a large number of units, which leads Pavnext to perform a thorough market study before proceeding to any version.

Throughout the dissertation, the potentialities of Next-Cross were recognized and, although it was possible to optimize many aspects, it is important to recognize that there are others under which it is possible to work in order to intensify the capabilities of the product. Therefore, based on all the knowledge acquired throughout the work period, the prospects for future works that are considered interesting for the progress of Next-Cross products will be presented in the next section.

7.2 Future works

With regard to the development of Next-Cross products, the author of this dissertation considers it worthwhile to continue the following development:

1. Topological analysis.

   Perform an extensive static and dynamic study in order to optimize the topology of the manufactured products to save more material, thus making it even more advantageous for mass production. As well as the help of regenerative design as a way to optimize the structures.

2. Analysis of impact behavior in the LED Marker.

   Perform an extensive analysis of the impact behavior in the LED marker, in order to ensure that the geometry guarantees the rigidity required for its use.

3. A broader product life cycle study.

   Perform more detailed analysis considering the different speeds and impacts that the LED Marker and the Pedestrian Sensor are subjected to.

4. Development of a flat solution for the LED Marker.

   Developing a version at the same level as asphalt (flat) in order to avoid impact and to be able to add photovoltaic cells throughout the product in order to make it more sustainable.

5. Developing new ways of fixing.

   Development in civil engineering, new forms of foundations in order to avoid "mounting frames" and thus further reduce the cost of the product unit.

6. Developing new approaches for the Pedestrian Sensor.

   Use cameras and artificial intelligence for detection and identification of crossings to increase the detection area and reduce costs.

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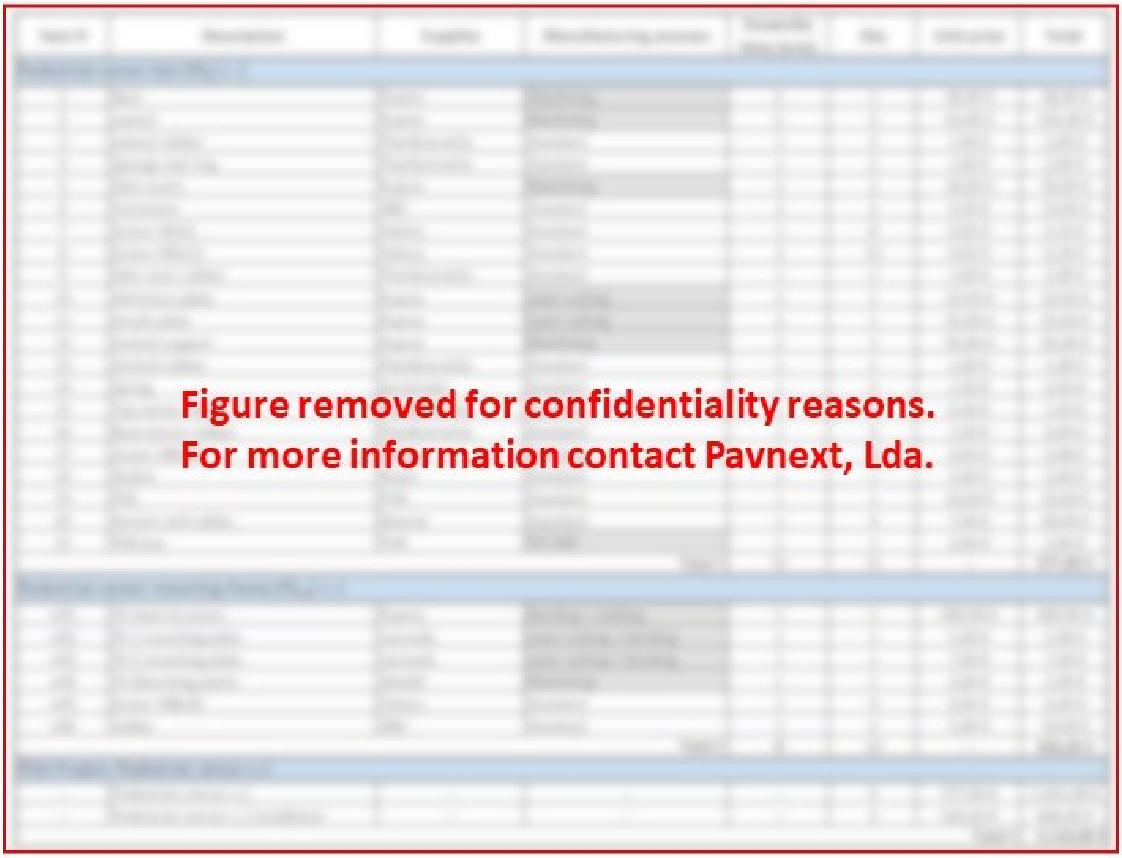
Appendix A

Next-Cross *v.1*

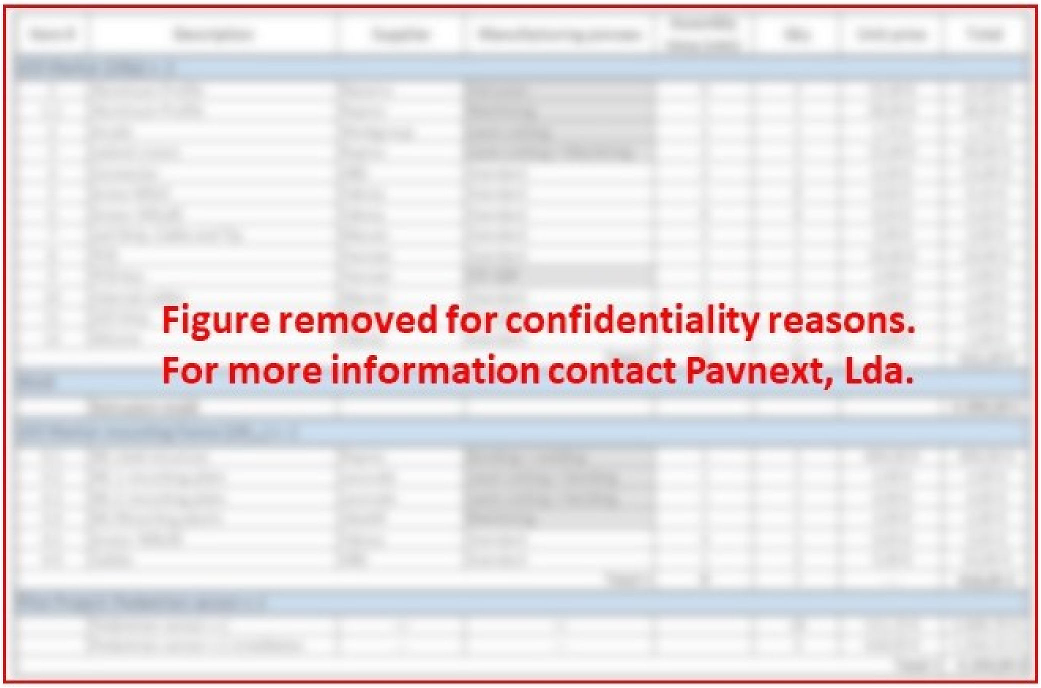
A.1 Pedestrian Sensor *v.1* BOM

Table A.1: BOM Pedestrian Sensor *v.1*



A.2 LED Marker *v.1* BOM

Table A.2: BOM LED Marker *v.1*



Appendix B

Next-Cross *v.2*

B.1 Pedestrian Sensor *v.2* by extrusion

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For more information contact Pavnext, Lda.

Figure B.1: Pedestrian Sensor *v.2* by extrusion exploded view

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Figure B.2: Pedestrian Sensor *v.2* base by extrusion

B.2 Pedestrian Sensor *v.2* by injection molding

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Figure B.3: Pedestrian Sensor *v.2* by injection molding exploded view

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Figure B.4: Pedestrian Sensor *v.2* base by injection molding

B.3 Pedestrian Sensor *v.2* by bending

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Figure B.5: Pedestrian Sensor *v.2* by bending exploded view

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For more information contact Pavnext, Lda.

Figure B.6: Pedestrian Sensor *v.2* base by bending

B.4 LED Marker *v.2*

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Figure B.7: LED Marker *v.2* exploded view

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Figure B.8: LED Marker *v.2* profile

B.5 LED Signal *v.2*

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Figure B.9: LED Signal *v.2* exploded view

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Figure B.10: LED Signal *v.2* base

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Figure B.11: LED Signal *v.2* top cover

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Figure B.12: LED Signal *v.2* LED support

B.6 BOM *v.2*

Table B.1: Pedestrian Sensor *v.2* by extrusion BOM

Table B.2: Pedestrian Sensor *v.2* by injection molding BOM

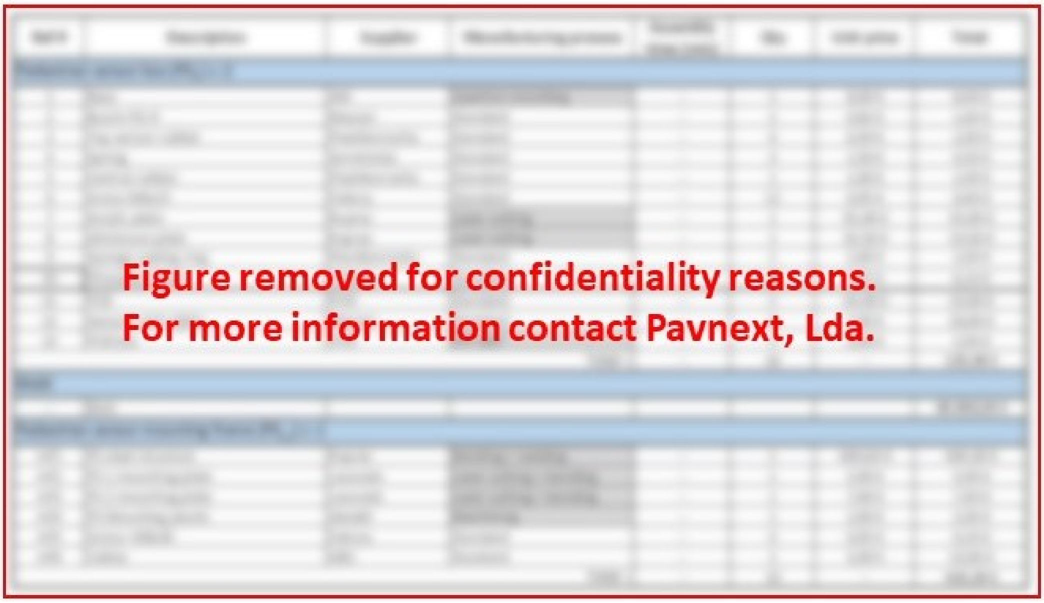
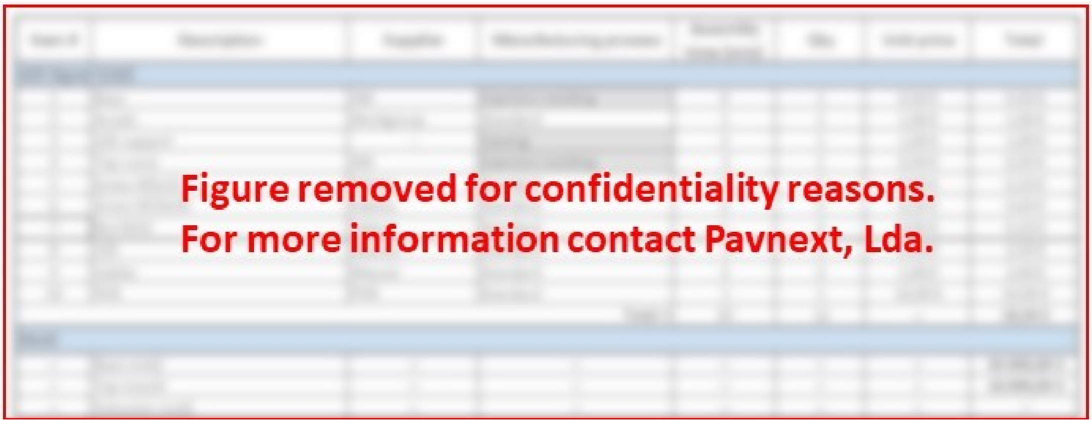


Table B.3: LED Marker *v.2* BOM

Table B.4: LED Signal *v.2* BOM



Appendix C

Product Simulations

C.1 Pedestrian Sensor *v.2* — Extrusion

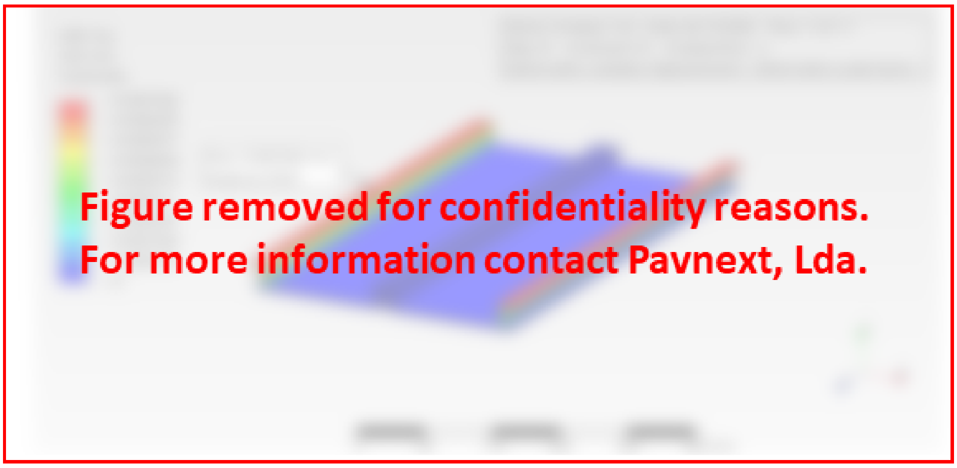


Figure C.1: Pedestrian Sensor *v.1* displacement

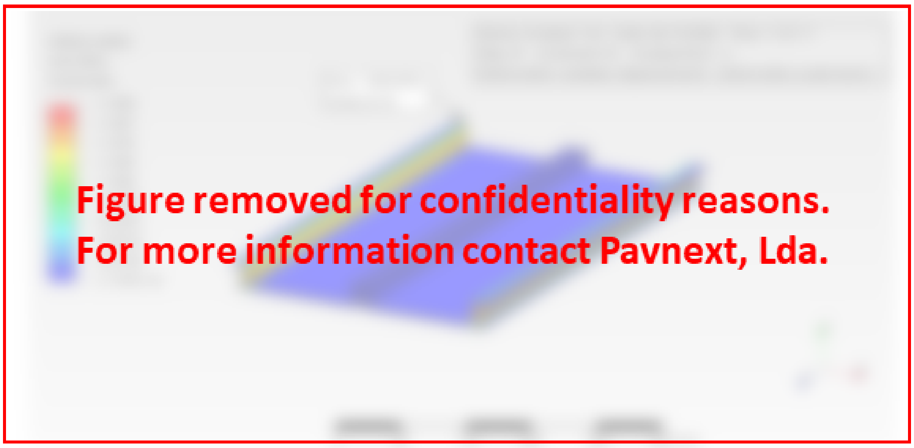


Figure C.2: Pedestrian Sensor *v.1* Von Mises stress

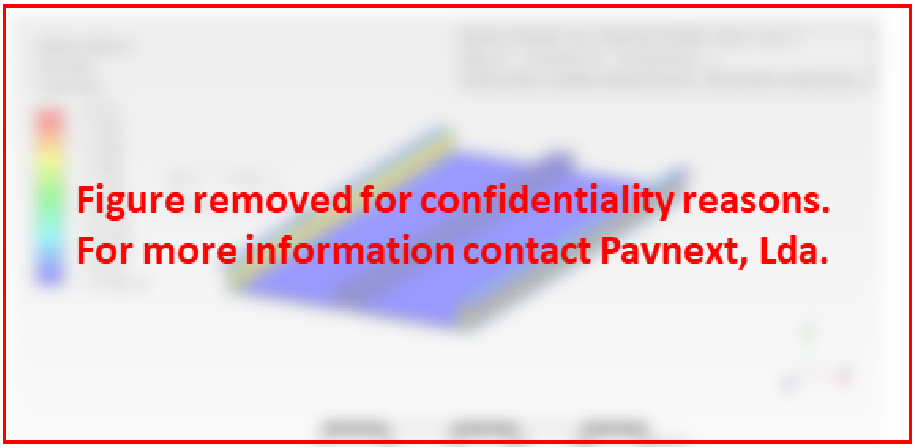


Figure C.3: Pedestrian Sensor *v.1* Tresca stress

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Figure C.4: Fatigue analysis of PS *v.2* by extrusion

C.2 Pedestrian Sensor *v.2* — Injection Molding

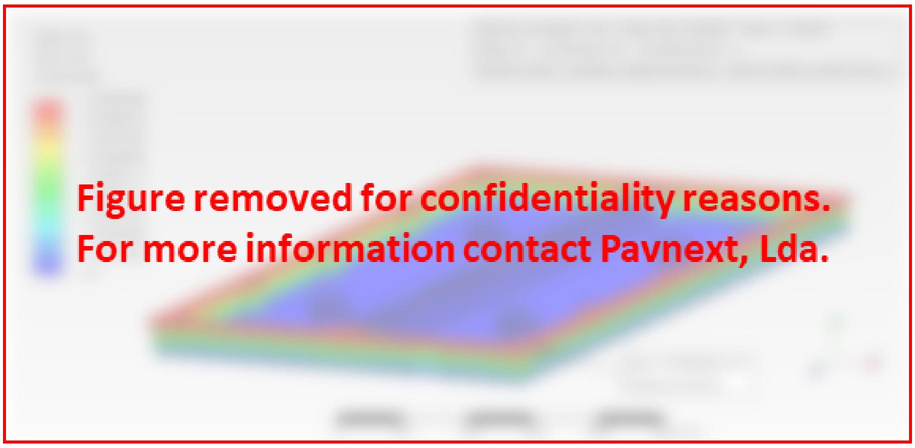

Figure C.5: Pedestrian Sensor *v.1* displacement

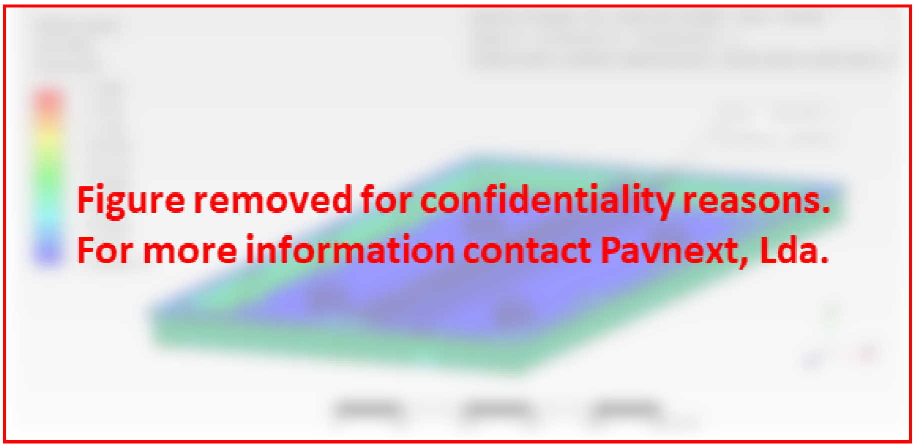

Figure C.6: Pedestrian Sensor *v.1* Von Mises stress

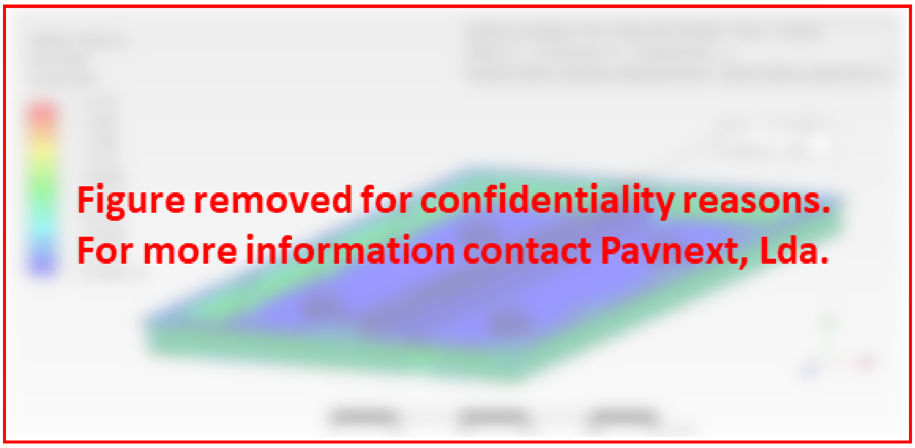

Figure C.7: Pedestrian Sensor *v.1* Tresca stress

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Figure C.8: Fatigue analysis of PS *v.2* by injection molding

C.3 Pedestrian Sensor *v.2* — Bending

Figure C.9: Pedestrian Sensor *v.1* displacement

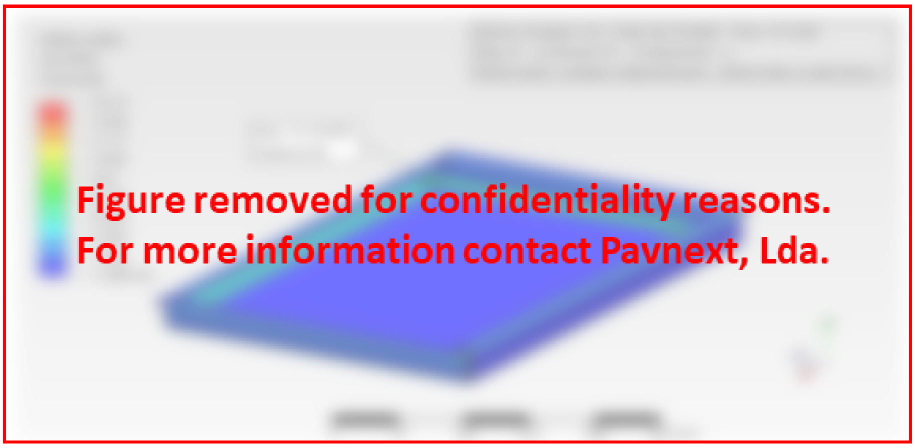

Figure C.10: Pedestrian Sensor *v.1* Von Mises stress

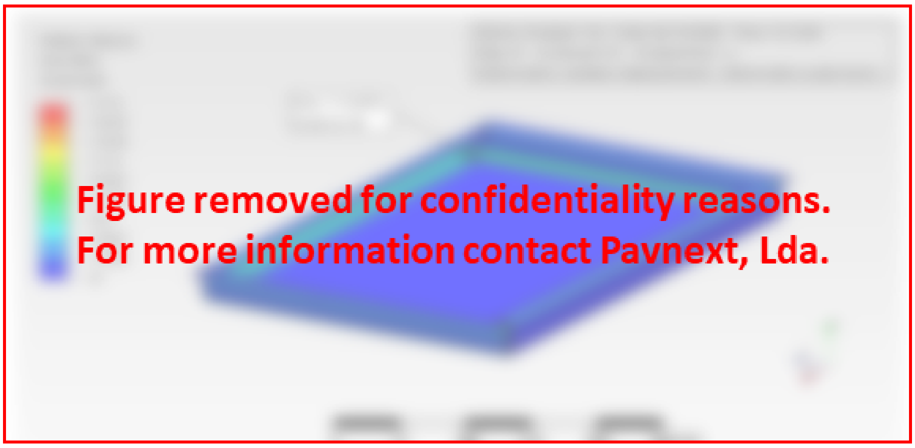

Figure C.11: Pedestrian Sensor *v.1* Tresca stress

Figure removed for confidentiality reasons.
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Figure C.12: Fatigue analysis of PS *v.2* by bending

C.4 LED marker *v.2*

Figure C.13: LED marker *v.1* displacement

Figure C.14: LED marker *v.1* Von Mises stress

Figure C.15: LED marker *v.1* Tresca stress

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Figure C.16: Fatigue analysis of LM *v.2*