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Design and Development of a Compact Mosquito Net with Innovative Applications for Environmental Impact Reduction

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Abstract

When dealing with the design or revamping of products or services in the modern days, it is necessary to take into account the effects of global concerns such as climate change and environmental pollution. During this process, it is essential to make use of established techniques, such as the 3R recovery approach and the circular economy approach, both of which aim to reduce the amount of waste produced while simultaneously increasing recycling, regeneration, and reusability.

The current work is set in this framework, presenting a study that was carried out within a manufacturing company of mosquito nets, during the process of designing and industrialization of a novel type of product.

In particular, the work has three main goals. The first one is related to the identification of possible reuses for mosquito nets that have reached the end of their useful lives. The aim is in this case to mitigate the impact that the product takes on the environment, opening up new avenues of commercial activity for the business.

To address this issue, several strategies for finding new product applications have been researched and analysed in the available literature, choosing the most suitable one for this case. The technique involves the employing of patent databases to perform ad-hoc searches and retrieve a set of Cooperative Patent Classifications (CPCs). These CPCs contain descriptions of application fields that can be used as external stimuli in the creative process. No other industrial applications of this method are known in the literature. Therefore, this can be considered as a reference for future similar purposes. The results acquired in terms of generated ideas are ultimately exposed, offering a practical example of reuse in the textile context.

Furthermore, the phases of designing and developing the new product, where the net would be utilized, are described in detail. In comparison to the existing state of the art, four key innovations were developed and subsequently industrialized. These innovations aim to create a compact product that prioritizes safe and easy installation, high reliability, and aesthetic appeal, especially for the Italian and European markets.

The final part of the study aims instead to investigate the effectiveness of textual stimuli of the form previously employed in generating larger, more original and varied sets of ideas in the creative process of identifying new product application fields. To explore this, an experimental test was conducted with a group of volunteers. Contrary to expectations, the results indicate that this type of textual stimuli has no significant impact on the outcomes in terms of these metrics.

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Nomenclature

CPC: Cooperative Patent Classification

EK: Expanded Keyword

IPD: International Patent Database

SAO: Subject-Action-Object

S:F.: Safety Factor

VBA: Visual Basic Application

DFD: Data Flow Diagram

b: axial tooth length

$F_{t\ amm}$: admissible tangential force

m: module

y: shape factor

η_d: velocity coefficient

σ_r: Ultimate tensile strength

1 - Introduction

It is universally acknowledged that environmental issues, such as pollution and climate change, cannot go on indefinitely. Therefore, it is imperative to always consider these effects as potential outcomes of our actions, especially within the industrial sector. This is particularly crucial when engaging in the development or modification of new products or services (Kamp Albæk et al., 2020).

The United Nations' 2030 agenda encompasses numerous objectives aimed at promoting prosperity, economic progress, and environmental protection. Among these goals, a key area of emphasis is the adoption of sustainable production and consumption practices. This comprehensive agenda consists of seventeen distinct goals that require active pursuit (World Top 20, 2022). One of the primary objectives is to minimize waste generation through conscientious practices, including recycling, regeneration, or reutilization of generated waste, whenever feasible (UNRIC (United Nations Regional Information Centre), 2019).

To achieve these objectives, effective strategies are implemented, known as the "3R recovery approach" (Moreno et al., 2016), which is part of the broader and more intricate Circular Economy framework. Based on these principles, it is essential to consider product and goods design, taking into account not only the environmental consequences at a single stage in the product's lifespan but throughout the entire life cycle, which is conceptualized as a closed loop, from cradle to cradle (McDonough and Braungart, 2002).

Hence, it is imperative to address the potential for multiple object utilizations, such as through repair or reconditioning, alongside the idea of reusing developed products and material recycling, from the initial stages of the design process. The significance of avoiding challenging recyclable materials and harmful chemicals is particularly pertinent for all of these objectives.

In order to mitigate the environmental consequences associated with a preexisting product, the most effective and appropriate approach(es) to pursue are contingent upon the specific nature of the product in question and its current life cycle. If the design for sustainability method (Moreno et al., 2016) has not been considered from the beginning, certain techniques may prove challenging or even harmful to adopt. For instance, if different materials are welded or bonded together, the recycling procedure will be more difficult and less economical and environmentally friendly.

In this scenario, the most practical strategy may be to reuse (Bocken et al., 2016) all or a portion of the product as-is after disassembly (Crowther, 1999) or after reconditioning. The research conducted in this thesis is set in this context, focusing on identifying possible reuse strategies for a product that already exists on the market: mosquito nets. This type of products plays a crucial role in the fight against mosquitoes and the diseases they carry in some parts of the world. Besides, the installation of these devices prevents this and other insects to enter in indoor spaces, providing protection against bites and annoying buzzing.

In particular, the research was conducted within a manufacturing company specializing in this type of goods, during the development process of a new product model. The company, named Palagina, is located in the province of Florence, Italy, where the author was engaged while participating in the industrial PhD program. The first goal of the project, as described in detail below, is in fact to create a device with a lateral sliding rollable net, with a reduced thickness and low visual impact. This, maintaining high product quality standards and ease of installation. It would be the first type of mosquito net on the market with this combination of attributes.

In fact, existing lateral sliding mosquito nets have high overall dimensions perpendicularly to the direction of net unrolling, which can hardly fall below 40-45 mm. Therefore, the insect screen cannot be installed in all those situations where there is limited space between the window and, for example, the shutter. Although there are specific insect screens with a smaller footprint, these have limitations in terms of durability of mesh, high costs and considerable visual obstruction. These are the pleated mosquito nets, a well-established but delicate product and, in terms of design, not very appreciated by Italian and European customers. On the other hand, the historic Bettio company has recently launched the “Picoscenica” product, a thin flat screen mosquito net which, however, is excessively delicate and complex to assemble.

The project phases consisted in, first, performing a feasibility study, on the basis of given objectives and constraints. Hence, a literature review about the already existing technologies in the field has been executed. This is one of the most important steps, in order to be aware of the already patented solutions that can not be replicated. Then, product development is performed, through an iteration process in which different solutions are identified, drawn, tested and improved.

Lab tests are performed, first for each sub-assembly to acquire data of the specific constructive solutions, then with all the elements combined, in order to observe the behaviour of the final product. As in all types of products, if the entire assembly is tested without having proved the effectiveness of the single parts, if a problem occurs it will be more difficult to isolate the cause. The main method to perform tests is through the construction of rapid prototyping parts, especially for the components that will be realized in plastic, while for the aluminium profiles the extrusion matrixes are created almost immediately, using prototyping only in the very preliminary phase.

The second goal of this work is to reduce the environmental impact of the new product under development and, possibly, of all the other types of products already on the market.

In order to complete projects for new mosquito nets models quickly and with a rapid return of investment, one of the drivers followed during the process is to try to reuse as many components as possible that are already used in other products. This is because it reduces design time on the one hand and costs both during the development phase and afterwards, thanks to a leaner management of component parts at a company level. For the same reasons, the firm has always focused, during product development, mainly on meeting the stringent requirements of the various stakeholders, identifying new, robust design solutions.

Consequently, although ecologically sustainable design guidelines are always generally followed during development (Maccioni et al., 2021), no well-structured environmental impact analyses on the life cycle of mosquito nets or their components have been carried out so far. An in-depth study of a product Life Cycle Assessment (LCA) remains outside the scope of this work. However, a preliminary analysis was made on which are the main sources of wastes and at which stages of the product life they occur. As it will be discussed in the following sections, nets resulted to be the most critical elements to treat at the end of their life. Therefore, new ways to reuse scraps and end-of-life insect screens will be identified, following a procedure found from literature (Fiorineschi et al., 2018). The selected method provides a systematic way to generate stimuli to be used in the design process. These stimuli are of textual type and are related to the descriptions of patent subclasses (CPCs), as will be discussed further.

It is also important to note that the previous absence of this type of analysis, and thus the implementation of any corrective actions to reduce the product's environmental impact, was never conducted by the company staff because it was unknown how to deal with them effectively.

In the final part of the work, an attempt is made to assess the general effectiveness of using such a kind of textual stimuli during the findings of new application fields for a given product. To do this, an experimental activity was carried out in which the same issue was presented to two groups of participants: a test group and a control group. The control group was asked to generate ideas with only a simple description and a graphical representation of the starting product. The test group, on the other hand, has to employ a set of additional given stimuli. The obtained ideas were then categorized according to functions and areas of application, evaluating whether there were differences in terms of quantity and originality of the outputs obtained.

It should be noted that the results of this analysis will not determine the overall effectiveness of the method itself. Instead, they will indicate whether the provided textual stimuli can or cannot modify the outputs of the design process. The results will only be able to suggest an estimate of how effective or ineffective the type of stimulus provided by the method is in generating ideas, according to different metrics considered, that will be exposed in a detailed manner in the subsequent sections.

An in-depth explanation of the thesis objectives, and how they are interconnected, is provided in the following subsection, outlining the main contributions of the work from both an industrial and a scientific literature perspective. Subsequently, the structure of the thesis is illustrated, with indications of where information related to the different stages of the work can be found.

1.1 - Objectives and Contributions of the Work

This thesis, conducted within an industrial framework, outlines three primary, interconnected objectives. Achieving these objectives involves leveraging a diverse mix of methodologies, drawing from both standard product development practices and insights directly sourced from scientific research.

The first objective focuses on creating a new mosquito net model that features a lateral sliding mechanism, reduced thickness, and minimal visual impact without compromising quality and installation ease. This goal addresses a market need for a mosquito net that blends functionality with aesthetic appeal and spatial efficiency. In fact, traditional models, especially those with lateral sliding handlebars, face challenges in dimensional profile and installation due to spatial constraints. The development process for this objective is systematic and iterative, including feasibility studies, thorough patent searches to avoid infringement and take inspiration, and detailed lab testing for product refinement. Much of the development and design work took place over the first year, which was then followed by detailed design and the implementation of improvements resulting from the design reviews.

The company's need to mitigate the environmental impacts generated by the production and marketing of the product, now widely shared by various industrial sectors, led to the definition of the second main objective of the work. In particular, the focus was on implementing end-of-life strategies that target the primary sources of waste, especially the nets. For this purpose, various methodologies capable of generating useful stimuli for designers to identify new possible reuse application sectors were researched in the literature. Among these, the one most easily implementable in the specific industrial context was selected. Through targeted patent research, descriptions of patent classes (CPCs) were identified and then used as promoters of ideas for possible alternative development sectors. Thus, a systematic approach was adopted, which can be more easily replicated in different application sectors, thereby having broader validity. This objective illustrates the project's alignment with international sustainability goals, advocating for sustainable production and consumption. Moreover, as interesting results have been obtained, this work serves as an example for those who wish to implement a similar approach in future applications.

The third objective, conversely, is to assess the extent to which the patent class descriptions utilized in the second part of the study have effectively supported the process of identifying new application fields for end-of-life products. Indeed, while it is true that a certain number of ideas, with varied functions and application sectors, were generated with these stimuli, it remains unclear, from this part of the study alone, whether such a quantity and variety of ideas could have been similarly obtained without the employment of these additional descriptions. To provide a preliminary indication of the benefits derived from employing such textual stimuli in the conceptual phase of identifying new application areas for existing products, an ad-hoc experimental study was conducted. A group of volunteers from the Mechanical Engineering course at the University of Florence was involved, which was divided into two subgroups. A general description of a starting product was assigned, and only one of the groups was provided with additional patent descriptions, hence asked to imagine possible alternative application sectors. The results were then collected, and the relative differences between the two groups were analysed according to certain predefined metrics. The procedure was carried out with two different starting products, in such a way as to make the results less case sensitive.

This experimental activity proved to be a natural continuation of the second part of the study, as it places the specific results obtained within a broader context of validity, allowing for a more objective evaluation of the performance achievable with this methodological approach. Moreover, as observed in the literature, there are no similar studies in which patent class descriptions are used with the aim of identifying alternative end-of-life application sectors for existing products. For these reasons, the product design approach provided by the thesis in this respect is novel.

Given the aforementioned factors, the three objectives of this study can be summarized as follows:

- first, the design and development of a new mosquito net product that the company wants to undertake, in order to generate new potential for commercial expansion, taking into consideration not only product innovation but also the reduction of environmental impact and associated costs;
- secondly, after a preliminary analysis of the end-of-life environmental impact of the various components that make-up the product, the investigation into possible new reuses for the nets,

exerted through a methodology that utilizes patent classes descriptions as stimuli for the designer. This approach aims to explore new horizons of reuse, emphasizing sustainability and innovation;
- lastly, the assessment of the effectiveness of introducing such textual stimuli to determine whether they lead to ideas with significantly different characteristics in identifying alternative product uses, compared to not using any stimuli. In this way, a contribution is made towards a more general understanding of the innovative and sustainable potential that can be achieved with this methodology.

The mosquito net concept from which the new product takes inspiration is, as requested, the *Sintesi* model, one of the products most sold by the company. The design of the new product has followed a standard methodology, with the main following steps:

- objectives and constraints definition: a first trial list is drawn up;
- technical feasibility study: all the necessary parts for the correct functioning of the product are analysed. New components will be investigated to reduce product dimensions with respect to the other existing products. The outputs will include functional diagrams, a preliminary bill of materials for determining product costs, and preliminary investment assessments;
- literature review: patent searches are performed in order to have a background of what already exists on the market;
- prototype study, design, and engineering: drawings are realized for the creation of a functioning prototype to verify the components' performances;
- production design: final 3D and 2D CAD mechanical drawings are drafted with dimensions, control tolerances and selection of components' materials for the industrialization phase;
- organization of production processes: study of the assembly cycle and integration of the new components into the company production lines.

For the reasons stated so far, this study has led to the creation of a new mosquito net product, incorporating a unique combination of characteristics not seen before, by employing technological solutions that have become the subject of four different patent applications. By targeting key sources of waste and environmental impact, this study also aims to contribute to the urgent need for sustainability in design and manufacturing practices. This focus not only improves the project's environmental standing, but also contributes, in its own modest way, to the wider dialogue on sustainable development.

1.2 - Thesis Structure

A schematic overview of the thesis chapters is here provided, delineating the inputs and outputs of each part. In the subsequent sections of the introduction, a detailed presentation of the key characteristics of mosquito nets is outlined. This will help readers who are not experts in the field to grasp the fundamental operational principles and the challenges that are being addressed. Then, the typical product life cycle is reported, together with the main critical aspects of mesh recovery and recycling. The background is completed with the description of the benchmark products, in terms of semi-finished parts and assembly process. In particular, the *Sintesi* model is introduced, from which the new project will take inspiration for some of the technologies. The critical aspects for the new model designing are then briefly introduced in section 1 -, with the first operational diagrams and objectives and constraints list to be fulfilled.

Literature review follows in section 3 -, with the patent searches performed for the most important mechanisms of interest for the product, in order to acquire a first knowledge of the technical state of the art. Hints will be derived for the subsequent phases of design. A brief overview of contributions already existing in literature for helping designers to develop new products or to improve them is provided, highlighting their limitations, and explaining why the specific method has been chosen in this study.

In the methods section, first, an overview of the design process followed for the development of the new mosquito net is provided. This is based on information from the feasibility study provided in section 1 -. Then, a detailed explanation of the methodology employed for the identification of reuse strategies for end-of-life nets is outlined, together with its application to the specific study. Finally, the steps followed to assess if CPCs are beneficial, on a more general basis, in generating new product applications, is described in detail. This includes the metrics definition, hypotheses and research questions formulations, and the design of experiment.

In section 5 - work results are described in detail. They are reported in the following order: firstly, a deep explanation of the developed product, making reference to the four patented sub-systems; secondly, the outcomes of the subsequent study performed to accomplish with the firm requirement for reducing the product environmental impact, conducted with the method outlined in 4.2.2 -; lastly, the results of the experimental activity described in 4.3 -, in terms of data distributions and statistical significance values. Discussion and Conclusions follow in the final part.

1.3 - Mosquito Nets Characteristics

Different types of insect screens exist on the market, which are different on the basis of various specifications and technical characteristics, satisfying several categories of final users. One of the most critical factors in this sector concerns the thickness of the products. The thinner the insect screen, the easier it is to install, even in types of frames where there is little space. Achieving a small footprint is, however, always a challenge from a technical point of view because, with the same maximum reachable dimensions in width and height, the components must be miniaturised while maintaining good quality standards.

Considering a standard insect screen model, shown in Figure 1.1 below, the following elements can be identified: a headbox (1) which is fixed to a wall or to a lateral upright, inside which the winding tube (3) is housed; a fabric or insect screen net (5), rectangular in shape, with a first end fixed to the tube and a second opposing edge fixed to a handlebar (6) on which the user acts to wind and unwind the fabric. The handlebar is made of an aluminium profile that can take various shapes and sizes. In addition, there are two horizontal guides (4,9) arranged along the upper and lower walls of the opening, respectively, to which the handlebar is slidingly bound. On the opposite side to the headbox, there is another aluminium profile (8) fixed to the wall, which completes the entire frame. The product is then closed by means of special components (7) which, coming into contact with each other, ensure the correct anchoring of the handlebar. The net is kept in tension during all the operating phases of the insect screen thanks to specific parts that can be of various types. Generally, a torsion-type spring (2) is used, placed directly inside the winding tube, from which it receives the rotational movement, loading and unloading itself. The construction variants for each component and assembly are manifold and some examples are given below.

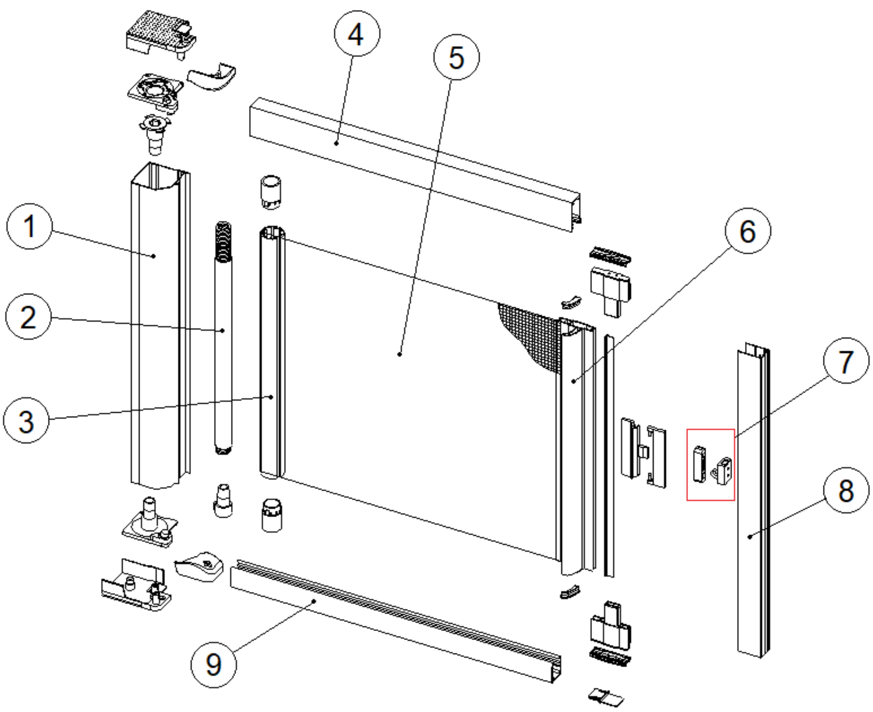


Figure 1.1 – Assembly example of a lateral sliding mosquito net.

Below are the main elements by which flyscreens can be categorised:

1.3.1 - Installation types

It can be of two types: recessed or in light. If the insect screen has to be installed in an already constructed backdrop with no predispositions, the choice must fall on an in-light installation. Otherwise, if the housings for inserting the profiles into the wall are already present, the installation is of the recessed type. An example can be seen in Figure 1.2.

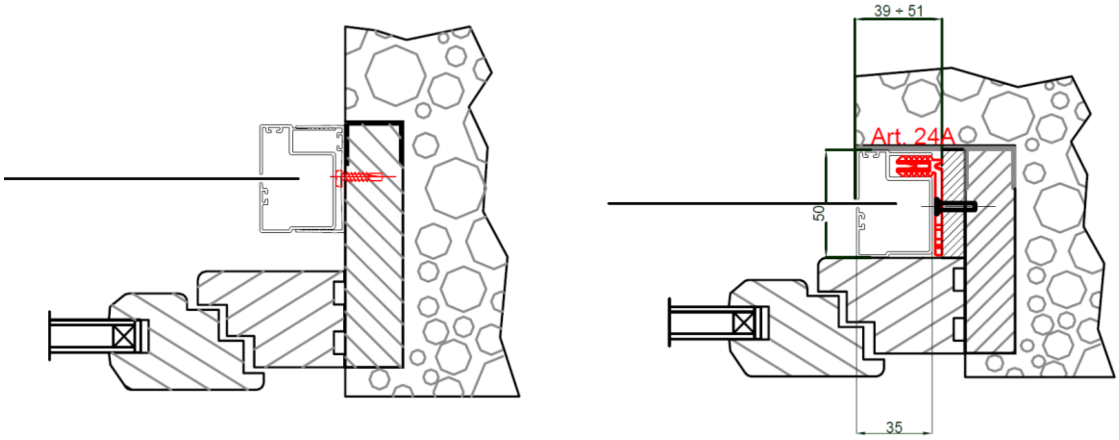


Figure 1.2 – In-light and recessed installation types.

1.3.2 - Net sliding modes

It can be vertical, lateral, central, bilateral or fixed. The choice varies depending on the size and type of opening to be covered, whether window, door or glass door. Generally, for window openings, vertical sliding insect screens or fixed frames are preferred, while for doors the recommended choice is the lateral type. The number of shutters of the insect screen (1 or 2) depends essentially on the width of the opening: if the size exceeds the maximum feasibility for one shutter, a central type product will be required. Bilateral products, on the other hand, offer the possibility of having a single net package but with closure on both sides. Three examples of a vertical, side and centre product are shown in the Figure 1.3 below.

Figure 1.3 – Vertical, lateral and central sliding models.

1.3.3 - Net tensioning technologies

The net can be retained in position by means of two main technologies, which involve either the use of an elastic return element, such as a torsion-type spring (Figure 1.4), or the use of a system of wires placed under tension during installation.

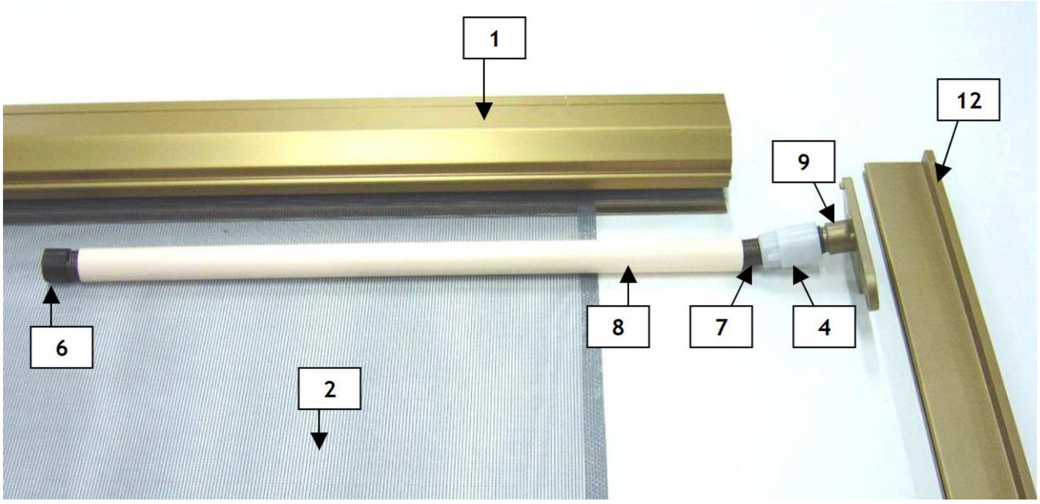


Figure 1.4 – spring group contained in a vertical mosquito net head-box.

Most products employ the first type of solution, but there is a category of insect screens, known as pleated nets, which adopt this alternative system. In the latter ones, the net is not wrapped around the winding tube during movement, but is folded on itself, opening or closing the frame. Small holes are created thanks to a special machine in specific positions, in which wires are later inserted. These wires, according to a predetermined configuration scheme, goes to hold the net and allow the correct sliding of the handlebar.
An example of this type can be seen in Figure 1.5. It should be noted that with this type of net, as the winding tube is not required, the overall dimensions are considerably reduced, at the expense, however, of a greater visual impact of the net, which is not always appreciated by the end user.

Figure 1.5 – Vertical sliding Plissé product example.

1.3.4 - Actuation

Most of the products are moved during use in manual mode, by acting on the aluminium profile known as the handlebar. The returning spring requires the user to apply a force when closing the insect screen, moving the handlebar away from the winding tube, while in the opposite direction the movement is ensured, in part or in total, by the spring itself. If the insect screen is of the pleated type, movement must be exerted by the user in both directions. Alternatively, the chain or motor-driven options are available. The chain, only for vertical products, allows the movement of the net without having to act directly on the handlebar, and has the great advantage of allowing it to be realised in width and height dimensions not achievable by products with returning springs. The motor, on the other hand, if present, is located inside the winder tube, and allows its movement.

1.3.5 - Closing technologies

Different technologies exist for holding the net in the closed position, which can be either mechanical or magnetic. Among the mechanical systems, the absolute simplest are realised by means of two counter surfaces, set against each other by the simultaneous movement and rotation of the handlebar. Alternatively, a solution known as 'Quick Lock' has been patented, in which a plastic rotor, located at the lower end of the aluminium guide, engages with the side end of the handlebar when it is approached, locking it in place. To disengage, it is then necessary to press the handlebar downwards again, releasing the rotor from its locked position. Figure 1.6 shows a rappresentative picture of the system.

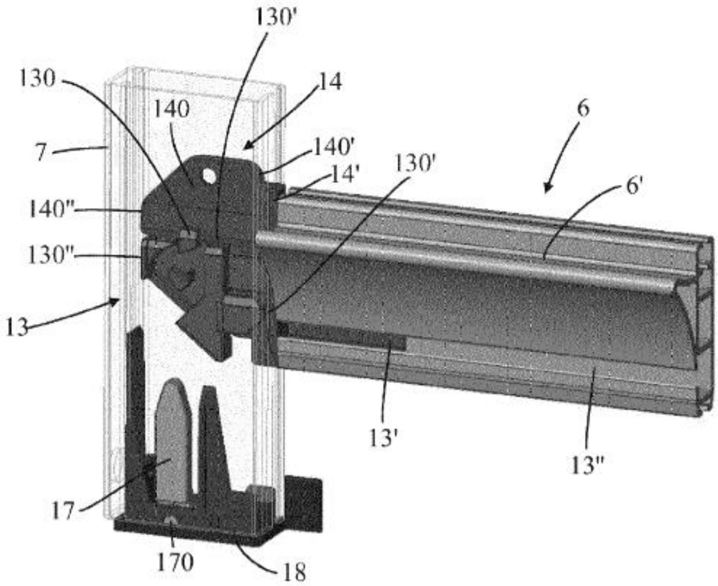


Figure 1.6 – Quick Lock retention system.

Alternatively, there is the so-called 'ratchet' release type, in which a rod placed inside the handlebar and coaxial to it, is pressed outwards by a spring. A plastic element with an overhanging surface is instead placed inside the aluminium guide. When the handlebar is moved downwards, the rod is pushed inwards by the protruding flap on the plastic and, once it has passed through, it remains in position. To release, instead, it is sufficient to press on a plastic lever on the handlebar, which causes the spring to compress, thus releasing the rod vertically.

On the other hand, magnetic closures can be characterised by several construction solutions. In vertically sliding insect screens, usually there are shaped magnets inside the plastic elements of the handlebar caps and guide feet. These, when coming into contact, provide a holding force equal to the difference between the magnetic attraction force and the returning force of the spring (Figure 1.7). On the contrary, in case of side-sliding solutions, extruded magnetic bands are more commonly found inside specific hollows in the handlebar and abutment profiles, which, coming into contact with each other, guarantee the necessary holding force (Figure 1.8).

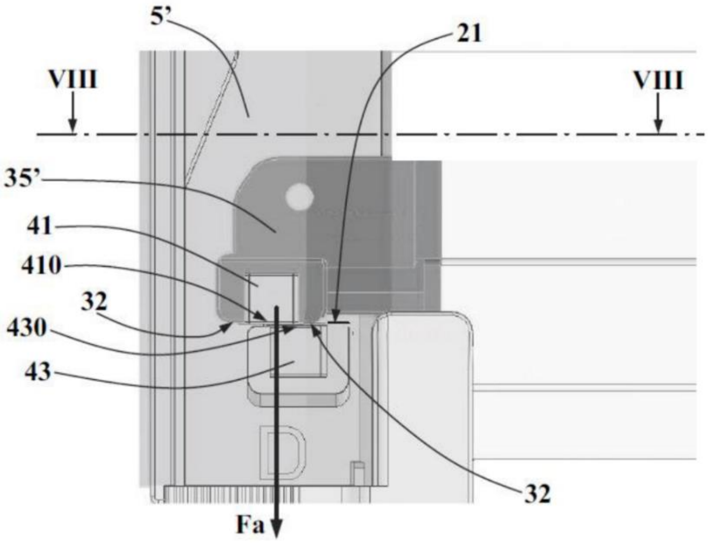


Figure 1.7 – Magnetic retention system.

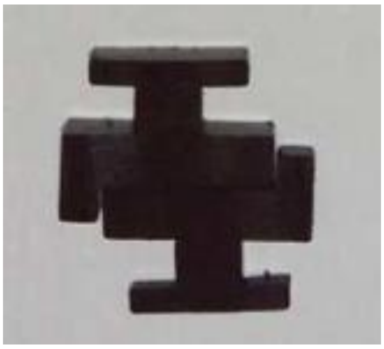


Figure 1.8 – extruded magnetic bands coupling.

1.3.6 - Net – frame interface

The insect screen, the main element of mosquito nets, must guarantee adequate protection from insects under all possible operating conditions. These include the presence of wind or impact from the user or accidental break-through events. There are different levels of retention that the net can offer and depend on how the net is connected to the horizontal or vertical guides. The main existing technologies involve the use of anti-wind brushes or buttons, or the use of zips or retaining chains. Below is a brief description of each system:

Anti-wind brushes

Medium-strength solution. Two stiff bristle brushes are placed in each side rail as shown in Figure 1.9. These have a flat base which is inserted into the slots along the profile. The bristles, inclined with respect to the normal to the base, are placed in the direction in which, if the mesh is impacted and tends to move away from the guides, they fit inside the mesh elements, holding it in place.

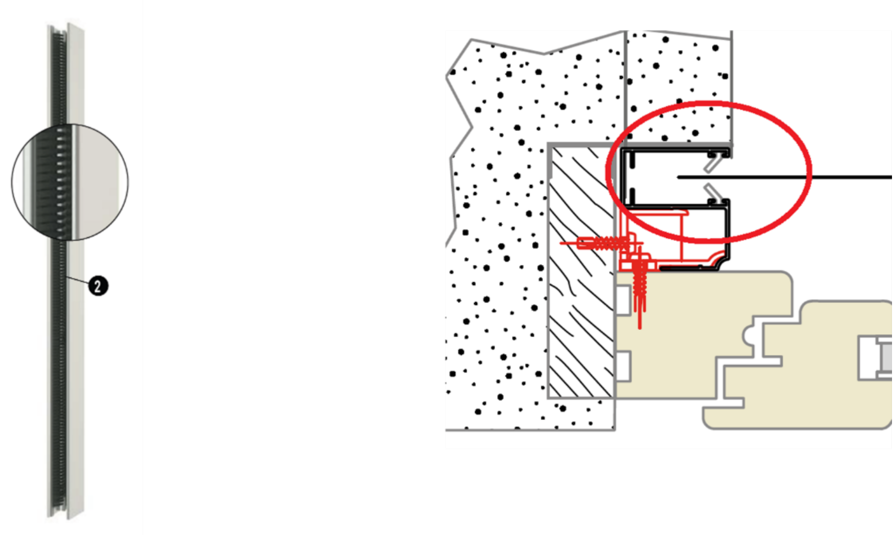


Figure 1.9 – Anti-wind brushes representation.

The main advantage of this solution is that it works properly even with high levels of frame out of square. Furthermore, no additional machining is required at the ends of the mesh, allowing it to be made directly from a semi-finished product with a single cut of aluminium tube and mesh. The drawback is that the guaranteed edge seal against insects is not optimised, as there is a rather large opening in the aluminium of the guides.

Anti-wind buttons

In this solution, the net is produced by cutting it separately from the tube and welding two strip lines to the free ends to strengthen it. Plastic buttons are then applied to the same sides using a special machine to create a localised thickness. The net is then wounded to the tube and assembled to the product. The side guides employed have a much narrower opening, as it is visible in Figure 1.10. This ensures that, when the net is unwound from the tube, the buttons are confined within the guides, preventing the net from completely exiting.

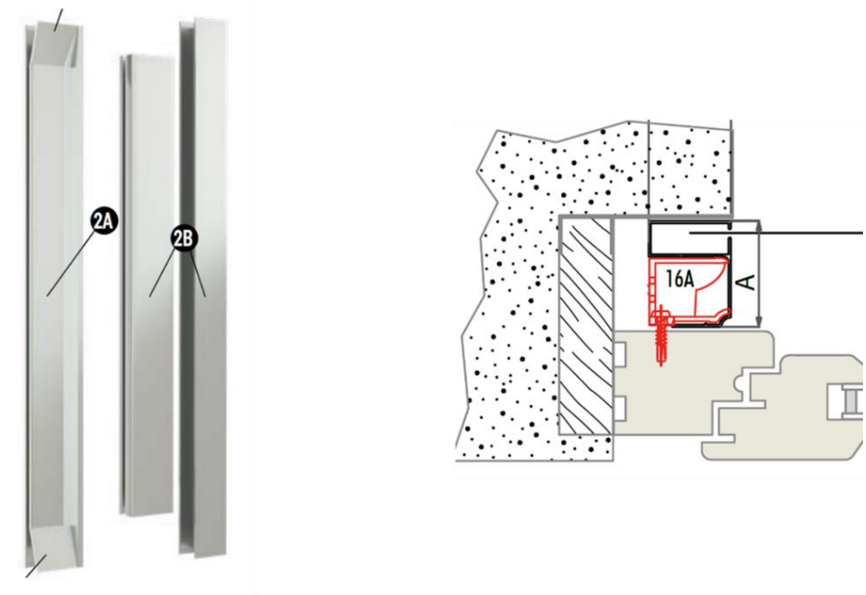
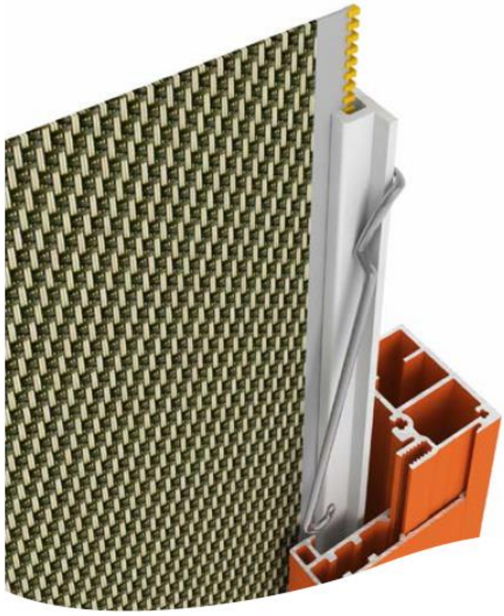


Figure 1.10 – Representation of lateral guides for the employment with anti-wind buttons.

A disadvantage of this type of products is that they only work with smaller out of frame levels. If the variation in the width of the background is excessive, the use of double aluminium rails is necessary to recover the correct orthogonality.

Zip

When the customer requires the highest level of sealing of the net, and desires a product with high quality standards, the most suitable solution is the use of two zips at the free ends of the fabric. These are welded to the edges during production. Then, two extruded pvc profiles, characterised by a C-shape with a very narrow opening, are located inside the lateral guides, as it is shown in Figure 1.11. When the insect screen is unrolled, the zip enters inside these profiles, and the narrow opening prevents it from coming out. In addition, the PVC profiles are securely held in place within the guides, thanks to a series of custom-shaped springs that reacts to the force applied by the wind, also visible in Figure 1.12.



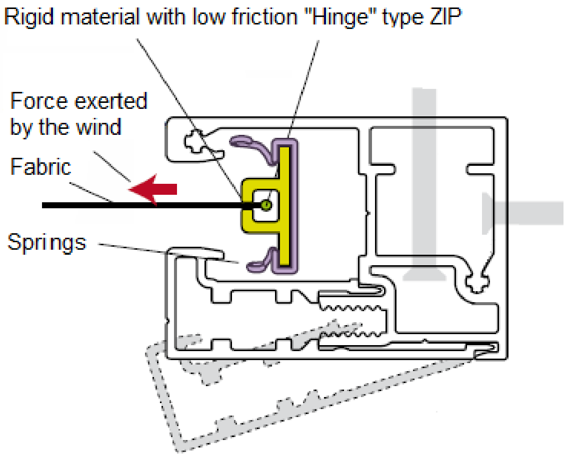


Figure 1.11 – Representation of K.Zip lateral guide.

Figure 1.12 – 2D upper view of K.Zip lateral guide.

The break-through force that the net can guarantee without falling out of the lateral guides is therefore very high. Thus, the critical point of the system shifts to other aspects, such as the maximum holding force of the handlebar locking system or the maximum force that can be withstood by the mesh material itself. The main disadvantage of this type of product lies in the fact that the zip, when wound inside the headbox, has a high overall thickness, thus requiring a high overall dimension of the product from the internal to the external side, if compared to other solutions. The footprints that can be reached are of the order of more than 8 cm.

Chains

Within the category of side-sliding insect screens, the bottom guide rail can be of various designs. In standard products, this consists of a simple aluminium profile, like the other elements of the insect screen frame. But if the objective is to minimise, or completely eliminate, the encumbrance caused by the fixed presence of this profile, there is another category of solutions widely used in premium products, which involve the use of chaining elements. These are plastic elements, with a more or less complex geometry, connected to each other to form a long chain. The main characteristic of such elements, for which they are widely used, is that they can perform a rotary movement during operation, allowing the assembly to move from a horizontal to a vertical position. When the chain is extended and horizontal, it is rigid and can therefore provide a guiding function for the fabric. However, when the insect screen is open, i.e. the handlebar and box are in contact with each other, the chaining elements are in a retracted position, fitting into the vertical cavity in the handlebar. There are many different types on the market, differing in form, functioning and complexity. However, the main common characteristics are as follows:

- each element has two opposite side walls, parallel to the plane that forms the net when it is unfolded;

- there is a portion of material in a transverse position to the two previous walls, providing support and stability;
- the chain is constrained at one end to the lower portion of the box, while the other end is free to slide inside the handlebar.

In Figure 1.13, Figure 1.14, Figure 1.15, Figure 1.16, Figure 1.17, Figure 1.18 and Figure 1.19 some of the main design solutions than can be found on the market and protected by patents.

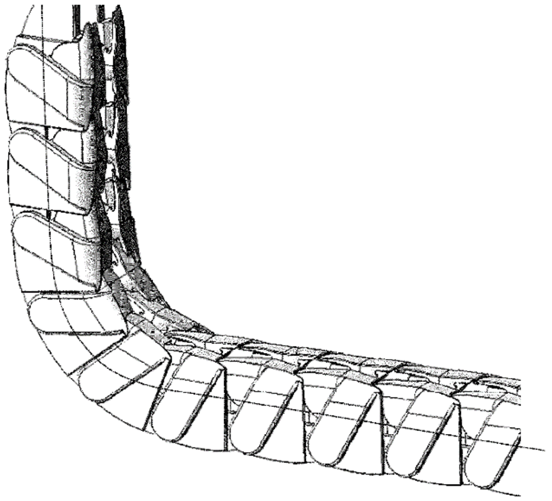


Figure 1.13 – Palagina *Sintesi* lower chain geometry (Francalanci and Ostuni, 2019).

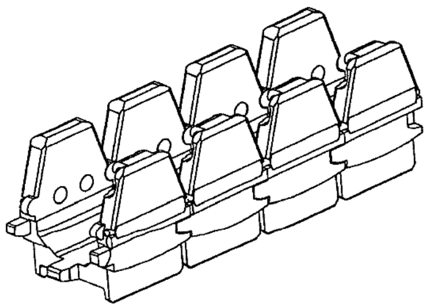


Figure 1.14 – Chain geometry form (Bettio, Denis and Bettio, Loris, 2016).

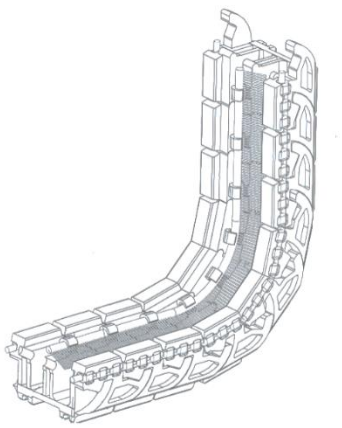


Figure 1.15 – Chain geometry form (Bettio, Denis and Bettio, Loris, 2010).

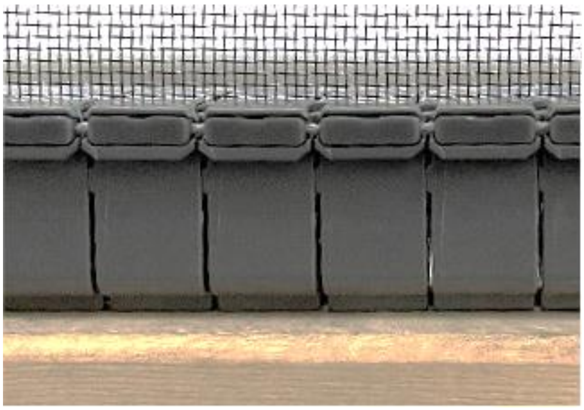


Figure 1.16 – Chain geometry from Bettio *Neoscenica* product.

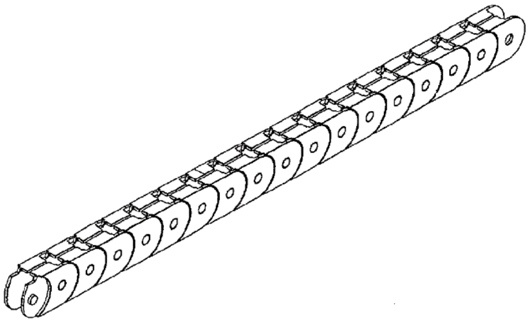


Figure 1.17 – Chain geometry from MV LINE SPA (Montanaro and Schettini, 2003).

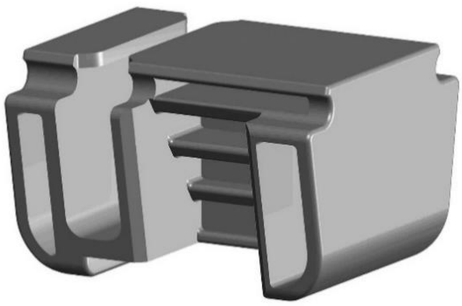


Figure 1.18 – Alternative chain geometry from MV LINE SPA.

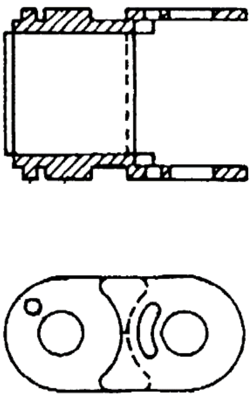


Figure 1.19 – Chain geometry from (Tsuchida, 2000).

As can be seen, there are different levels of construction complexity, starting with the solutions of (Tsuchida, 2000)and (Montanaro and Schettini, 2003), in which the connection between the elements is realised by means of a simple pin-hole coupling, up to the solutions of (Bettio, Denis and Bettio, Loris, 2016) and (Francalanci and Ostuni, 2019) in which the stiffness of the extended chain is significantly increased and the aesthetic aspects are also improved.

1.3.7 - Out-of-square recovery

A scenario that often occurs when installing a product in an existing location is the presence of out-of-square conditions, that need to be accommodated. They are of different nature and they can typically be attributed to common errors made by builders during the construction of doors and windows openings in homes, especially in older buildings. This, typically results in a difference in width measured at the top or at the bottom, or a variation in height between the left and right sides, as illustrated in Figure 1.20.

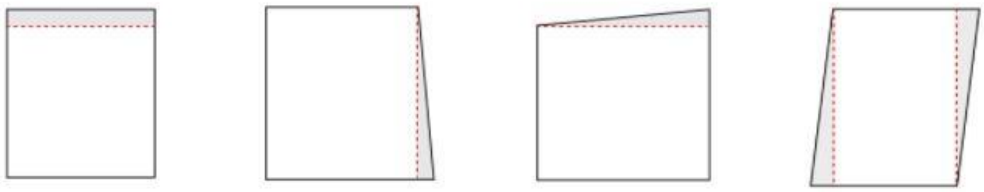


Figure 1.20 – Possible out-of-square conditions.

These defects, if not properly addressed, can be particularly problematic for the installed product, leading to various types of malfunctions. Specifically, in vertically sliding products, there can be issues with the engagement of the handlebar in the closed position, such as for the quick lock system. Additionally, the screen tends to form wrinkles in areas where it is less taut, resulting in aesthetically displeasing outcomes.

Many of these problems can be resolved by selecting the appropriate product types and by conducting a proper installation. However, to facilitate easier installation, even by a less experienced installer, some custom construction solutions have been developed. An example of such a solution is illustrated in Figure 1.21 .

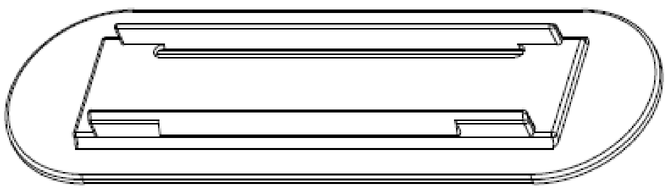


Figure 1.21 – Out-of-square regulation clip.

A plastic component has been created, which couples with the clip present in the abutment profile, thereby creating an additional thickness of 5mm. This block can also be adjusted along the cavity in the profile as needed. By doing so, when the headbox is positioned, it can be adjusted to be perfectly vertical.

Regarding vertically sliding products, those most sensitive to this issue are models with a button retention system compared to those with a brush system. For this reason, they are equipped with double side compensation guides.

1.4 - Mosquito Nets Life Cycle

The main life cycle phases of a typical insect screen are here illustrated, showing in particular where it is most convenient to act to reduce the environmental impact of the product. Mosquito screens are mainly composed of the following parts:

- extruded aluminium profiles, painted in different colours;
- plastic elements made using injection moulding technology (Nylon, POM, ABS);
- extruded plastic elements, mainly composed of PVC;
- metal parts such as springs, rolling bearings, Seegers, screws, nuts, magnets, iron plates;
- brushes of different types and lengths;
- double-sided adhesive tapes;

- nets of different types. The most commonly used nets are made of a composite material with long fibreglass filaments covered with plastic material (PVC);
- packaging, mainly consisting of paper and plastic sheets.

The firm realises the necessary moulds and dies to manufacture the custom components from specialised external suppliers, while it purchases all other components such as small parts, magnets and double-sided adhesives from what is already on the market as a standard. Nets also belong to this category, and they are purchased from specialised companies that produce them in rolls of various characteristics such as height, length, thicknesses and materials. There are only a few companies producing nets in Europe, and their production technology is now well established. The purchased components are then assembled in the company's production department in various ways depending on the specific insect screen model, through different semi-finished products.

There are two different types of sales: one is called bulk sale, in which the company supplies the purchaser with the entire aluminium bars and the plastic components to be assembled, so that he in turn can produce the insect screen to the desired size; the other, preponderant, is the packaged sale, in which the company itself produces the finished product to the desired size, cutting the components to the correct dimension and assembling them completely. In this case, the reference customer is always a retailer, who, however, places the order for the insect screen on the basis of the measurements already taken to the house of the final user.

The main processing phases carried out inside the company concern the assembly of the nets to the aluminium tubes, the cutting to size of the profiles that make up the insect screen and any additional processing on them, the assembly of the various semi-finished products containing the net tensioning spring and the plastics, the final assembly of the product and the packaging phase.

All these steps involve a more or less significant amount of waste and scrap that must be properly managed. Cutting to length from whole aluminium bars generates an average of 8 per cent scrap, which is due to several causes. Firstly, in order to carry out the painting process, the bars are drilled at the ends and then hung up. This causes those areas to be later excluded from cutting. There are also defects that are not always acceptable due to incorrectly applied paint or dents caused by transport. As it is easy to imagine, however, regardless of this, it is never possible to fully utilise the bar, as the dimensions of the products to be made always vary. A small part is therefore always discarded.

Another very important discard is that of nets. Nets are an extremely important type of component, the quality of which affects the correct behaviour of the finished product. They are also very delicate, needing controlled temperature conditions to be stored correctly over time. In fact, the thermoplastic nature of the nets means that, when subjected to hot-cold temperature cycles, deformations are created in the material that, when the coils are opened, they generate abnormal folds in the stretched mesh, which are not acceptable for the quality of the final product. Furthermore, the mesh geometry and the way it is cut and wound by the supplier must meet certain standards. A special study was carried out on this subject, the results of which will be shown later.

Other types of waste in production are mainly due to material non-conformities or operator errors. For example, wrong aluminium or net cuts, incorrectly assembled nets to the tubes, non-compliant quality brushes, or others.

The mosquito net is then packaged and shipped to the customer, who will, in turn, carry out the assembly at the destination. In normal use, the product is designed to last for years. Typically, the first component to show signs of wear and tear is the mesh, as it is the most exposed to weather conditions and varying cycles of temperature, humidity, and sunlight. Therefore, after a few years of use, the product is returned to the company for repairing, with only this component being replaced. At this stage, the previously installed mesh is discarded as waste, along with any other components that may have been changed. This approach allows for extending the useful life of the mosquito net for years, if not decades. The minimum expected lifespan of this type of product is set at 10 years.

Upon reaching the end of its useful life, the mosquito net must be disposed of, and to do so properly, its components need to be disassembled from each other (Crowther, 1999). For this purpose, these operations must be carried out manually by an operator and require a substantial amount of time, making the process less cost-effective. Currently, there is also no direct end-of-life control by the company. Therefore, neither the exact average lifespan of the mosquito net nor whether it is effectively disposed of correctly is known with certainty.

Regarding the collection of generated waste, they are categorized based on the type of material and collected by specialized companies, according to the reference European Waste Catalogue (EWC) code. The codes for various material categories are listed in Table 1.1.

Table 1.1 – Wastes categorization, according to the European Waste Catalogue (EWC).

Material	EWC Code	Details
Aluminium	170402	-
Plastic packaging	150102	-
Filings and shavings of plastics	120105	-
Nets and fabrics	040222	Waste from processed textile fibres
Wooden packaging	150103	-
Paper and cardboard packaging	150101	-

The categories of aluminium, plastic, and plastic, wooden and cardboard packaging are recycled, thus closing the life cycle correctly (Kalmykova et al., 2018). Furthermore, the company receives a fee for the aluminium and plastic based on the provided material's weight. In contrast, nets and fabrics are the only components mandated by law to be disposed of in landfills and are not typically recycled.

In Table 1.2 the total amounts of waste produced by the firm in the year 2020 are reported. As it is possible to note, nets and fabrics are one of the most important items on the list in terms of weight, with a total of 59 tons. For these motives, the study focused exclusively on this type of element.

Table 1.2 – Amount of waste produced by Palagina in 2020.

Material	Amount [kg/year]
Aluminium	11700
Plastic packaging + Filling and shaving of plastics	24400
Nets and fabrics	59300
Wooden packaging	150100
Paper and cardboard packaging	34100

The reason nets are disposed of in this manner is that they are particularly challenging to recycle due to their bicomponent nature. Consequently, the regranulation process is expensive and not cost-effective.

The quantities produced by the company of this material are quite substantial, reaching nearly 60 tons in total waste in 2020. Considering that the company incurs a cost of €230/ton for disposal, the annual cost for this operation amounts to more than €13,000. Identifying an alternative utilization solution would, therefore, be an economically advantageous strategy.

1.5 - Challenges in the Net Recovery and Recycling

Currently, as previously mentioned, the nets disposed of by the company primarily originate from the following sources:

- waste generated during production processes, resulting from both non-compliant materials and scraps produced during the cutting to finished size;
- nets that have already been manufactured and returned to the company for replacement, either due to defects or after completing their lifecycle (significant material degradation).

The main challenges currently observed in net recovery, in the case of both the aforementioned categories, are that the net can be combined with other plastic materials, depending on the type of product it is intended for. In particular:

- gaskets, typically made of PVC, welded to one or more ends;
- strips of plastic material welded with buttons (made of Nylon);
- additional polyester strip with adhesive, welded along one side of the net;
- polyethylene rod inserted in the previously mentioned strip.

In the most complex scenario, all the aforementioned elements may be found applied to a single piece of net. This could potentially create challenges for the recycling of these materials, depending on their intended subsequent use. Furthermore, industrial waste material (post-production) is currently disposed of together with post-consumer waste, with no clear tracking of the percentage of one versus the other. This could pose difficulties in establishing a standard quality level for the waste material's subsequent recycle.

The challenges raised so far are difficult for the company to overcome, both due to its current internal structure and the way mosquito nets are designed and manufactured today. Unless significant redesign or organizational restructuring investments are considered, achieving waste material that ensures uniformity and consistent quality levels is therefore not viable. For these reasons, recycling may not be the most suitable strategy in terms of feasibility.

Furthermore, there are inherent issues within the net material itself, which is not solely composed of plastic. Indeed, the most employed type of nets are made by a compound of fiberglass, coated with a uniform layer of PVC. The fiberglass core inside each wire provides the net with the necessary strength, while the total amount of external PVC gives it the final thickness and colour (usually black or grey). The production process of the net takes place in an external company and is well-established. The necessity of using such a combination of materials is driven by the requirement of durability over the years that the net must fulfil, thus limiting the use of alternative and more ecological materials. In order to reduce the environmental impact of the net, various recycling strategies have been tested over the past ten years by the manufacturer itself, and some interesting results have been found, especially for the production of tiles, pipes, and blackout fabrics. At the same time, many difficulties have been encountered, particularly during the grinding process to convert the material back to the granular form. This is due to the presence of long fiberglass wires constituting the mesh, which often make the grinding mills stuck during the process.

1.6 - Reuse as a Strategy for Sustainable Design

While numerous challenges have been highlighted in pursuing the recycling path, the feasibility of reduction and reuse strategies (Moreno et al., 2016) still remains to be analyzed from an environmental impact reduction perspective.

Although “reduce” unquestionably remains the primary objective to pursue, as it enables the elimination of waste volume even before it is generated, it is also true that within the scope of the current study, there is no possibility to explore strategies for redesign (Design For Sustainability) or for reducing resource consumption in the production of nets. This is because it is a product purchased on the market from third-party suppliers, who, moreover, operate in a near-monopoly regime. Therefore, any modifications would be challenging to implement and lie beyond the capabilities of the company. Hence, the reuse strategy, appears to be the most suitable one.

However, reuse within the same production cycle is not feasible in this case as the nets are already cut to size, and it would be difficult to process them again at the machines with the same productivity. Moreover, after years of use, the net material is often damaged (sometimes the mesh is broken), making it hard to reemploy it for the same purpose.

Therefore, entirely different contexts from which the item was firstly intended for have to be analyzed. Numerous alternatives exist and it is the designers' responsibility to choose which field is more practical than others depending on their experience.

In the scientific literature, several strategies have been documented to offer methodological support in the identification of potential areas for reusing a particular good or its components (Zwicky, 1967; Beitz et al., 1996; Smith, 1998; Gadd, 2011; Fantoni et al., 2013; Gonçalves et al., 2014; Srinivasan et al., 2018; Tauqeer and Bang, 2020). These tools assist users and designers in breaking down the problem into smaller, more manageable, and reproducible phases. Furthermore, it is possible for them to provide a quantitative measure of the extent to which the research has been conducted, and ultimately offer guidance on next avenues of investigation. Simultaneously, it has been extensively documented in the literature (Crowther, 1999) that the utilization of methodological instruments is essential for assessing the precision of design decisions and developing an understanding of the achieved level of success and originality.

1.7 - The *Sintesi* Product

In this section a more detailed description of the *Sintesi* product that mainly inspired the new one under investigation is reported. In particular, its innovative technologies, the manufacturing process and the installation phases. *Sintesi* is considered to be the top-quality product of Palagina company. The peculiar aspects that characterise it are the presence of a very thin lower guide, with modular elements that form a chain, and the specific shape that this assumes on the product. In particular, the lower end is fixed on the final part of the headbox, while the upper one is positioned on the top part of the abutment profile. The main aim of this assembly is to guarantee the correct horizontal movement of the handlebar, while closing the frame, preventing mosquitoes to pass through. The net is planar and wounded around an aluminium tube. A torsional spring is positioned inside the tube and gives the net the correct tension under exercise.

It is characterised by a relatively high footprint, equal to 46 mm or 50 mm, depending on the type of installation. It can be put in light or recessed. The difference between the two lays only in the aluminium profiles of the frame and the plastic parts on the corners. The assembly that contains the net is always the same. The maximum dimensions that can be realised are 210 cm in width and 320 cm in height. It is also available in a central version, with two opposite headboxes on the two sides, for very large frames to be covered.

1.7.1 - *Sintesi* lower chain

The geometry of the lower carriage is described in detail here, by referring to the relevant patent (Francalanci and Ostuni, 2019). Each element is characterized by two side walls, joined together at the bottom by a horizontal wall. The connection between multiple chains occurs by inserting the protruding element (11) – referred to as the trilobe – in the Figure 1.22 – inside its seat located in (17) – the visible cavity (16) in Figure 1.23. During the insertion phase, the flap (17) elastically deforms, allowing the entry of (11) through an inviting area. Once coupled, the pieces remain connected to each other during normal operation.

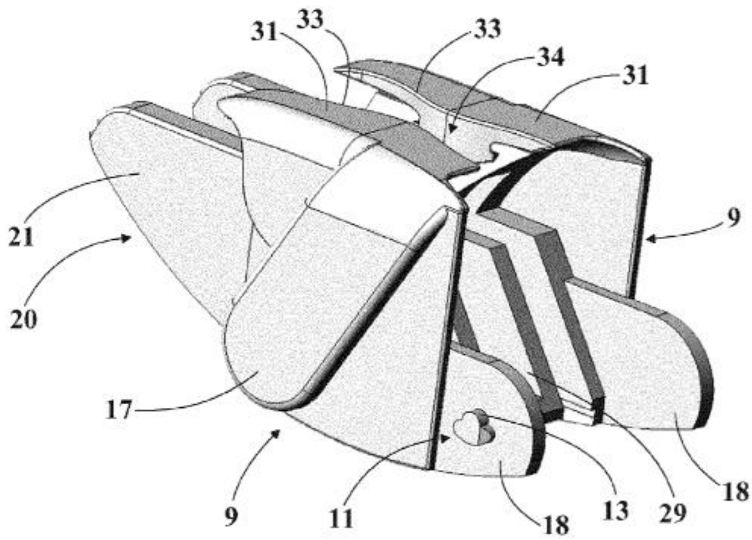


Figure 1.22 – *Sintesi* lower chain.

The relative rotation of two components is made free by the elongated trilobe seat, which extends towards the lower part of the chain. In this way, the element (11) has clearance in all directions. Once the chains return to their straight position, the clearance along the main development direction disappears, making the assembly rigid.

The prevention of over-rotation occurs instead thanks to two contact surfaces: one is provided by the upper portion (13) of the trilobe, which encounters the upper wall of the seat (19); the other is the upper surface (32) of the front fin (21), which goes in contrast with the portion of material in the upper part of the chain. The minimum curvature radius of the chain is instead obtained when the vertical rear surface comes into contact with the inclined wall of the portion (17) on the preceding chain, as it is visible in Figure 1.24.

The upper part of the carriage is more open transversely, with opening mouths at (33) that ensure easier reinsertion of the net in position, after an accidental dislodgment.

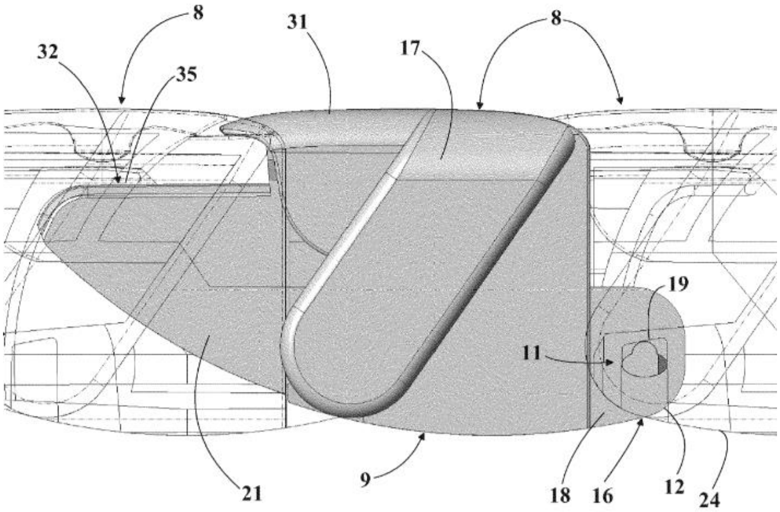


Figure 1.23 – *Sintesi* lower chain in extended position.

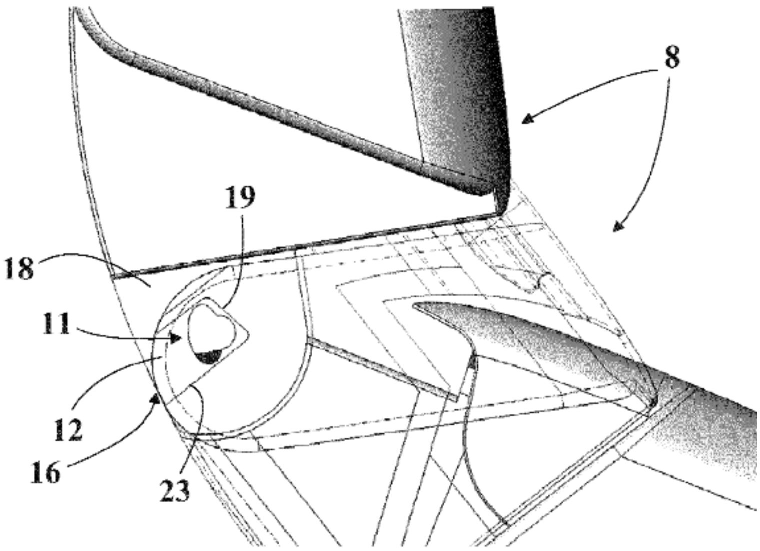


Figure 1.24 – *Sintesi* lower chain in tilted position.

1.7.2 - Upper chain

In (Francalanci and Ostuni, 2020), the upper chain of the *Sintesi* product is described. It allows the correct movement of the handlebar from the closed position to the open one, thanks to an innovative technology. In fact, in similar products on the market where lower chains are present, the handlebar is held in place by connecting various types of devices to the free end of the lower chain:

- flexible cables arranged inside the handlebar and connected to its ends, in order to synchronize the advancement during the unwinding of the chain;

- metal strap with curved section placed in proximity to the upper rectilinear guide, fixed on one side to the vertical upright and on the other side fixed to the end of the guide chain through a connector strap
- an upper chain with one end connected to the same head-box and the other slidable in the guide bar. In this case, the free ends of the two chains are connected with flexible cables to align the terminals of the handlebar.

All the solutions mentioned so far have some drawbacks. In particular, in the case where the product needs to be shortened during installation, the wires need to be repositioned, and this can only be done at the factory due to the high difficulty of the operation. Furthermore, after many years of use, the wires need to be tensioned again, requiring the product to be returned to the firm.

The presence of the metal strap, on the other hand, implies greater assembly difficulty and higher costs. Additionally, the strap must be cut to the exact size, preventing installation in all those cases where the frame measurements have not been taken perfectly.

What distinguishes the upper chain of *Sintesi* from the others in terms of construction is that its free end is connected to the top part of the abutment profile, opposite to that of the head-box. This allows the mosquito net to be perfectly adapted to the opening even during its installation, in a quick and easy manner. Besides, no maintenance is required after years of use, as no wires to be tensioned are present.

A representation of the two chains is reported in Figure 1.25. A detailed view of the upper chain is also reported in Figure 1.26.

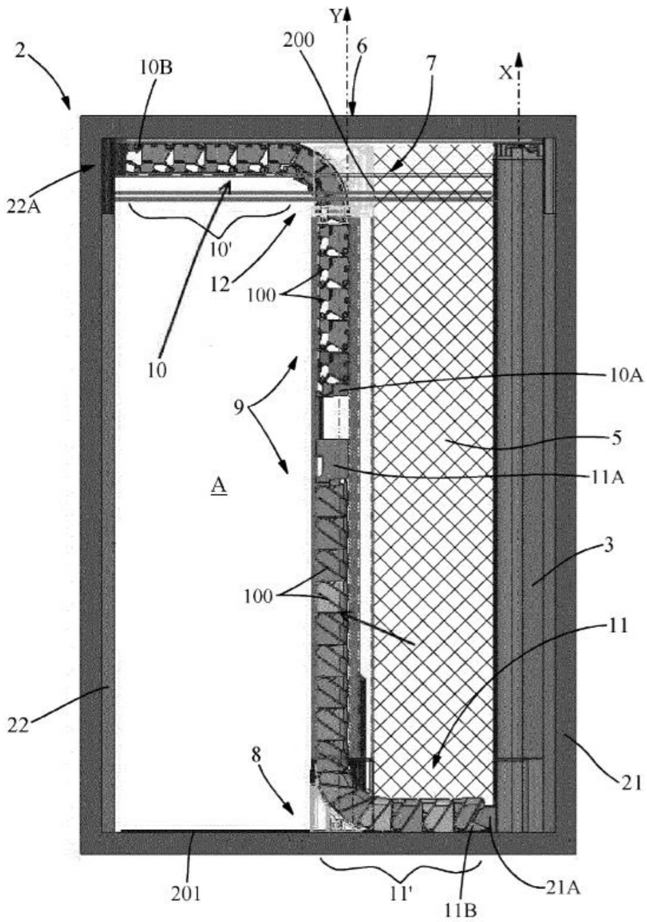


Figure 1.25 – *Sintesi* synchronization mechanism of the handlebar movement.

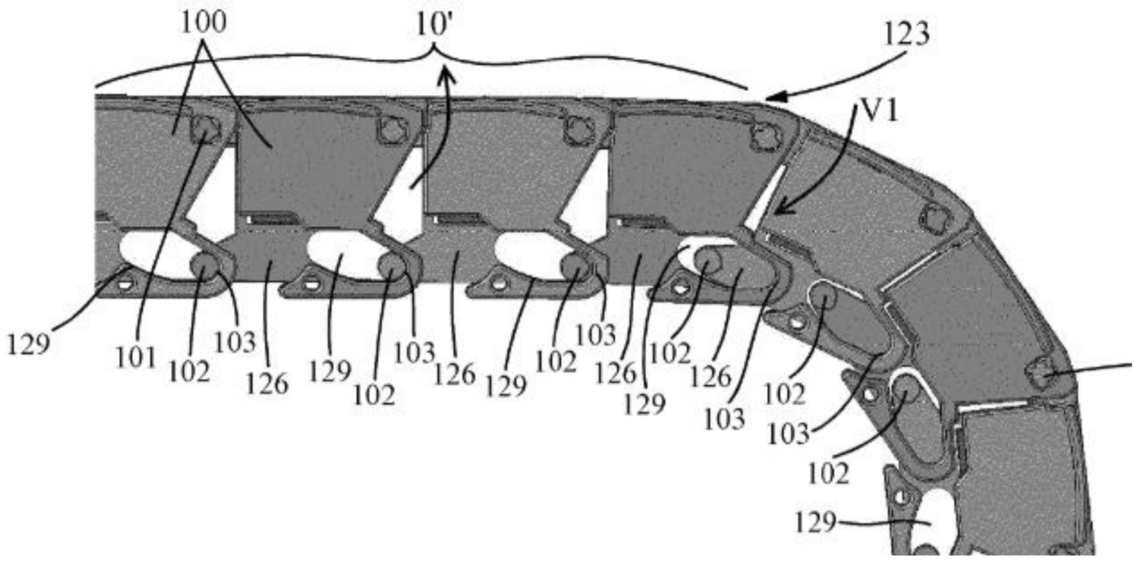


Figure 1.26 – *Sintesi* upper chains.

As it is possible to note, each element is connected to the adjacent one by means of an upper shaped pin, called trilobe as well, which enters its seat, forming a coupling with slight interference when the chain is extended, and with clearance when the chain is curved. In the lower part there is another pin (102), also shaped with a slight protrusion, which provides a constraint against over-rotation of the carriages. When the handlebar is in contact with the head-box, and the chain is completely extended horizontally, it is constrained only at the two ends and subjected to its own weight. The drop of the chain, with an over-rotation of the elements, is prevented precisely by the particular shape of the pin (102).

1.7.3 - Magnetic connector

The two adjacent ends of the upper and lower chains are connected to each other by means of an intermediate component, called connector, located inside the handlebar. This element must allow the relative movement of the two chains, in such a way as to ensure the correct alignment of the handlebar, within a certain adjustment range. This is necessary during the installation phase, to allow the mosquito net to adapt perfectly to the actual measurements of the frame in which it is placed, without having to modify the product's components or perform complex operations. Therefore, it represents a significant advantage for the installer. For these reasons, it has been protected by patent (Rossi et al., 2023).

The main components of the assembly are two plastic elements, one attached to the lower chain and one to the upper chain. A metal plate is fixed to one of the two elements, while a cylindrical magnet is attached to the other. The plate, attracted by the magnet, remains attached to it, allowing for the relative fixing of the two chains. If the axial force acting on the chains increases and exceeds the frictional force between the magnet and the plate – generated by the magnetic attraction force – then the two chains can slide relatively to each other. The maximum relative sliding is determined by the stroke of the magnet along the plate. This system allows for easy adjustment of the correct position of the two chains during installation, adapting to the specific frame, simply by applying manually an external force to the handlebar. The system is visible in Figure 1.27.

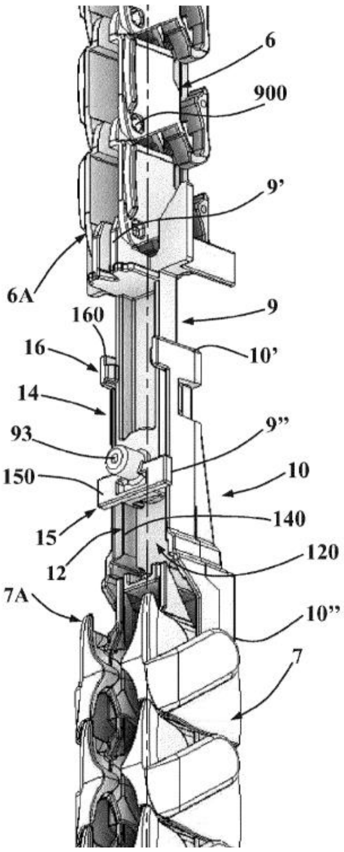


Figure 1.27 – *Sintesi* magnetic connector.

1.7.4 - Manufacturing process

Mosquito nets are assembled in the manufacturing plant through different steps. The raw materials enter the factory in the form of aluminium profiles – in bars – painted in various colours. Additionally, plastic components, produced by injection molds, brushes and gaskets from specific suppliers and springs, small metal parts, double-sided adhesive tapes and nets.

The assembly process begins with the creation of the semi-finished products. These involve certain plastic components, the assembly containing the spring and the net tubes. Incorporating semi-finished products into the production line offers the possibility of taking advantage with the manufacturing process, as it allows for the production of standardized components used in the final products, regardless of their size. This also simplifies workforce management, enabling a more consistent workflow independently from the quantity of orders to be processed at any given time. First, the semi finished products will be analysed. Then, the final assembly process will be discussed.

Semi-finished parts

One of the most important semi-finished products in terms of economic value that are made within the company are the net tubes. In general, these are comprised of an aluminum tube onto which the net is wound using various fastening technologies. The diameter of the net tube varies depending on the type of product it is intended for. Two different types of machinery are owned by the company to carry out this process. In both cases, the net roll is positioned on a shaft on one side of the machine. Subsequently, the free edge of the net is unwound on the workbench, pulled by a special press. Gaskets are then laid out on the machine, alongside the net and longitudinally to it. Two gaskets are present: one on the side where the tube will be assembled and another one on the opposite side, where the handlebar will be positioned, as shown in the Figure 1.28.

Figure 1.28 – Net tubes processing machine.

The gaskets are then positioned using specific guides near the edge of the net and welded at the lateral ends in two welding stations, which operate by localized heating and pressure increase. Subsequently, the aluminum tube, typically measuring 6 meters in length, previously placed by the operator along the edge of the workbench, is positioned in a dedicated slot and secured at both ends with two pins. Once the initial portion of the net is welded, the press slides it, inserting the gasket into the cavity on the tube. At the end of the process, the net is cut to size using a specific cutter. The tube is then set in rotation by two chucks, and the fly screen is consequently wound tightly around it. The final result is visible in Figure 1.29.

Figure 1.29 – *Sintesi* semi-finished tubes.

The cutting of the final assembly is performed with specific machines by an operator, visible in Figure 1.30. After selecting the desired measurement, an electric motor moves the cursor to the corresponding dimension and the cut is performed. The bar is then optimized as much as possible to produce the maximum number of useful cuts.

Figure 1.30 – Aluminium cutting machine.

The other important semi-finished product is the spring group. In fact, the fly screen is correctly held in position thanks to an elastic torsional element located inside the aluminium tube. The technology is similar to the one found in other vertically sliding products: at the lower end of the spring, there is a plastic component called "dragger", which transfers the motion of the tube to the spring. The upper end is entirely constrained by the plastic head, which defines the upper end of the head-box. The connection, in this case, is ensured by a worm-gear coupling, which allows for the adjustment of the spring from the outside. The assembly is visible in Figure 1.31.

Figure 1.31 – *Sintesi* spring group.

The elements of the upper and lower chains are pre-assembled as well using two specially designed machines. In particular, strips of 20 elements are produced – as it is shown in Figure 1.32 and Figure 1.33 – and then joined together during the final assembly phase.

Figure 1.32 – *Sintesi* pre-assembled lower carriage.

Figure 1.33 – *Sintesi* pre-assembled upper carriage.

Assembly phase

The initial analysis of the assembly concerns the semi-finished products ‘preparation times that occurs in advance so that they can be directly used in the final production. The following subassemblies are included, as shown in Table 1.3. As it is possible to note, carriage chains are not here reported, as the company buys these strips already mounted, paying the supplier for the mounting processing.

Table 1.3 – List of *Sintesi* semi-finished products and execution times.

#	Description	Time [s]
A	Spring group	100
B	Net tube	196
C	Elastic connector	60
D	Lower guide	81
E	Accessory box	60
Total		497

The final assembly phase of the product is entirely carried out manually, following standard procedures, on one or more workbenches. Based on the customer's required product dimensions, aluminium profiles are prepared by cutting them to the correct size at dedicated automatic cutting stations, in the same way as it happens with the net tube. Subsequently, the necessary processes are carried out using punching machines to create indentations and holes for fastening. These are reported in Table 1.4.

Table 1.4 – Processing to be performed on the aluminium profiles of *Sintesi* product and execution times.

#	Description	Time [s]
1	Drilling of the first abutment profile (3 steps)	27
2	Drilling of the second abutment profile (3 steps)	27
3	Drilling of the upper guide (2 steps)	18
4	Realization of the groove on the upper guide for head-box insertion (1 step)	12
5	Realization of two lateral windows for upper cap installation (2 steps)	24
Total		108

The actual assembly operations can then commence. Each operator is provided with a workstation equipped with all the necessary plastic components and accessories. A summary of the tools employed follows:

- screwdriver;
- scissors;
- special scissors with built-in jig;
- customized tool for facilitating the net tube positioning;
- flathead screwdriver;
- hexagonal insert.

Production phases are schematically subdivided into steps required for the preparation of frame aluminium profiles and for the rest of the product. The operations required for the first category are reported in Table 1.5, while Table 1.6 reports the final assembly phases.

Table 1.5 – Steps for the final preparation of *Sintesi* aluminium profiles and execution times.

#	Description	Time [s]
6	Insertion of three clips along the first abutment profile	60
7	Insertion of the magnet along the second abutment profile and cutting	18
8	Insertion of two brushes along the upper guide and cutting	24
9	Removing of the two containment wires	7
Total		109

Table 1.6 – Final production phases of *Sintesi* product.

#	Description	Time [s]
10	Gasket insertion in the headbox and cutting	30
11	Positioning of the tool for the correct net insertion	8
12	Net tube insertion	30
13	Removing of the tool for the correct net insertion	5
14	Cutting of the lower portion of the net gasket	8
15	Positioning of the bushing in the lower end of the tube	10
16	Positioning of the axial bearing in the lower head-box head	5
17	Positioning of the lower head-box head	13
18	Fastening of the lower head-box head with four screws	55
19	Insertion of the handlebar along the net gasket	25
20	Insertion of the upper spring group	12
21	Spring tensioning	25
22	Final positioning of the upper head-box head	5
23	Fastening of the upper head-box head with four screws	49
24	Lower chain construction at the right length	45
25	Insertion of the elastic connector in position	5
26	Insertion of the lower chain with the elastic connector in the handlebar	19
27	Conjunction of the two parts of the upper handlebar head	8
28	Positioning of the upper handlebar head	7
29	Fastening of the upper handlebar head with two screws	18
30	Magnet insertion along the handlebar and cutting	17
31	Positioning of the lower handlebar head	10
32	Fastening of the lower handlebar head with two screws	18
33	Connection of the lower portion of the chain with the lower head-box head	17
34	Final cutting of the magnet to the correct length	7
35	Positioning of the downer handlebar support	10
36	Upper chain construction at the right length	48
37	Positioning of the final component of the upper chain	5

38	Insertion of the upper chain in position and snap fastening	16
39	Product testing	140
40	Separation of the upper chain and insertion of the stopper	25
41	Product packaging with stretch film	96
Total		791

It is possible to conclude that the total amount of time is of 1505 seconds, given by the sum of 1008 s of final assembly and 497 s of semi-finished products. Instead, the product final cost, given by the sum of materials and labour costs, is of 26,8 € per square meter, as declared by the company. These values will be considered as benchmarks for the estimation of assembly times and costs of the new product.

Installation phases

In order to complete the *Sintesi* product description, installation phases must be shown. In fact, this is an important parameter that is first considered by the company's customers, because an easy installation means less time and costs, and therefore a higher profit margin for installers. The operations are divided into 12 steps, that are shown in a detailed manner in Table 7.1 in Appendix A. Again, this number will be considered as a reference for the future product.

2 - Feasibility Study

In this section, the preliminary phase of the new mosquito net product's study will be introduced, starting from the specifications it should have and the constraints it must comply with. The set of characteristics has been obtained from both previous market analyses and the industry knowledge possessed by the company's executives, who provided most of the sources where the necessary information could be found.

Like any other phase of the design process, in this case as well, the process was iterative, with continuous feedback required from the company's managers. As is known, the more changes are made in these preliminary stages, the more quickly and with less economic expenditure it is possible to arrive to the final project definition and production. During the design process, several decision changes were made, and the initial specifications varied many times. For a better understanding of the work, and to provide linearity to the writing, the conclusive results obtained at the end of the various iterations will be presented, indicating that the industrialized product meets the requirements.

The main feature that the new product must possess, is a reduced overall thickness. The primary reference benchmark in this regard is the Bettio *Picoscenica* product, shown in Figure 2.1, along with its main characteristics. As per the commercial request, the subject of the study must belong to the same family of the *Sintesi* product, from which it will take the name *Nano Sintesi*. Therefore, the required constructive solutions, as specified, are as follows:

- the presence of a lower carriage chain, which should as closely as possible resemble the same aesthetic of the previous product (as the component will be visible when in use);
- an upper carriage chain, which should be installed in the same way as the *Sintesi* product (attachment of the free end to the abutment profile).

One of the initial project requirements is also to ensure that the installation phase is simple. In this case as well, the steps should be as similar as possible to the ones of *Sintesi* . This is particularly important for the commercial success of a product because a mosquito net model is generally more appreciated when installation times are minimized. This observation is particularly relevant because the installers themselves are the company's main customers, and they choose the product primarily for this characteristic.

Figure 2.1 – Bettio *picoscenica* product characteristics.

The product's aesthetics should also be pleasing for the final user. This translates into both the sinuous and minimal shapes of the aluminum profiles, an aspect managed by industrial design experts, and the type of net to be used. In fact, it should not be pleated like the products on the market characterized by smaller dimensions, but it should be flat. This is to better satisfy the Italian market, which generally does not appreciate the aesthetics of a pleated net, which also requires more maintenance in terms of cleaning.

The product must also be reliable and have the lowest possible assembly cost. To increase simplicity during maintenance and/or installation, and, in particular, to modify the net tension once the product is already installed, an adjustment system accessible from the outside must be present.

To increase safety and reduce time during the assembly phase, there must be the possibility of quickly loading the tensioning system from the outside of the product, without the risk of injury to the operator, if the tension is accidentally lost.

No specific net retention is required, as in the *Sintesi* product. The net material will therefore be free to exit from the carriages, and their particular shape should ensure correct retraction into position if this occurs.

In order to ensure adequate product robustness, it is required that the lower carriage chain cannot exceed a certain threshold of maximum deformation when subjected to a transverse load, as it will be better seen later. Nevertheless, a lower guide profile must be present, sufficiently small to be walkable, to keep the flat chain in the correct position.

In order to ensure installation even in situations with out-of-square conditions, the possible inclusion of a double telescopic upper guide should be considered, ensuring it remains perfectly vertical at all times. Moreover, it is essential to offer supplementary mechanisms to facilitate the proper installation of the system, in cases involving lateral misalignments.

The required installation type is currently only in light and of lateral type (a single headbox). The maximum expected size is 140 cm in width by 280 cm in height.

Lastly, efforts will be made to keep development costs within reasonable levels by utilizing existing components as much as possible, and standard ones, readily available on the market.

Table 2.1 summarizes all the constraints and objectives gathered in the initial feasibility phase, in relation to the reference product *Sintesi*.

Table 2.1 – List of Objectives and constraints for the new mosquito net model.

Objective/Constraint	Description
Constraint	The mosquito net must be equipped with an upper and lower chain, similarly to the *Sintesi* product
Constraint	The product must be of lateral type
Constraint	The product must be installed in an in-light frame
Constraint	The overall footprint must not exceed 30 mm
Constraint	The maximum feasible dimension must be: 140 x 280 cm
Constraint	The product functioning must be guaranteed for 10 years of use
Constraint	The maximum height of the lower guide must be of 5 mm
Constraint	The maximum manageable out-of-square values on the headbox must be of 8 mm (+/- 4 mm up or down)
Constraint	The maximum manageable out-of-square values on the abutment profile must be of 4 mm (+/- 2 mm up or down)
Constraint	The stiffness of the lower chain must be such that if a force of 1 kg is applied at the center of 1 meter of chain (chain hinged at the ends), the deformation of the chain must not exceed 3.5 cm
Constraint	The net must exit centrally with respect to the headbox
Constraint	No retention elements are required inside the lower chain
Objective	Maintain a simple phase of installation

Objective	Increase the aesthetic appeal of the aluminium parts
Objective	Maintain the reliability of the product
Objective	Increase simplicity during maintenance
Objective	Increase safety for the operator during the assembly phase
Objective	Maintain assembly times unchanged
Objective	The out-of-square recovery capabilities must be maintained
Objective	Minimize assembly and material costs

2.1 - Operational Diagrams

Based on the main features listed so far, it is possible to identify the key subassemblies that will constitute the final product. Each of them will be dedicated to performing one or more fundamental functions of the product, aiming to achieve the objectives while staying within the predetermined constraints.

Since the screen must be of flat type and not pleated, when the mosquito net is not in use, it should be wound around a winding tube, located inside a head-box. To make the system easier to assemble in the production facility and enhance its reliability, the chosen technology for tensioning the net during operation is that of using a classic torsion spring. This technology was selected because it is widely tested, being present in a significant portion of the products on the market and has proven to be safe and reliable. Furthermore, aspects related to easy maintenance during operation are thus more guaranteed.

In fact, the possible alternative of using wires to be tensioned during installation – as with pleated products – would have undoubtedly led to a slower and more complex assembly on the one hand, and the need for more invasive interventions to maintain the product, on the other hand. In fact, wires tend to lose their tension over time, are more susceptible to blockages due to dirt, and risk entangling with each other, requiring the customer to perform repairs at the factory.

To maintain ease of assembly and reduce possible malfunction events due to improper use during transport and assembly, it was chosen to place the tensioning system entirely inside the aluminum head-box containing the net tube.

Considering the maximum thickness constraint of 30 mm for the product and the maximum closing width of 140 cm – as per specification – preliminary evaluations were made regarding the size of the maximum dimensions of the winding tube when the required net is completely wound.

From a preliminary analysis, even by observing the main competitor, the need arose to use a winding tube with a very small diameter, approximately 10 mm, to allow the net to be correctly wound. This implies that the torsion spring must be installed in an external position relative to the tube.

In Figure 2.2, a rudimentary diagram of the net tube + spring system is shown. As can be observed, the only available area inside the casing to position the tensioning device is located at the rear of the tube, on the opposite side from the net exit. In fact, there was no strict space constraint imposed in that direction.

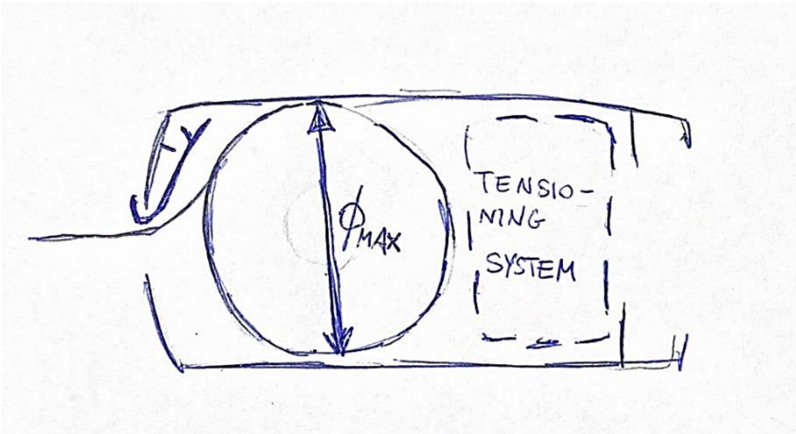


Figure 2.2 – First diagram of the head-box with net tube and tensioning system.

Therefore, the torsional spring will be positioned as depicted in Figure 2.3, with its main axis of development parallel to that of the net tube. It was necessary to provide a mechanism for transferring the elastic energy possessed by the spring to the tube. This function is typically performed by the 'dragging element,' as described in Manufacturing process section, since the spring is located inside the tube. However, in this case, the only area of the product that can be utilized for this function is at the outer end of the spring. In other words, at one of the two ends of the aluminum casing.

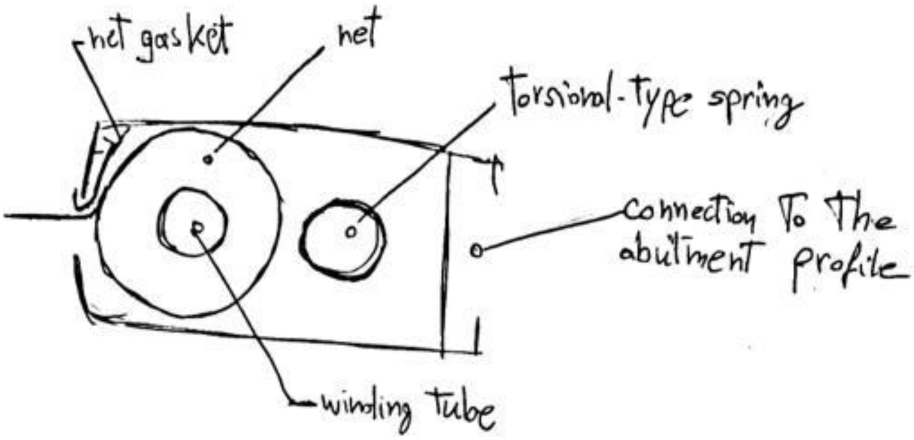


Figure 2.3 – Second representation the head-box with the use of torsional-type spring.

For simplicity of design, it was decided to introduce the spring at the upper part of the casing, as is commonly done in all products on the market to facilitate the tension adjustment phase by the customer or installer. Inserting the spring at the lower part would have also introduced greater design complexities, as that section of the product is already used, as an initial design constraint, for connecting the end of the lower guide to the casing.

In Figure 2.4, several conceptual drafts for the transfer of the resisting torque from the spring to the tube are presented. In particular, it was hypothesized that the two axes could be connected using a gear mechanism or through a belt with pulleys. An alternative solution, subsequently also found in literature, was to employ two spools wound with a wire. This wire would move from one spool to the other during the mosquito net's operation, alternately loading and unloading the spring. This solution is theoretically viable because the relative rotation of the two gears is always confined within a certain range, determined by the maximum number of revolutions the net tube can make, based on the width of the mosquito net. However, in practice, this solution is more challenging because, in the event of accidental loss of the charge, additional systems would need to be provided to prevent the wire from loosening from the spools and entangling. This, in addition to incurring extra costs for the product, is further complicated by the extremely small dimensions in which this system must operate. For the same reasons, the potential use of belts was also considered difficult to implement.

Regarding the spring tensioning, to meet the initial requirement of increasing safety during the product assembly phase, a strategy was identified, which involves performing the tensioning operation only after the head-box is closed. This significantly reduces the probability of the spring accidentally losing the accumulated elastic energy. To meet the requirement of keeping production times unchanged, this tensioning operation should be performed by connecting to the free end of the spring, with a transmission ratio equal to or less than 1. For ease of implementation, a direct connection of the screwdriver element to the spring was chosen, thus adopting a 1:1 transmission ratio.

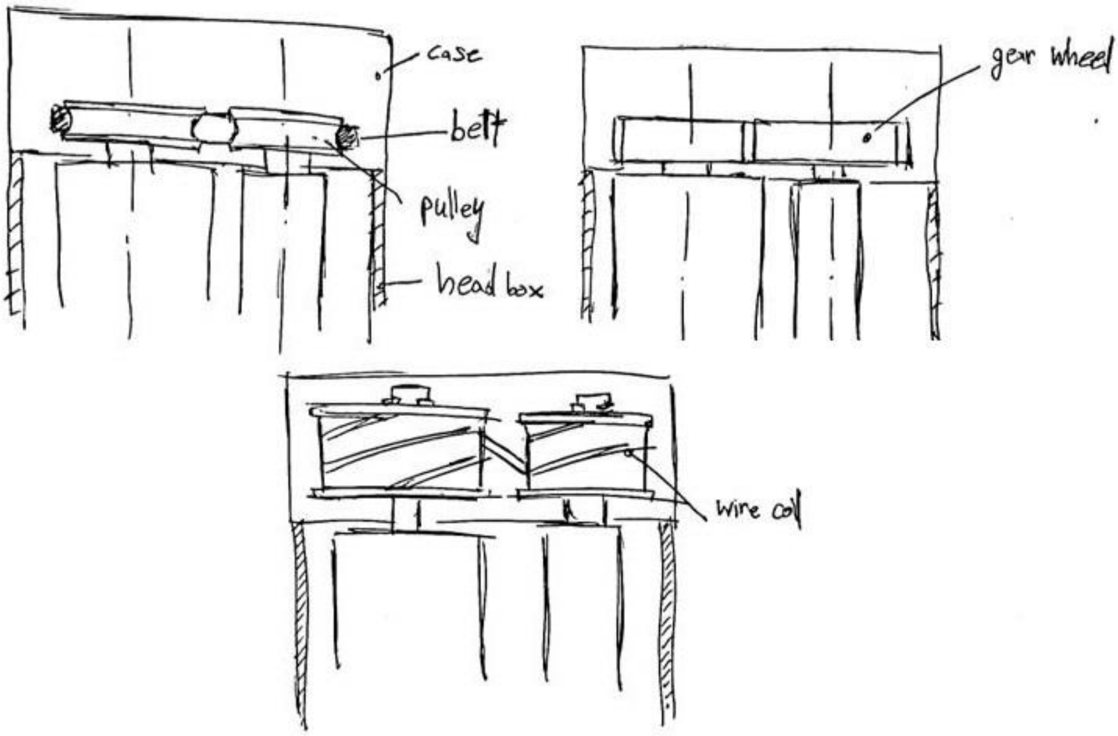


Figure 2.4 – Alternative concepts for the torque transfer from the spring to the tube.

In this case, the free end of the spring is located on the opposite side from that of the head-box edge. Therefore, an intermediate means of torque transmission is required. According to two alternative solutions identified in Figure 2.5, this element can consist of a control rod, which extends to one of the two free ends of the casing. At the end of this rod, an element is positioned through which external action can be exerted with a special tool for the fast spring tensioning. In both cases, the rod is held securely in place by a compression spring that presses the loading insert against its designated housing created on the head. The rotation of this insert must be prevented, and this can be achieved through properly shaped abutment surfaces made directly inside the head. To disengage the components, it is therefore necessary to press axially along the rod during loading and rotate in the correct direction.

Between the two proposed solutions, the second one, with the rod positioned inside the spring, leading the torque to the same end of the head-box, is certainly more easily manufacturable. In the other solution, the rod would need to vary depending on the product's height (although standard lengths could be provided for measurement ranges). Furthermore, it would not be possible to create a single semi-finished product, requiring assembly to be completed in the final production phase, resulting in increased time and reduced resource manageability. Also, from a material usage perspective, consumption would certainly be higher.

With the solution identified here, it is possible to act on the spring from the outside, but only from the top of the product. Therefore, it is not possible to operate once the product is installed, as initially required. To overcome this drawback, the solution shown in Figure 2.6 has been proposed, in which the loading insert takes the form of a gear, while the abutment surface is made up of a worm screw. In this way, with a specific insert, it is possible to act in an orthogonal direction with respect to the main development plane of the net. Hence, the required condition is met.

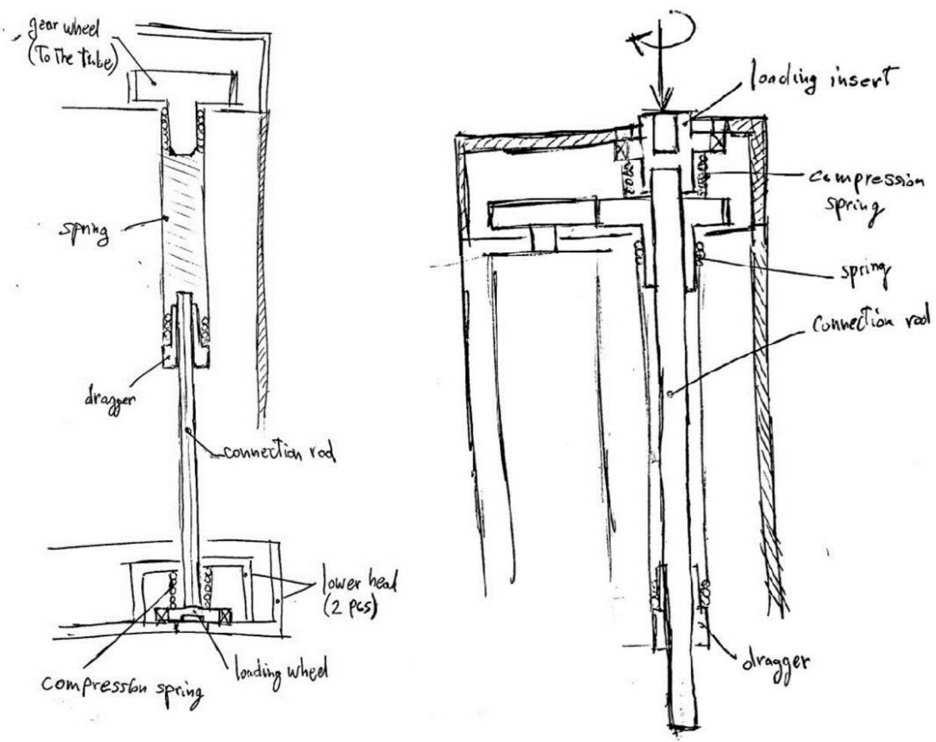


Figure 2.5 – First concepts for the external adjustment of spring tensioning.

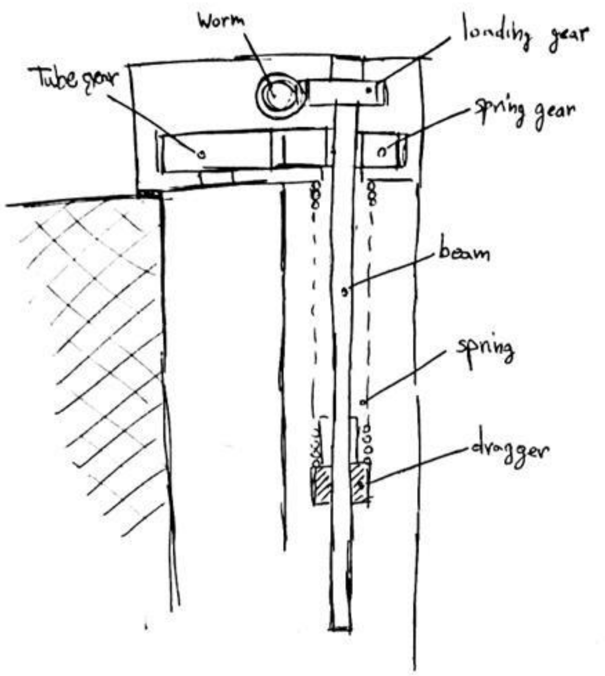


Figure 2.6 – Final concept for the spring regulation system from the outside.

The lower carriage chain, consisting of smaller elements compared to those of the reference product *Sintesi* requires a new solution for interconnecting the modules with each other to meet the overall stiffness constraints. Looking at the main competitor, it is evident that a possible solution is to use long, flexible elements to create the connection between individual pieces of the chain. As will be described in more detail later, in the case of one of Bettio's products, these elements are characterized by two cords with rigid plastic modules positioned on it, spaced at a constant pitch from each other. These modules have protrusions that fit into counter-shaped seats in the carriage elements, thus establishing the desired connection. Therefore, constructive solutions that leverage the same principle but with different forms and attachment methods were initially considered. In Figure 2.7, it is possible to see some sketches of carriages and hypothetical connecting elements.

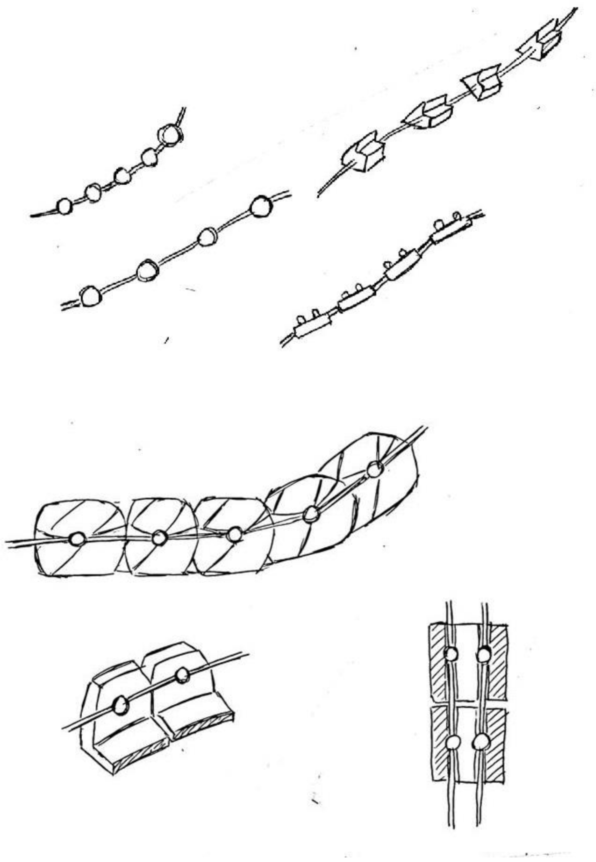


Figure 2.7 – First concepts of lower carriage chains.

To properly address any vertical out-of-square condition present in the frame, a system with a double upper telescopic guide has been thought. In other words, it consists in a fixed upper guide anchored to the wall, and a second upper registration guide, adjustable in height, to restore the correct orthogonality with the main development direction of the head-box. In this way, on one hand, the correct product functionality is ensured as per the initial requirements, and on the other hand, a significant improvement in the aesthetics of the handlebar is achieved. In fact, in the previous *Sintesi* product – not equipped with this technology – for compensating height misalignments, a certain nominal clearance had to be left between the upper guide aluminium and the handlebar, and this gap was sometimes perceived as visually displeasing by customers.

Therefore, the upper guide regulation methods, as well as its attachment to the net package and the principles for handlebar constraint and sliding, must be defined. Regarding the first point, Figure 2.8 shows two alternative concepts. In both cases, there is an adjustment screw anchored to the telescopic guide and an insert with which the screw will engage for the fine adjustment. In the solution on the left, the insert is already mounted in position on the upper guide, and the screw must be centred. In the solution on the right, which is more complex to develop, the insert is already partially screwed onto the screw, and during assembly it will anchor to the telescopic guide, allowing for the desired adjustment later.

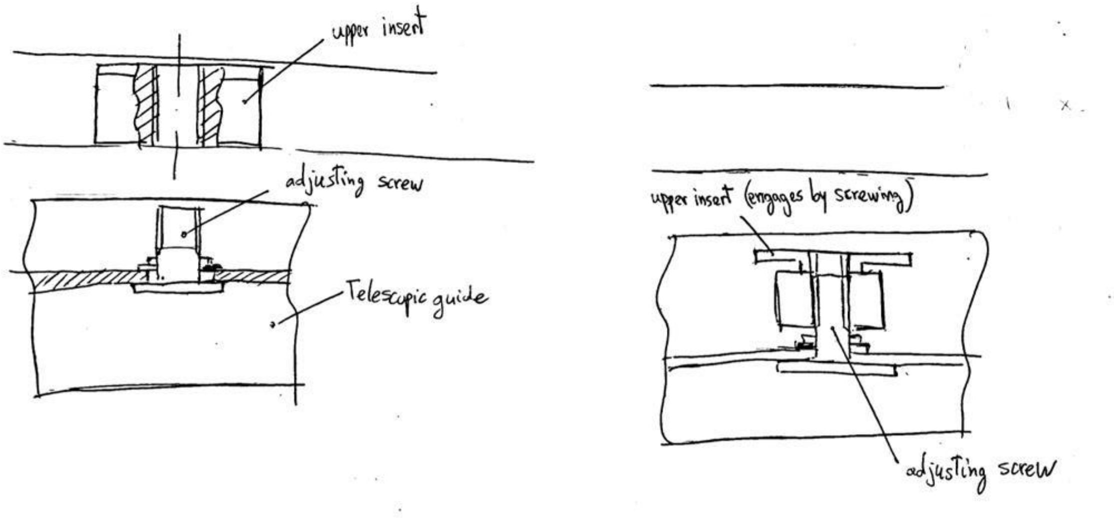


Figure 2.8 – First concepts for the regulation of the upper guide height.

The telescopic guide connection to the net package must be achieved by interposing a plastic cap. This is to enhance the overall aesthetic appearance and prevent sharp edges of the aluminium from being visible. In Figure 2.9, there are some construction sketches in which the cap is either installed prior to the net package or already attached to the telescopic guide during assembly. The connection to the upper head of the head-box can be made through screws or snap-fits, while the guide can be secured with suitable fastening fins, designed to achieve a quick installation and for preventing undesired detachments during operation.

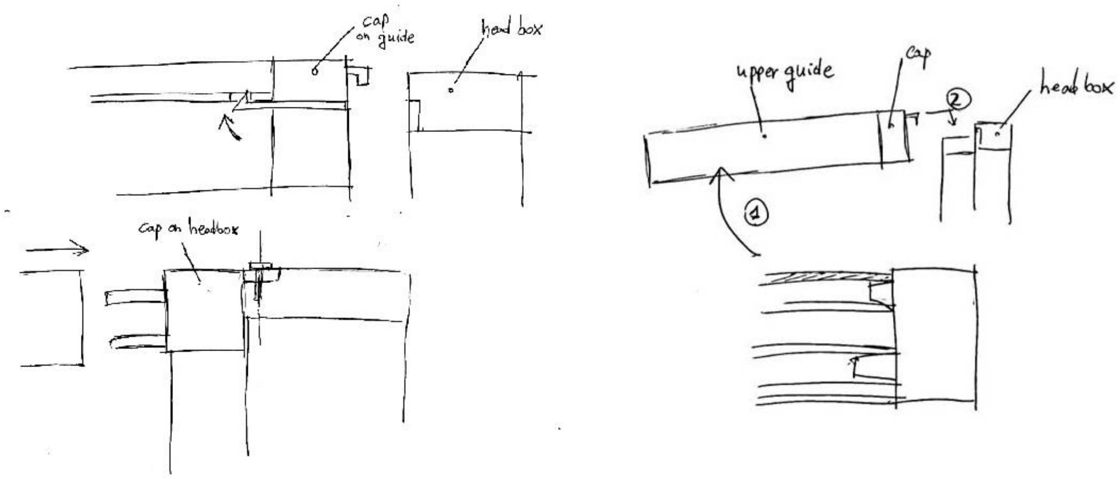


Figure 2.9 – First concepts for the connection between the upper guide and the head-box.

Regarding the constraints necessary for the handlebar's smooth movement, to minimize friction, the use of rolling elements is considered. These elements can be placed either above or below the handlebar, or in both positions, as shown in Figure 2.10. The transverse constraint is also necessary and can be achieved simply by appropriately shaping the lower head, so as to contain the lower guide inside it.

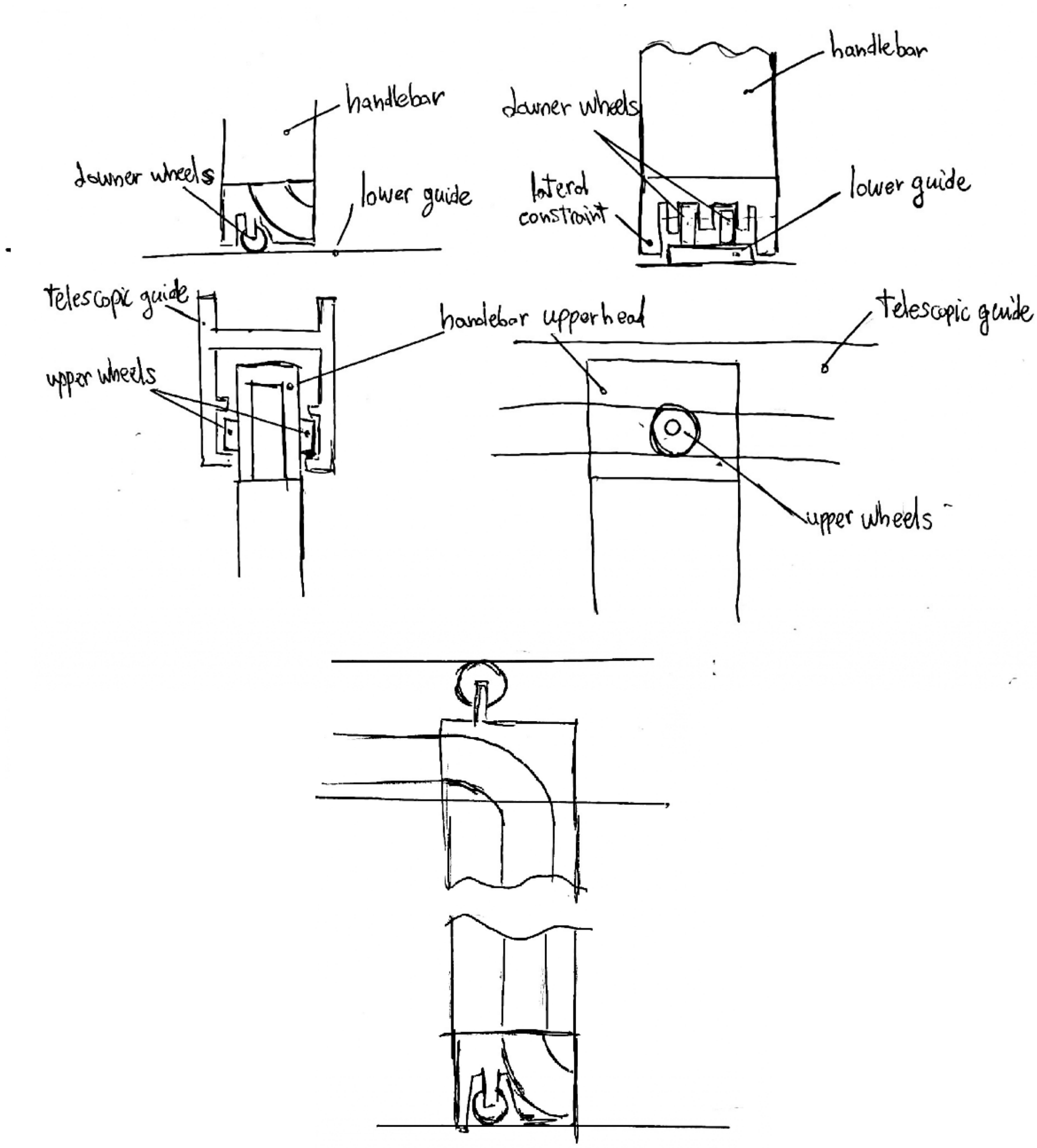


Figure 2.10 – First concepts for the constraining of the handlebar during its movement.

The synchronization of the horizontal movement of the handlebar is operated according to the technology already present in the *Sintesi* product, which is schematically shown in Figure 2.11. The lower carriage chain moves inside the handlebar and is connected, with a specific component, to the upper carriage chain, which continues its path, exiting from the top of the handlebar and connecting to the upper part of the abutment profile. Therefore, no tensioning and/or synchronization wires are required for the system functioning, which is preferred for reliability, ease of assembly, and maintenance.

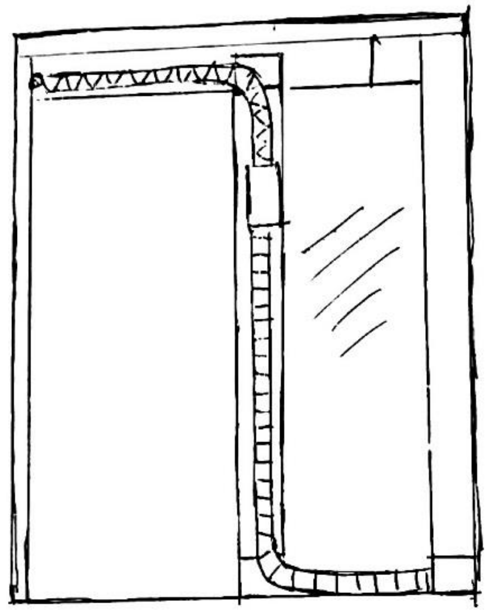


Figure 2.11 – Schematic representation of the synchronization mechanism of the handlebar movement.

To verify the project feasibility, once the main subassemblies have been identified, the next step is to create a preliminary bill of materials, which is of course temporary but still capable of providing a rough estimate of the future production costs. This parameter is crucial, in addition to technical feasibility, to understand whether the new mosquito net model can be introduced to the market within the desired price range or not. If the preliminary costs turn out to be too high, it would be necessary to review the assumed constructive solutions, or alternatively, some of the constraints and/or objectives initially set, considered of secondary importance.

For the estimate, a product of medium size was considered, with dimensions based on the history of similar products sold by the company. In particular, the product size is of 1,32 x 2,20 meters. Similarly, the costs of aluminium and some plastic components were estimated proportionally to other already-known parts, but of larger dimensions. The details of this analysis and the discussion about the methodologies applied for cost estimation remain out of the scopes of this work. Table 2.2 shows the overall starting results.

Table 2.2 – First estimation of mosquito net model production costs

Resume	
Aluminium [€/product]	€ 24,2
Plastics [€/product]	€ 17,7
Accessories [€/product]	€ 11,0
Assembly [€/product]	€ 10,5
TOTAL [€/product]	€ 63,4
TOT [€/m^2]	€ 21,83

As it is possible to note, the total cost per square meter of surface for an average product is € 21,83. Compared to the reference *Sintesi* product, this overall cost is around 18,5 % lower, even if the estimated assembly times are 39,5 % higher. Therefore, it can be considered that the product, as a first estimate, is economically feasible as well, in particular because of the reduction in aluminium weight.

3 - Literature Review

In the field of blinds and mosquito nets, there are few major competitors in the market, especially in Europe. However, the number of patents in this sector is quite high. In Espacenet database, under the relative classification (fixed or movable closures for openings in buildings, vehicles, fences, or similar enclosures in general, e.g., doors, windows, blinds, gates), the number of patents containing the words 'fabric roller' or 'shad*' in the abstract is 3126 (Espacenet – search results, n.d.).

Palagina company has a total of 12 European patents to its name. These cover both the more specific field of blinds and that of mosquito nets, even though, as is known when granting a patent, efforts are made to extend protection as much as possible, including related fields of use.

In particular, some of the patents refer to the *Sintesi* product, the top-of-the-line mosquito net produced by the company. The presence of two chains, one lower and one upper (Francalanci & Ostuni, 2019, 2020), and the connection system between the two (Rossi et al., 2023), are features that, according to the company's initial request, must belong to the new product under development. However, due to the different design specifications, in particular related to the reduced thickness, the detailed constructive solutions will need to be modified significantly.

During the preliminary feasibility study of the project, certain challenges arose, which required significant changes to many of the characteristics that define the *Sintesi* product. This made it necessary to conduct more extensive patent searches, focused on specific sub-assemblies of the product. This has been done in order to be aware of existing technologies and to ensure that no patents would be infringed upon during the design process.

In particular, patent searches have been performed for what concerns:

- net tensioning technologies (Tomita, 1997; Igarashi, 1998; Agliolo, 2011; Chen, 2012; Martin, 2016; De and Meinster, 2017);
- methodologies for varying the tension of the net, through external action (as per specification)(Heckman and Haggard, 1942; Tedeschi, 1990; Wilgehof, 2006; Ng, 2011; Tao, 2019);
- methodologies of lower chains assembly and tightening of the carriage (Bettio, Denis and Bettio, Loris, 2010, 2010; Vittore, 2017; Grützner, 2019);
- installation mode and adjustment of the upper guide (Bettio, Denis and Bettio, Loris, 2016; Shipman, 2021).

The identification of the results primarily occurred through two distinct methodologies: firstly, by using the company's knowledge on the presence of analogous technologies within the market (search by applicant), and secondly, by employing keyword-based approaches. The following findings have been derived from the patent databases of Espacenet.

Subsequently, an overview of contributions already existing in the literature for helping designers to develop new products or to improve them is provided, highlighting their strengths and limitations. The method considered to be the most suitable for our purposes will then be selected in order to identify possible fields of reuse for end-of-life fly screens, explaining the reasons for the choice.

3.1 - Net Tensioning Technologies

As anticipated in the introduction, the patent research conducted in this case concerns tensioning systems for blinds or mosquito nets using a spring, which is located externally to the net tube. This constructive solution has become necessary to comply with the specified maximum dimensions and to keep production costs at not excessively high values.

In (Chen, 2012) a vertical roller blind is described, consisting of a pair of lateral anchoring brackets, visible in Figure 3.1. These brackets (2,3) are fixed to the side walls of an opening in the building and support a roller mechanism (11) on which a fabric (12) is wound. It's important to note that the roller mechanism (11) is mounted on each anchoring bracket through a swivelling element (422), which is fixed in rotation with the roller mechanism but has the ability to rotate freely relative to the anchoring bracket.

Additionally, this blind is equipped with elastic return means (411), visible in Figure 3.2 that are mechanically connected to the roller mechanism (11). These elastic return means exert a return force on the roller mechanism when it is unwound. This allows the roller mechanism to automatically return to a closed configuration, in which the fabric rewinds around the roller mechanism.

In particular, the elastic return means are mounted on a protruding pin (31) from the anchoring bracket. This pin is positioned off-center and parallel to the roller mechanism. The main component of the elastic return means is a torsion spring, which is wound between a first end fixed to the protruding pin of the anchoring bracket and a second end fixed to the swivelling element of the roller mechanism. In practice, when the roller mechanism rotates, the torsion spring unwinds from the protruding pin and winds around the swivelling element, creating an elastic return force that brings the roller mechanism back to the closed position, with the fabric rewound on it.

Although the spring is indeed positioned externally to the tube, the design does not involve the use of additional transmission means between the two, as in the proposed solution. Furthermore, it is believed that the thickness constraint imposed by a flat spiral spring of this type is not compatible with the maximum space limitation given.

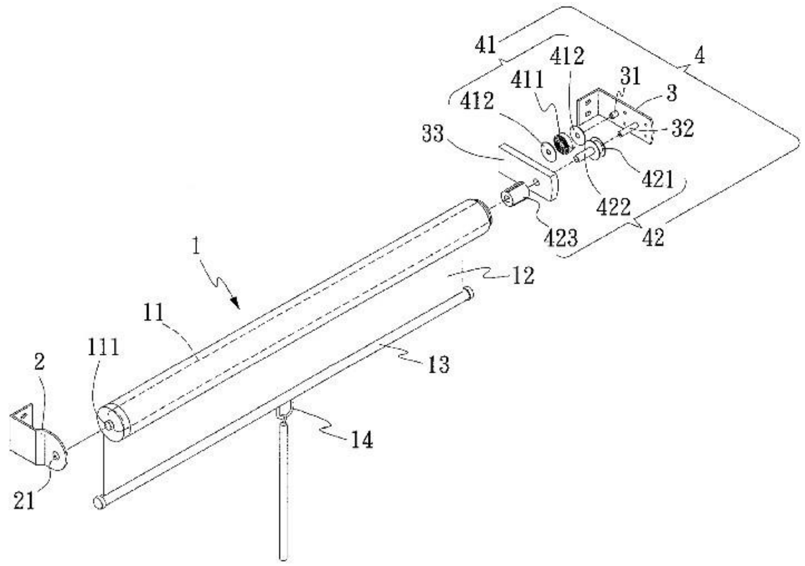


Figure 3.1 – Drawing of the invention from (Chen, 2012) (1).

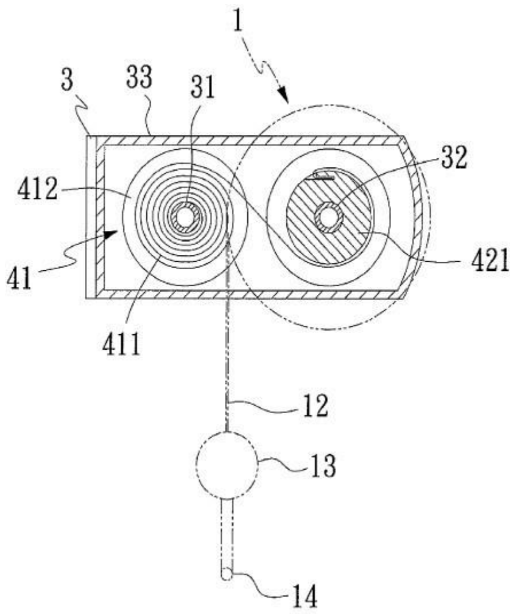


Figure 3.2 – Drawing of the invention form (Chen, 2012) (2).

The mosquito net described in (Tomita, 1997) – Figure 3.3 and Figure 3.4 – comprises a vertical head-box with a winding mechanism (20) located inside, on which the mosquito net material (C) is wound. There is also a handlebar (3) that slides along the upper and lower guides and to which one end of the mosquito net is attached.

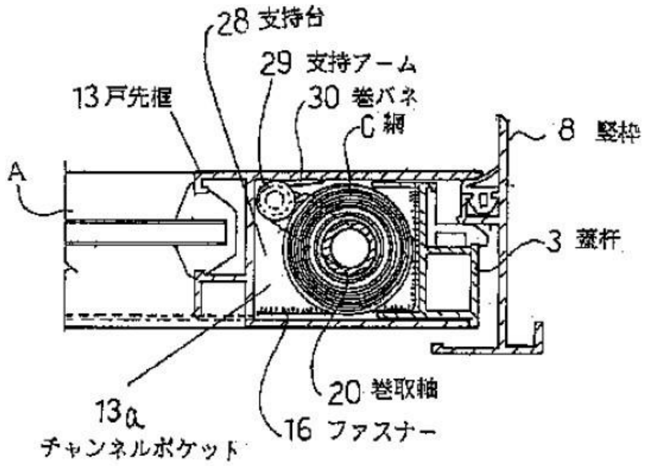


Figure 3.3 – Drawing of the invention from (Tomita, 1997) (1).

Additionally, the system is equipped with first elastic return means (not shown) consisting of a helical torsion spring, coaxial with the winding mechanism, and a second elastic return mean (30), i.e., an arm-type torsion spring, positioned off-centre with respect to the winding mechanism, and exerting an elastic force on it. This ensures that the netting (C) remains consistently parallel during unwinding. Therefore, in this case, in the retrieved invention the spring has nothing to deal with the net tensioning itself.

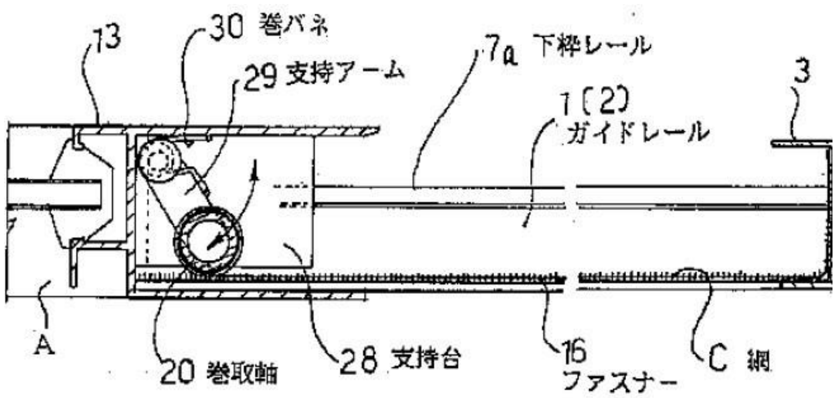


Figure 3.4 – Drawing of the invention from (Tomita, 1997) (2).

The patent presented by (De and Meinster, 2017) - Figure 3.5 and Figure 3.6 – shows another type of retractable mosquito net, comprising a vertical head-box (2), an upper guide, and a lower guide. A winding mechanism is located inside the cassette, and a handlebar (4) is allowed to slide along the guides. The mosquito net is also equipped with elastic return means (18), located externally to the vertical housing, which are mechanically connected to the winding mechanism at a first end and to the handlebar at a second end.

Each elastic return means comprises a tension cord (6) that extends between a first end, fixed to the winding mechanism, to be unwound and wound by the latter during its rotation, and a second end, fixed to the handlebar. Additionally, each elastic return means comprises a tilting element (19), equipped with two arms (24, 26) fixed to the mosquito net guide and connected to each other through a hinge pin (21).

One of the two arms of the pivoting element features a telescopic pin (13) and a spring (9) mounted on it, compressed during the movement of the handlebar to keep the tension cord taut and, consequently, the fly screen during unwinding from the headbox. Both arms are fixed to the guide through pulleys (27, 28, 29) to allow the tension cord to slide during the opening and closing of the handlebar.

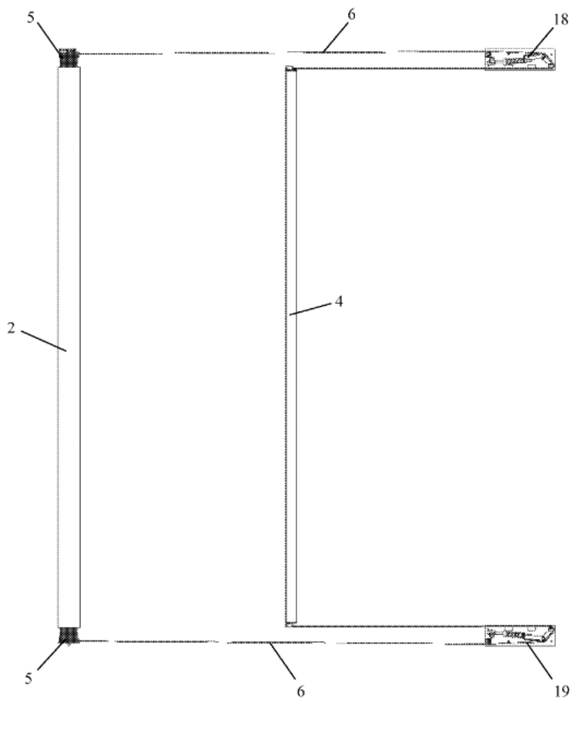


Figure 3.5 – Drawing of the invention form (De and Meinster, 2017) (1).

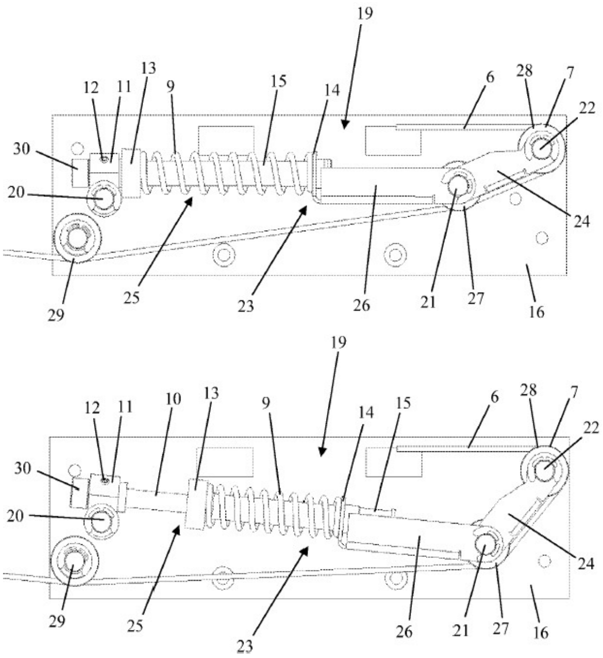


Figure 3.6 – Drawing of the invention from (De and Meinster, 2017) (2).

In (Agliolo, 2011), an alternative solution for net tensioning involving wires is presented. As depicted in Figure 3.7, this mosquito net comprises a vertical headbox, an opposing profile (2), and two guides (4) extending both above and below between the cassette and the vertical stop.

Furthermore, the described mosquito net includes a roller mechanism (not visible) on which the mosquito net material is wound, housing a coaxial helical torsion spring. The handlebar (54) that slides along the guides, has one end of the fly screen attached.

Additionally, the described mosquito net also incorporates a second set of elastic return elements (78), positioned within the opposing profile. These elements consist of a helical torsion spring mechanically connected with a cord (15) to the handlebar. This arrangement applies an elastic force to the handlebar (and consequently to the roller mechanism) to maintain the system in a closed position, preventing any openings.

For this purpose, the spring has a higher spring constant compared to that of the first elastic return element, enabling it to overcome the resistance of the latter and allowing the mosquito net to be securely closed.

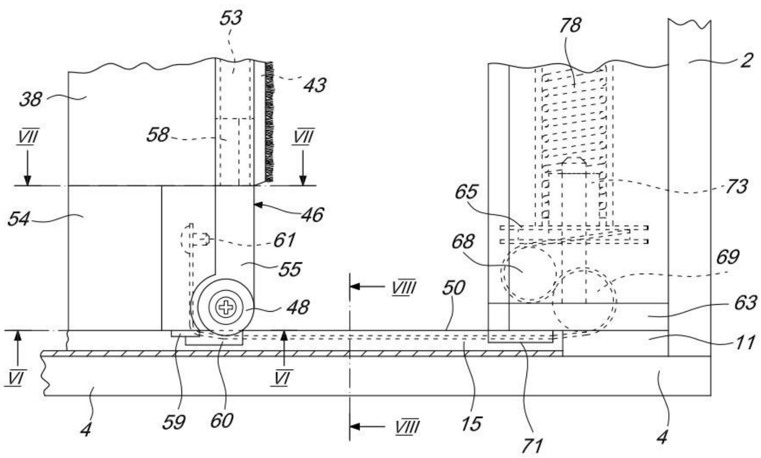


Figure 3.7 – Drawing of the invention from (Agliolo, 2011).

An alternative solution that combines the use of wires and gear wheels for transmitting tensioning force is described in (Martin, 2016). This patent details a vertical roll-up system – visible in Figure 3.8 and Figure

3.9 – featuring a roller mechanism (12) around which the net is wound. The textile material can be moved vertically between two lateral guides (16) and is equipped with elastic return elements (22) positioned at the bottom of the blind, opposite to the roller mechanism.

The elastic return means are connected to an edge (14) of the net using a cord (18). These means consist of a box-shaped body (10) in which three spools are secured, aligned with their axes parallel. Specifically, a first spool (104) has the other end of the cord attached, enabling it to unwind and wind on during the opening and closing of the net.

Furthermore, the box houses a ribbon-type torsion spring that wraps around between a first end fixed to a second spool (132) and a second end fixed to a third spool (134).

Both the first and the second spools (104, 132) have geared wheels (138, 136) that engage to transmit the rotational motion from the first spool to the second spool. Consequently, during the operation of the blind, the first spool rotates, transferring the motion to the second spool. In this way, the torsion spring unwinds from the second spool and winds around the third spool, accumulating an elastic return force that raises the blind when released.

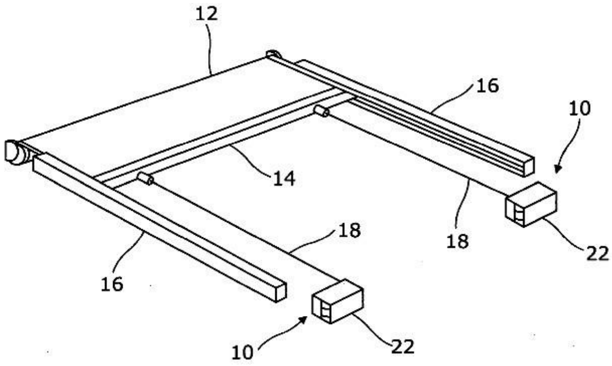


Figure 3.8 – Drawing of the invention from (Martin, 2016) (1).

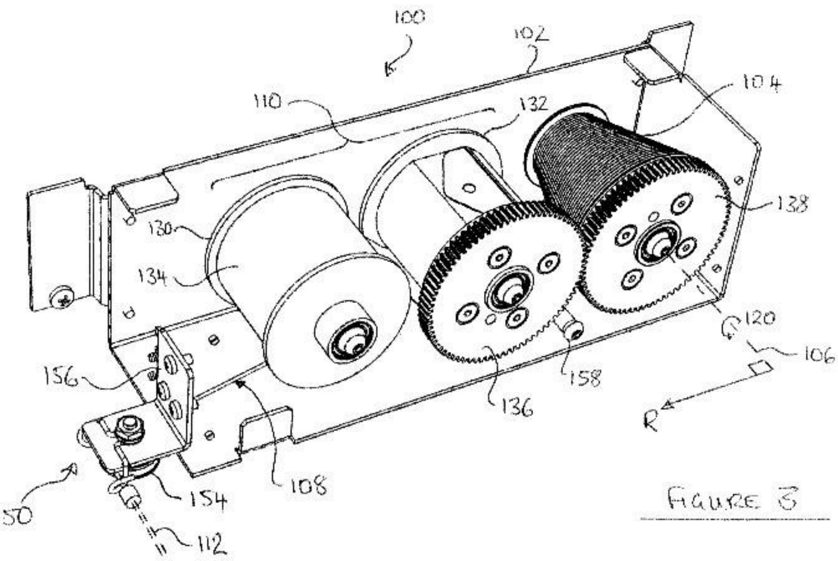


Figure 3.9 – Drawing of the invention from (Martin, 2016) (2).

In (Igarashi, 1998) a shutter is described, visible in Figure 3.10 – comprising a take-up roller and a helical torsion spring placed parallel and externally to the take-up roller. The loading means also include a thread and two reels, and in particular a first winding reel mounted on one end of the winding tube, a second reel on one end of the torsion spring, and a wire or cable with a first end fixed to the first reel and a second end fixed to the second reel. When the sheet is unwound from the take-up roller, the thread is wound on the first reel and unwound from the second reel in order to load the torsion spring. On the contrary, when the force of the torsion spring brings the sheet to be re-wound, the thread is unwound from the first reel and wound on the second reel again.

In the last four identified inventions, the outer spring is found always in connection with wires to transmit the tensioning force. Therefore, they all differ from the solution identified for the new mosquito net model.

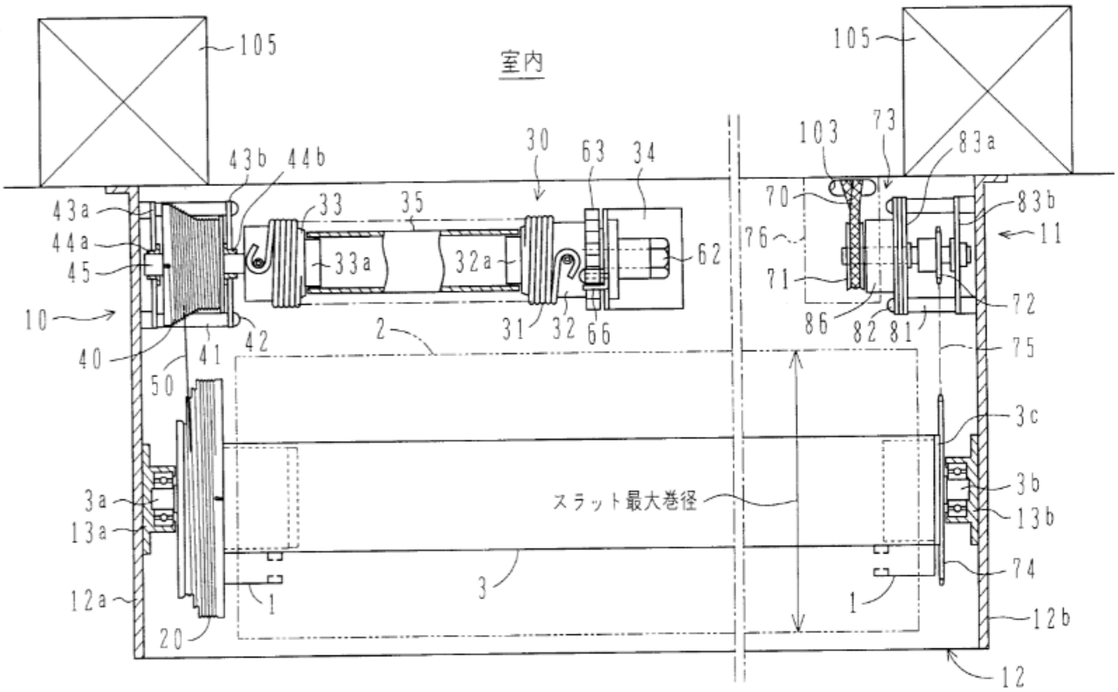


Figure 3.10 – Drawing of the invention from (Igarashi, 1998).

3.2 - Net Tensioning Variation Technologies

The patent research in this case has focused on systems for blinds and mosquito nets containing one or more gear wheels (eventually with worm teeth), useful for varying the tension of an elastic element (spring) when the product is already in operation.

In (Heckman and Haggard, 1942) a vertical roller blind is described, with a device for precisely adjusting the tension of a return spring, even after the blind has been installed. The system is visible in Figure 3.11 and Figure 3.12.

In detail, the tension adjustment device includes a shaft (15) and a torsional return spring (16) positioned around the shaft. The return spring has one end (100) rotatably connected to the shaft through a fastening element (17) and another end (101) connected to a slider (18) connected to the winding roller (14), enabling rotation with it.

The tension adjustment device includes a loading gear (22) mechanically connected to the shaft, and a worm screw (24) mechanically engaged with the loading gear, accessible from the outside for user operation.

To adjust the tension of the return spring, the operator rotates the worm screw, which in turn rotates the loading gear. Since the loading gear is connected to the shaft, it rotates and adjusts the tension of the spring, allowing for the desired adjustment. In this process, the worm screw, as is well known, serves as a locking device to prevent the rotation of the shaft and holds the spring in the desired tension position set by the operator.

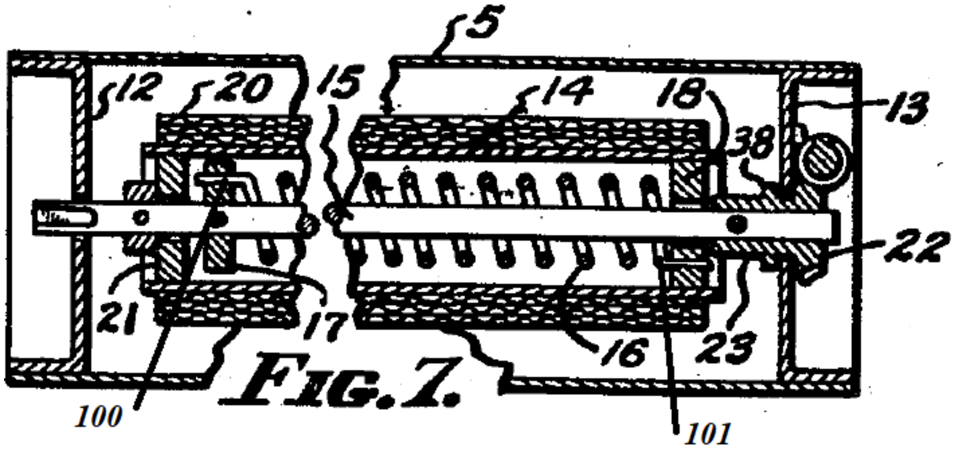


Figure 3.11 – Drawinf of the invention from (Heckman and Haggard, 1942) (1).

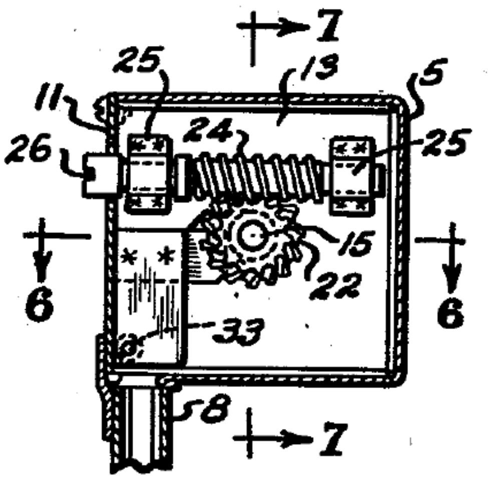


Figure 3.12 – Drawing of the invention from (Heckman and Haggard, 1942) (2).

(Ng, 2011) – whose invention is reported in Figure 3.13 and Figure 3.14 – proposes another mechanism with an irreversible worm gear coupling, in which the movement of the components is, however, transmitted directly to the spring at its nearest end.

In detail, the device comprises a torsional-type return spring (25), with one of its ends rotatably attached to a first fastening element (30), while the other end is connected to the winding roller (18) via a second fastening element (34). Furthermore, the device includes a loading mechanism (56) with a gearwheel rotationally integrated with the first fastening element and a worm gear (40) mechanically coupled.

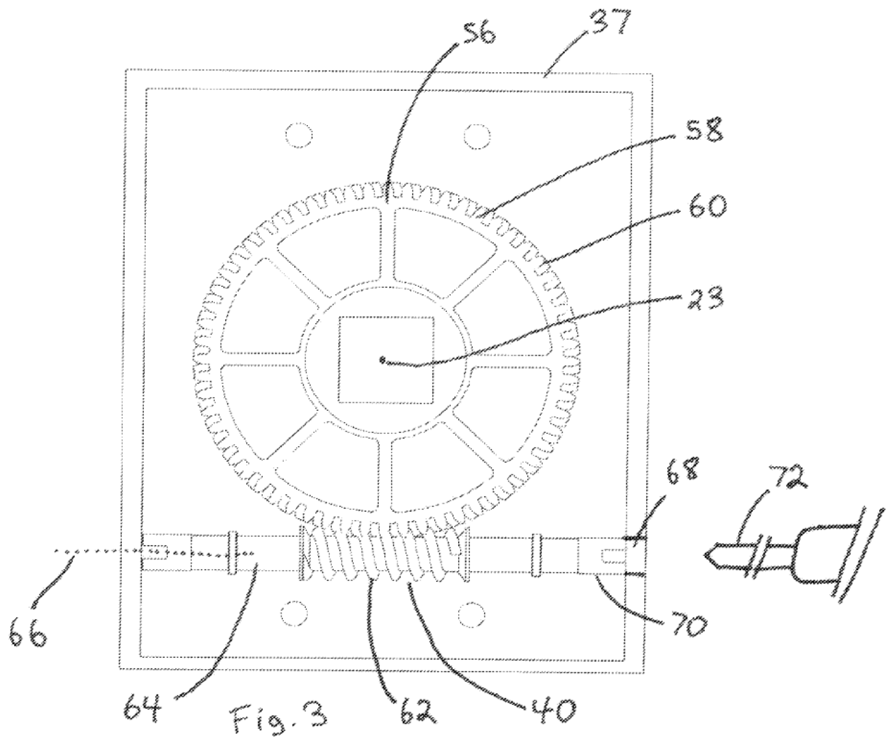


Figure 3.13 – Drawing of the invention from (Ng, 2011) (1).

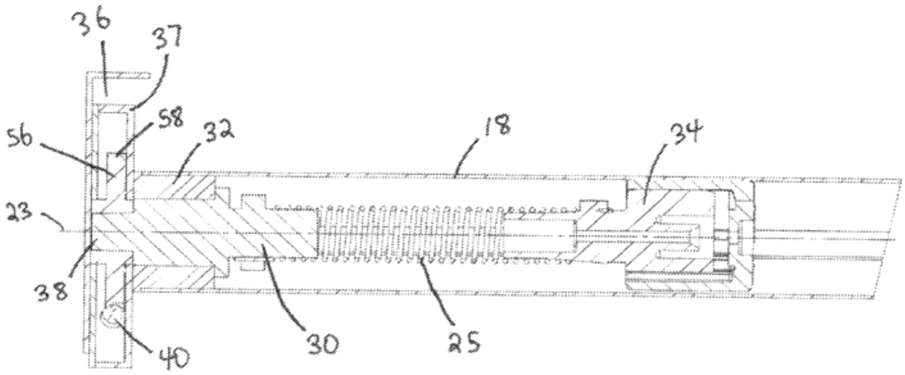


Figure 3.14 – Drawing of the invention from (Ng, 2011) (2).

In operation, to adjust the preloading of the return spring, the operator rotates the worm gear, which in turn, rotates the gearwheel and the first end of the spring. In this process, the worm gear prevents the rotation of the loading mechanism and maintains the spring in the preloaded position set by the operator.

In these two contributions, the spring adjustment can be performed only with a low gear ratio, through the worm gear. Therefore, this is not properly the case of the new model under development.

(Tao, 2019) describes instead a device for adjusting the tension of a return spring in a roll-up blind in a quick manner, visible in Figure 3.15 and Figure 3.16. In detail, the blind described includes a torsional return spring (4) mechanically connected to a rolling mechanism (7), which is coaxial with the roller itself and located on an adjustment shaft (3).

The device for adjusting the tension of the spring comprises:

- a first tubular body (23) fixed to the blind's frame and equipped with primary engagement teeth (231);

- a gear rod (22) inserted into the first tubular body, with a first end (223) having secondary engagement teeth (221) capable of engaging with the primary teeth of the first tubular body, and a second end fixed to the shaft (3);
- a second tubular body (24) positioned around the gear rod and fixed to the first tubular body;
- a spring (21) placed between the first end (223) of the gear rod and the second tubular body, which pushes the secondary engagement teeth toward the primary ones of the first tubular body.

To adjust the tension of the return spring, it is necessary to act with a tool on the first end (223) of the gear rod to separate it from the first tubular body (23), overcoming the elastic force of the spring (21) and disengaging the teeth from each other. Subsequently, it is possible to rotate the gear rod and the shaft (3) to adjust the tension of the return spring (4). Then, when the tool is removed from the gear rod, the spring (21) pushes the secondary engagement teeth on the ones housed in the first tubular body.

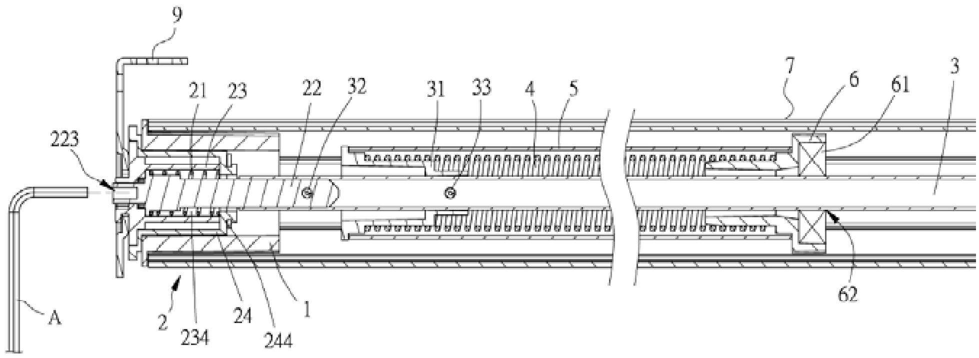


Figure 3.15 – Drawing of the invention from (Tao, 2019) (1).

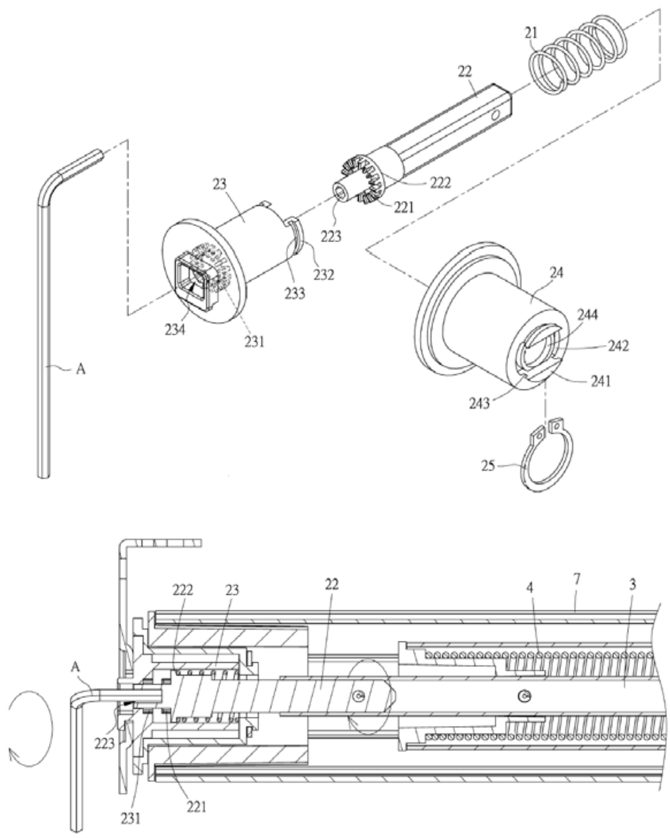


Figure 3.16 – Drawing o the invention from (Tao, 2019) (2).

Another contribution that describes a device for the quick adjustment of a return spring pre-load is reported in (Tedeschi, 1990).

This solution, reported in Figure 3.17and Figure 3.18, includes a locking element (3) integrated into the frame, characterized by multiple recessed parts (7), and a transmission element (6) mechanically connected to a shaft (14), equipped with multiple protrusions (8). These protuberances have shapes suitable for engaging with the previously mentioned recesses on the locking element, so as to prevent relative movements between the two.

Furthermore, an accessible opening from the exterior is present on the transmission element, that allows an operator to use a specialized equipment to act directly on it.

This pre-load device also includes a second locking element (10) in an opposite position with respect to the first one, and a spring (9) positioned between in and the transmission element.

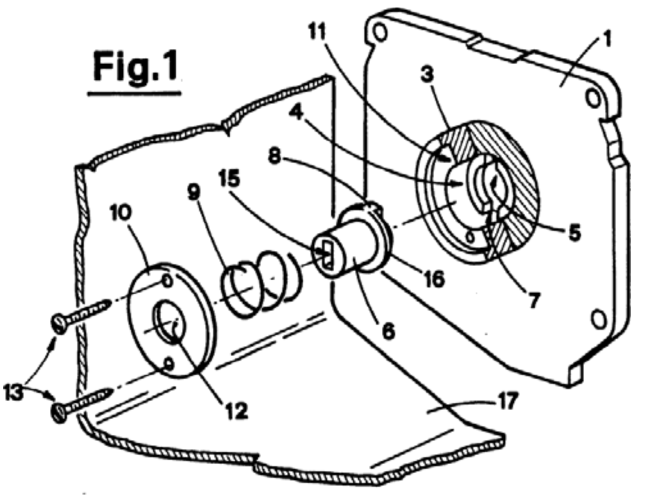


Figure 3.17 – Drawing of the invention from (Tedeschi, 1990) (1).

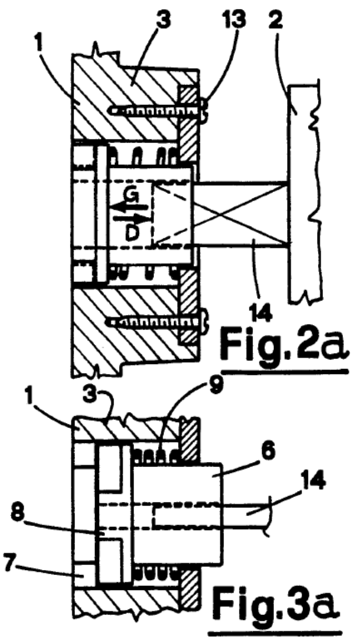


Figure 3.18 – Drawing of the invention from (Tedeschi, 1990) (2).

Under normal conditions, the spring keeps the protrusions of the transmission element engaged in the recesses of the first locking element, thus preventing the rotation of the component (6) and, consequently, the main shaft (14).

Instead, during the spring pre-loading phase, the operator must apply an axial force inside the opening of the transmission element, exceeding the elastic resistance of the spring and causing the disengagement of the protrusions. At this point, the component (6) can be rotated, allowing the movement of the roll-up shaft and the adjustment of the spring load.

The last patent analyzed for the fast spring pre-tensioning adjustment is (Wilgehof, 2006).

In particular, the system includes a return spring (18), visible in Figure 3.19, with one end connected in a rotatable manner to a shaft (5) and the other end connected in a rotatable manner to the winding tube (3) of the blind.

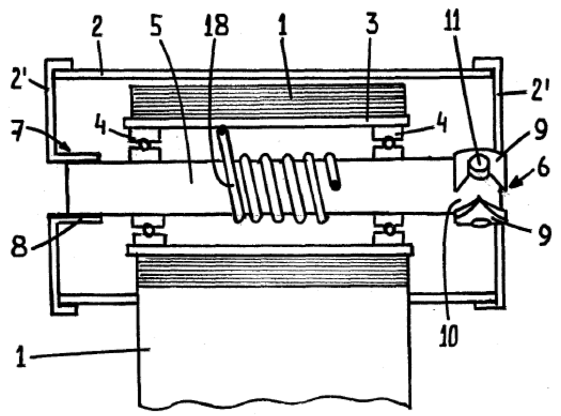


Figure 3.19 – Drawing of the invention from (Wilgehof, 2006) (1).

The shaft (5) has on one end multiple engaging protrusions (11) out of the surface. It also features a through-hole accessible from the outside of the blind, typically using a tool, which allows direct manipulation of the shaft (5). Additionally, the device includes an annular element (9) fixed to the frame and equipped with V-shaped grooves (10) designed to accommodate the engaging protrusions and prevent any movement of the shaft.

During the phase of pre-tensioning adjustment, the operator uses a tool to act on the axial hole of the shaft, thus disengaging the protrusions from the V-shaped grooves. In this condition, the shaft can rotate freely, allowing the return spring to be tensioned and adjusted, as reported in Figure 3.20.

It's important to note that the devices described in the last three patents do not include a worm screw that can be coupled to the engagement shaft to perform a "fine" adjustment of the spring's pre-tension. Therefore, the mechanism under study does not fall among them either.

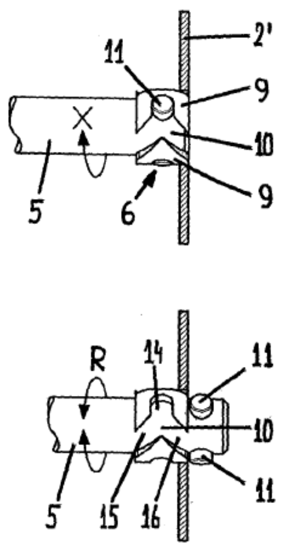


Figure 3.20 – Drawing of the invention from (Wilgehof, 2006) (2).

3.3 - Lower Chain

In this section, the patents related to carriage guide elements, where individual modules are connected using flexible filamentous structures, are listed. A multitude of products on the market employs this technology, as it is used to increment the overall stiffness of the chain and reduced undesired movement of the handlebar. Therefore, it is important to understand the aspects of the inventions that are described and protected in order to identify the best ways to differentiate from them.

In (Bettio, Denis and Bettio, Loris, 2016) the guide chain described – visible in Figure 3.21– is made up of several stiff guide components (81), which are connected by two flexible cables (83) on the lateral external surfaces. In particular, the connecting cord (83) is comprised of several engagement bodies (831) that are interconnected by a flexible wire (832). Each engagement body is securely positioned in a corresponding counterbored side seat of the guide element. However, in this patent, although this solution is described, it is protected in a dependent manner with respect to another element of the insect screen, relating to the fixing system of the upper guide. Therefore, it is possible to reproduce such a solution, provided it differs enough in the eyes of a non-expert user.

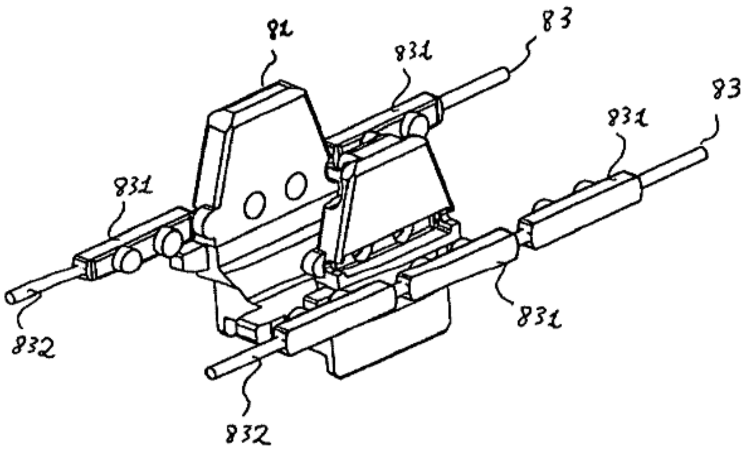


Figure 3.21 – Drawing of the invention from (Bettio, Denis and Bettio, Loris, 2016).

(Bettio, Denis and Bettio, Loris, 2010) describes instead a guide chain for mosquito nets with a mesh locking device 50. In more detail, as it is visible in Figure 3.22, the guide chain comprises a series of modular guide elements (300) interconnected through two chains (40), each of which is equipped with links (400) inserted into corresponding counterbored seats on the side walls of each guide element. However, this patent is aimed at protecting the arrangement of the adjustable locking combs (50) provided for retaining the net.

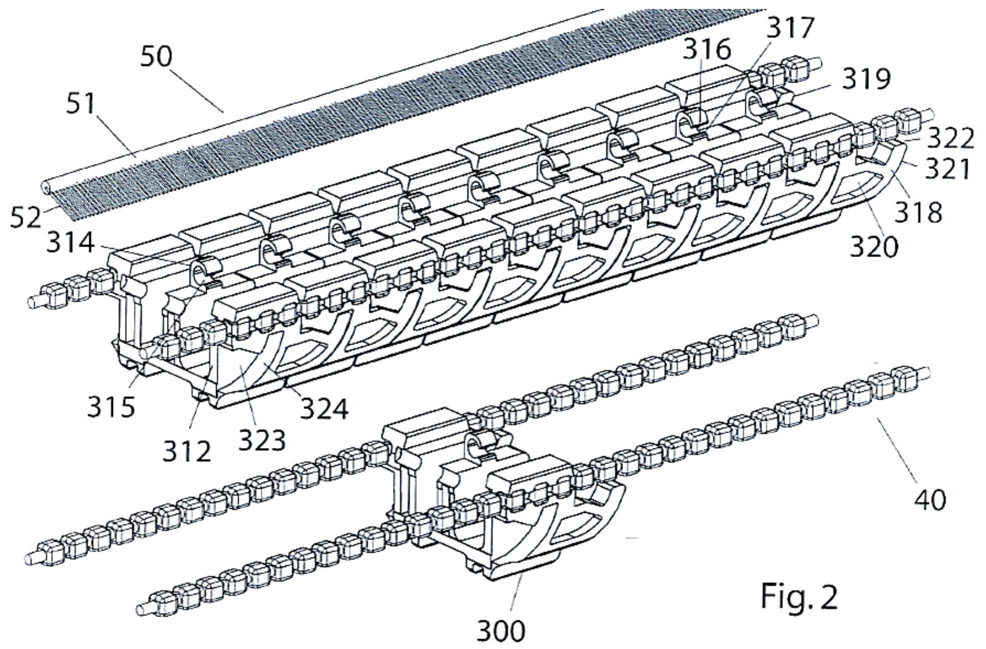


Figure 3.22 – Drawing of the invention from (Bettio, Denis and Bettio, Loris, 2010).

In these two described patents, the flexible sections placed between the adjacent engagement points of the chains are notably short. This results in a significantly reduced radius of curvature during bending, which, in turn, leads to high concentrated tensions that can easily cause wire breakage.

The patent from (Grützner, 2019), reported in Figure 3.23, describes a guide chain (1) that comprises a series of guide elements (2) connected to each other by means of a lacing (3), which includes a filament string (4) with a series of equidistant spheres (5) fixed on it. These protrusions are inserted into respective housing cavities formed on each individual guide element (2). The cavities (6) are longitudinally centered on each chain so that the filament string can be inserted from above to form the final assembly. In contrast to the previous patents, in this case the protection lies in the design of the carriage itself. However, it is specified that in order to fall under infringement, two slots (18) must be present at the ends of the chains to contain to size the thinner parts of the connecting wire. Therefore, this feature must be avoided.

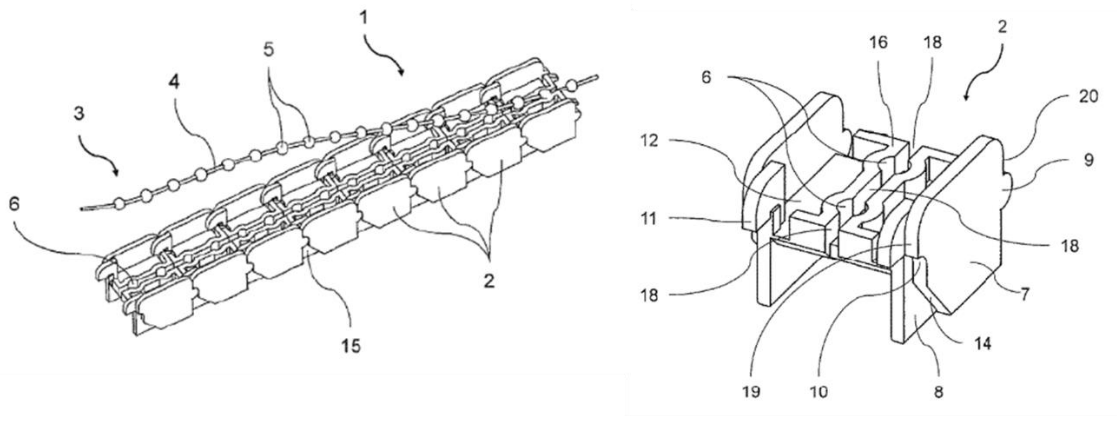


Figure 3.23 – Drawing of the invention from (Grützner, 2019).

A common drawback among the last three described patents is that the guide chain must have particularly precise size tolerances, with regard to the length of the flexible portions, so as to ensure a suitable tensioning of the chaining elements. Indeed, since the engagement portions (spheres or similar) are inserted to size in the housing seats, the tensioning of the guide chain will only depend on the extension of the flexible portions interposed between adjacent engagement portions. Therefore, an error of production tied to the extension of a single flexible portion can deviate the tensioning of the guide chain from the desired values.

Lastly, (Vittore, 2017) describes an alternative solution of a chain, constituted by connecting elements (2), visible in Figure 3.24, linked by means of an elastic strap (3). Such a band is connected to each individual chain in its central inner portion to form a foldable carriage. In particular, the patent protects the chain configuration when it is divided into multiple sections (modules “M”) of rigid elements (2), where the first element (2') of each module is rigidly attached to the last element (2'') of the previous module (M). Therefore, it is important not to replicate this arrangement.

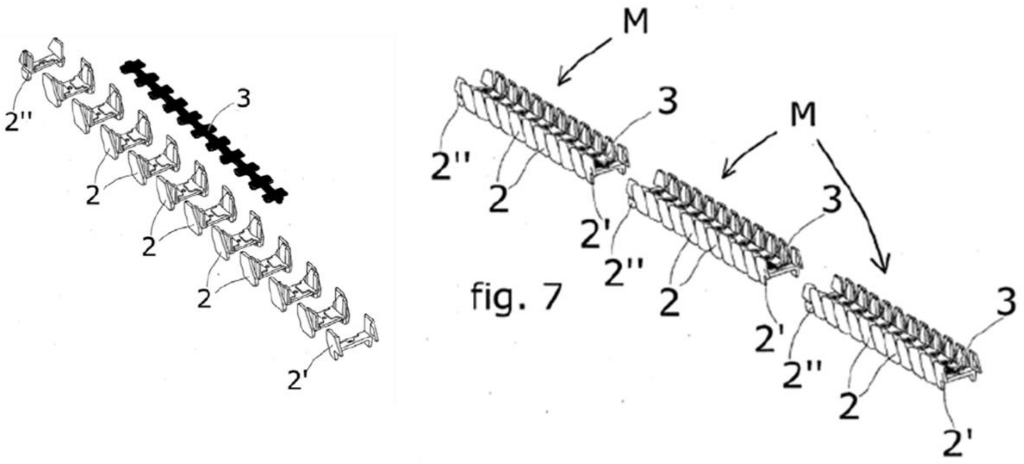


Figure 3.24 – Drawing of the invention from (Vittore, 2017).

3.4 - Upper Guide and its Regulation

The patent research has been focused on insect screens or roller devices characterized by an adjusting or regulation system of one or more guide elements.

In (Shipman, 2021) a screen assembly is described with a vertical winding tube, characterized by the fact that at least one of the guides has a static (20) and a dynamic (26) support. The dynamic support is displaceable relative to the static one in order to facilitate the sliding of the flexible panel. As it is possible to see in Figure 3.25, an adjustment mechanism (30) is operatively connected to the above mentioned supports in order to regulate in a precise manner the dynamic part of the guide in height. This device includes an adjustable head (32) and a threaded shank (34) extending from the head. This shank extends through part of the dynamic support with the head bearing against an inward surface of said part. A nut (36) is trapped in a channel (37) defined by part of the static support, with the shank threaded through the nut. A further nut (38) is threaded onto the shank in such a way that the dynamic support 26 is trapped between the head (32) and the nut (38). Thus, rotation of the head can result in inward and outward movement of the dynamic support relative to the static one. The head can define a suitable engagement formation for a conventional tool so that the adjustment mechanism can be manipulated.

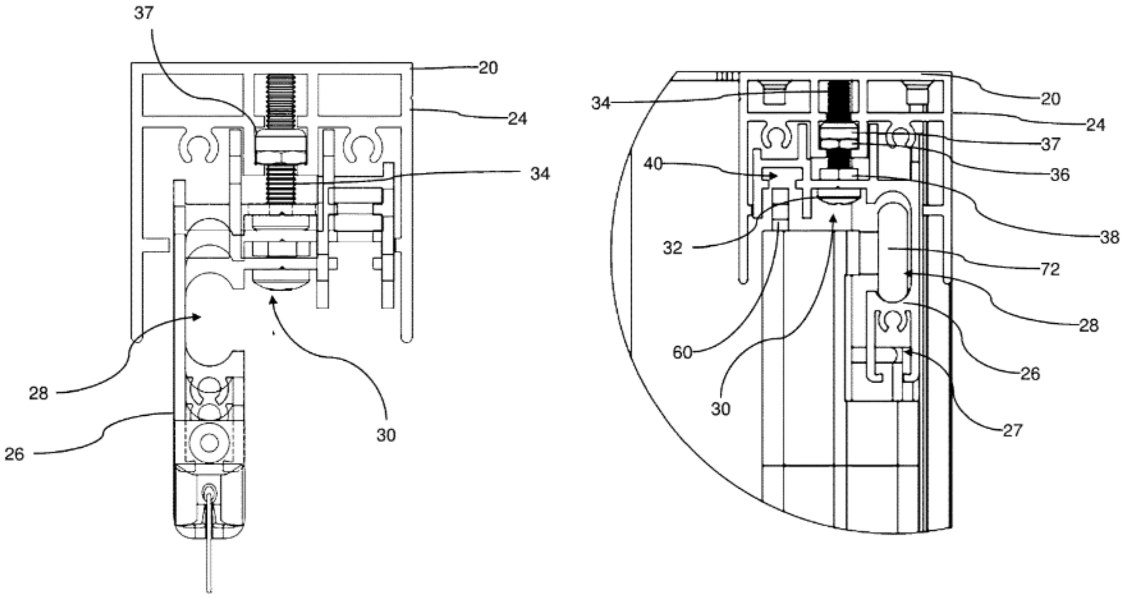


Figure 3.25 – Drawing of the invention from (Shipman, 2021).

.Although the embodiment is conceptually similar to the one proposed, the assembly methodology is not clearly explained. Furthermore, the protection also depends on other product features, such as the presence of retaining elements at the end of the movable part of the guide, designed to hold the bead attached to the edge of the net. Therefore, this patent does not pose an issue for the study.

In (Bettio, Denis and Bettio, Loris, 2016), a method is described for both mounting the telescopic guide in position and adjusting its height. In this case, as shown in Figure 3.26, the upper head of the headbox is hinged to the movable part of the upper guide, allowing it to move from an initial vertical position to a horizontal one.

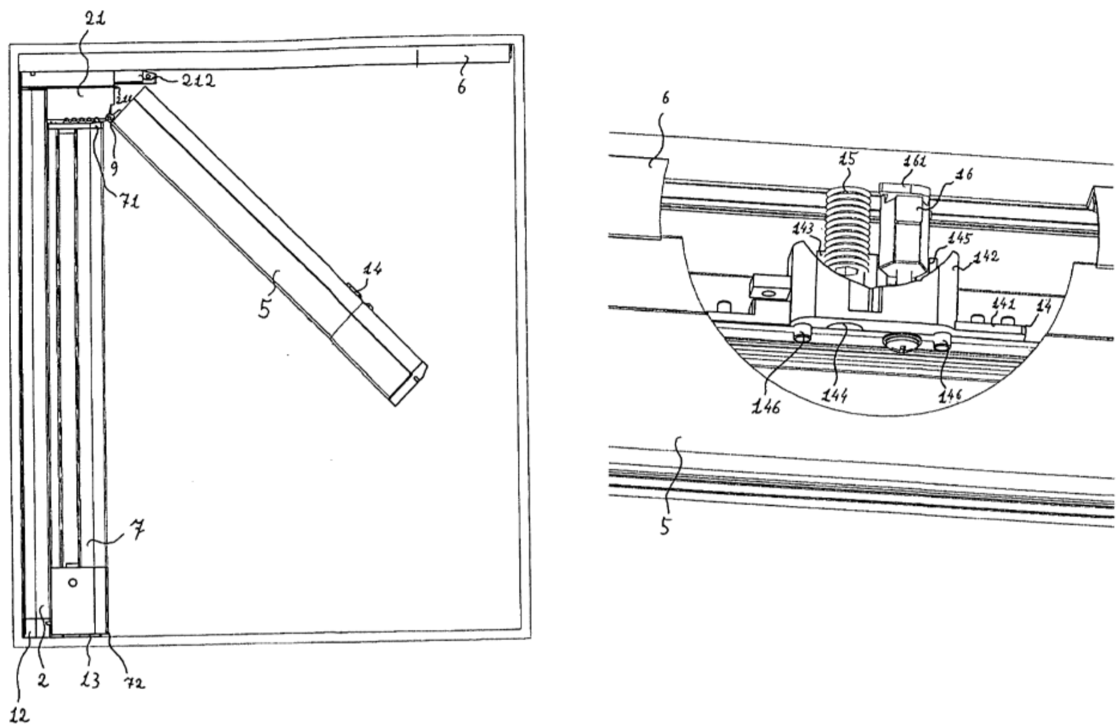


Figure 3.26 – Drawing of the invention from (Bettio, Denis and Bettio, Loris, 2016).

Fine height adjustment is achieved with an insert, visible on the right in Figure 3.26. This insert consists of two parts (14, 16), one attached to the upper portion and one to the lower portion of the guide. The connection is guaranteed by a screw that engages with the upper locking element (16). The final securing is achieved by applying an axial pressure with the threaded element (15), using a specific insert through the hole (144).

As it is possible to note, the main drawback of these adjustment means is that the coupling of the two guides and their relative adjustment of the positioning is complicated and time-consuming. Indeed, the guide profile must be inserted into the fastening profile, taking care to align the first hole with the threaded seat of the adjustment block. Therefore, the operator must hold the guide profile up with one hand while simultaneously inserting the screw shaft into the second hole with the other hand and screwing it in at least partially to prevent the profile from falling.

From the claims analysis, also in this case, the solutions suggested for the new insect screen are viable, as long as the telescopic guide is not hinged to the top of the headbox.

3.5 - Methodologies for New Product Applications Identification

Different approaches, checklists, and guidelines are available in the literature of the design science to be applied throughout the conceptual design phase of a new product ideation. These primarily seek to stimulate the designer's creativity by offering a variety of stimuli, enabling him or her to come up with fresh concepts and investigate the design space more methodically.

According to Smith (Smith, 1998), idea generation techniques are always based on the so-called active ingredients, which enable the user to activate certain cognitive activities. These may be based on instructions to be carried out by the user and/or on external stimuli or on particular conditions (e.g., anonymity). Active ingredients are divided into 15 macro-categories (Smith, 1998). The methods that are the subject of this analysis are derived from these and fall under the categories of both analytical and search strategies.

Among the analytical strategies, one of the most relevant is the so-called "morphological analysis" (Zwicky, 1967), an approach carried out to understand the structural interrelationships between objects, phenomena and concepts. "Functional analysis" (Gonçalves et al., 2014) then belongs to the same category; this approach, which decomposes the problem to be solved through an abstraction process, focuses on what the product will have to do and how it will do it, regardless of how it should appear externally. This is performed through the definition of the important concept of "function".

There are several definitions of the term "function" in the literature. One of the best known is provided by Pahl and Beitz (Beitz et al., 1996). For them, a function is a solution-neutral relationship between inputs and outputs, included in a general block diagram describing the system, based on the flow of energy, materials, and signals. Another definition, which is important for the purpose of this paper, is that of Gadd (Gadd, 2011). The author states that a function can be seen as an action performed by a subject, which has an effect on an object, changing its physical properties (S-A-O definition).

Many literature contributions exist in which the functions deriving from problem decomposition are taken as a starting reference to produce new ideas. This is true, for instance, for all the methods in which external stimuli are exploited.

Compared to other methodologies such as brainstorming (Gonçalves et al., 2014) or brainwriting (Smith, 1998), which are susceptible to psychological inertia, it is stated in (Tauqeer and Bang, 2020) that the use of these particular external stimuli allows for a better focus on the problem. Accordingly, this type of methodology is considered the most promising one for carrying out the work proposed in this paper.

The methods and sources from which the stimuli can be originated are manifold, as shown by several contributions in the literature ((Smith, 1998; Zwicky, 1967; Tauqeer and Bang, 2020; Fantoni et al., 2013; Howard et al., 2011; Lin et al., 2012; Howard et al., 2010; Yoon et al., 2015; Liu et al., 2021; Geum and Park, 2016; Verhaegen et al., 2011, 2012; Dewulf, 2011)). In particular, authors in (Verhaegen et al., 2012) introduced the so-called Systematic Method for Identifying Reuse Opportunities of Supporting Goods (SMIROSG). This method requires the product to be described with a series of attributes, which are then used to perform image searches through on-line databases (e.g., *Google Images*). The most recurring results should provide a good path for the product innovation or new employment of it. However, this methodology fails in describing how these attributes should be selected.

As stated in (Tauqeer and Bang, 2020), an important source of external stimuli can be derived from both international patent databases (IPD) and social media. In fact, they are capable of foreseeing the so-called trend technologies that, if well exploited, allow companies to obtain competitive advantages. International patent databases contain a great amount of information, however, and consultation must be done with certain criteria, otherwise it may result dispersive. To this aim, one possible technique is to extract specific key information directly from the patent text in an automatic manner. In this regard, various methods exist in the literature and a complete review of them is reported in (Abbas et al., 2014).

Among those, in (Fantoni et al., 2013), a method to identify, given a patent, which are the characteristics of the invention in terms of function-behaviour-state is provided. Indeed, according to (Umeda et al., 1990), this set of information well represents and models the product itself. This is done by the authors through the exploitation of available computational linguistic tools, combined with a large knowledge base. Another similar contribution from Cascini (Cascini and Rissone, 2003) provides a specific software, called PAT-Analyzer, based upon natural language processing that, applied to patent documents, is capable of extracting the SAO structures of the inventions. According to (Yoon et al., 2015) this retrieved information can be exploited for the discovery of new technology opportunities. In particular, applying this method to a large set of existing patents, a knowledge base is created. Hence, with a Technology Opportunity Discovery logic that measures the functional similarities of pairs of products or pairs of technologies, it is possible to obtain the requested hints for the innovation of an existing good. Unfortunately, to apply this methodology, an appositely devised software must be used, thus limiting the applicability of the method for our case. Furthermore, there is no guarantee that the knowledge base chosen for that study will be appropriate for the product we are studying.

Another contribution is the one from Dewulf (Dewulf, 2011). In order to find a product improvement, innovation or new application, the author suggests comparing different products in terms of their functions and properties. In fact, although two products can come from completely different fields, they could share these same characteristics. The analogy with the product "DNA" identification, through its properties (represented by the "genes") that go to make up the functions (i.e., "amino acids") is quite explicative: if two different products have the same functions, they share the same "DNA" and they can therefore be closely related. However, since the specific products to be compared with the starting one are not known beforehand, it would be necessary to perform a wide preliminary DNA extrapolation analysis on a large set of goods. This would therefore be not efficient and very time consuming. Besides, this method does not provide sufficient details on about how to perform, given a products database, the required DNA extrapolations and the needed comparisons with the starting product DNA.

Verhaegen (Verhaegen et al., 2011) proposes in his study an alternative method and algorithm that, given a product, supports identifying similar products and the associated properties. This is performed by the author using a large database of patents and in particular the title, abstract and description of them. Using automatic text analysis tools, the terms that refer to the properties of the product are extracted. Once a particular patent and the respective invention have been selected, the method is applied to generate a term-term correlation matrix in which all patents in the database containing the same adjectives and names of the original patent are reported, thus establishing a similarity between different products. Nonetheless, to apply this method, an extensive analysis of the information in the chosen patent database must be carried out in advance and this requires a considerable amount of time. Furthermore, the quality of the results will depend on the extent of said database.

(Jia et al., 2018) propose instead an analogy-based ideation framework for the generation of new patentable ideas in different fields from which the source design is taken. The process starts with the representation of an analogy source, which is a design problem and solution that has already been patented. The analogy source is then analysed for information about its function, behaviour, and structure, thanks to a commercial software. Next, three heuristics are suggested for searching a set of candidate target systems that have a similar design problem to the analogy source, where the source design can be transferred. This allows the designers to systematically explore new contexts where the core idea of the patent can be applied to generate more patentable ideas. However, the commercial software that has been used for the study may not always be available, as in the present research.

As it can be seen, the many existing methods in the literature to extract information from patents for product innovation purposes suggest a real importance of having systematic approaches to support the task. However, the methods seen so far are not readily applicable and require specific skills, information systems and database. In the context of a manufacturing company, therefore, they do not comply with the need to achieve the desired results in a short time and with low efforts also in terms of required resources.

To partially overcome the limitations mentioned above, in (Fiorineschi et al., 2018) an alternative method for deriving useful stimuli for new product applications is introduced. Unlike the literature contributions cited so far, this method provides a clear guideline with multiple steps to be followed and, above all, it is easier to be applied, as no knowledge database or ad hoc software is required beforehand. The primary source of information is always constituted by patents, but no tools are required to identify SAO structures or other complex information from the patent text. On the contrary, the authors suggest deriving the existing product functions directly with the help of the firm's staff. Then, a series of patent searches are performed taking the previously found functions as inputs.

What is considered as the only relevant information for each patent obtained from the search is the so-called Cooperative Patent Classification (CPC). CPC is an alphanumeric code, always present among the initial bibliographic data of a patent, that is important to characterize the application field of the invention. In addition, it has the good feature of being easily obtainable as a direct result from available patent search engines online. For all these characteristics, the authors in (Fiorineschi et al., 2018) suggest using the CPC definitions as creative stimuli by which the designer should trigger the creative process. Therefore, the method does not suggest new applications of an existing product in an automatic way but guide the searching process for their identification.

Table 3.1 provides a summary of the various supporting methods mentioned so far for product innovation purposes to facilitate better understanding.

Table 3.1 - Summary on the characteristics of the methods retrieved from literature for a guidance in product design improvement or innovation.

Method	Time of execution	Knowledge database	Ad-hoc software	Human factor
SMIROSG (Verhaegen et al., 2012)	Low	Google Images (Google Images, no date)	No	High
(Yoon et al., 2015)	High	Ad-hoc patent database	Yes	Low
(Dewulf, 2011)	High	Ad-hoc set of products	No	Low
(Verhaegen et al., 2011)	Medium-high	Ad-hoc patent database	Yes	Low
(Jia et al., 2018)	Low	Public patent database	Yes	High
(Fiorineschi et al., 2018)	Low	Public patent database (Google, no date)	No	High

Based on the aforementioned considerations, in the present study, carried out in the context of a production company and without having any available knowledge database, the latter methodology is selected in order to have a readily usable support for the identification of mosquito net new application strategies.

4 - Methods

In this section, the methodologies adopted for achieving the study's objectives will be presented. These pertain to the steps of the development process of the new mosquito net model, along with the design tools and methodologies used. It will also include the motivations that guided the selection of the final constructive solutions, and some relevant intermediate results will be shown.

The methodology chosen during the literature analysis phase to support the identification of new potential application fields for the mosquito net product will also be discussed and detailed, with reference to the original paper (Fiorineschi et al., 2018). The application of this tool to the specific case, within an industrial context, is then shown, highlighting the critical points encountered during the execution of the different steps and the assumptions that had to be introduced to complete the analysis.

Finally, the process followed to assess whether, in general, the stimuli derived from patent classifications - such as those provided by the previously used method - can be effective in identifying alternative product applications is presented. In particular, this was evaluated through an experimental activity that involved two groups of students in the execution of an innovation exercise, with and without the use of specific stimuli. Following this exercise, the results obtained by the two groups were assessed looking at what level of statistical confidence they were different or not according to different metrics.

4.1 - Design Workflow

The development process of the new mosquito net model followed an iterative procedure through different phases, starting from the initial definition of product objectives and constraints to the final production.

The complete definition of constraints was made possible partly through the company's knowledge of the target market, customer requirements, and partly through more in-depth technical research about what was already available in the market.

Subsequently, the main subassemblies of the product under development were identified, along with their constructive solutions. This resulted in the creation of the initial operational diagrams, which provided a rough understanding of the future necessary components. Details of the feasibility study were reported in Chapter 0 above.

A targeted patent research campaign then started to understand what was already protected in this sector and what technically existed. In addition to providing a reasonable degree of certainty regarding the possibility of adopting specific solutions without infringing on patents, this activity also partly stimulated greater creativity in solving some of the main technical challenges. In particular, by improving existing constructive solutions and seeking differentiation from them while addressing their main issues. An example of this is the lower carriage, which uses two wires to connect adjacent chains, like other existing patented solutions on the market. However, the developed solution differs from the other ones, as it will be explained later, thanks to at least two key characteristics that have allowed it to be patented as well.

The initial CAD drawings of the assembly were then created. The software used in this case was SolidWorks 2020 version. Once the components were sketched, preliminary product performance evaluations were conducted through the creation of 3D printed prototypes. In fact, for the components that will be produced through injection moulding, this technology is capable of reproducing their final behaviour quite faithfully. It was, therefore, extensively employed throughout the entire product development process, allowing the final equipment to be produced only after the performance evaluation process. In contrast, for all aluminium profiles, prototyping was only used in the very early development stages, since it cannot faithfully replicate the behaviour of the final material, especially for very thin sections, as in this case. Furthermore, the investment required for creating the extrusion dies for aluminium is much lower and more cost-effective for the company than realizing 3D prototypes. Therefore, the extrusion dies for aluminium were manufactured in the very early stages of the design.

The technology primarily employed for prototyping was Selective Laser Sintering, for the components intended for future plastic moulding. Meanwhile, for the production of future aluminium profiles, the Fused Deposition Modelling technology was heavily utilized.

The material mainly used to simulate the behaviour of plastic moulding material is Aluminium-filled Nylon. The combined effect of these elements imparts robustness and longevity to the material while simultaneously maintaining its low weight. The key mechanical and thermal characteristics of the material are presented in Table 4.1.

Table 4.1 – Mechanical characteristics of the Aluminium-filled Nylon

Description	Value
Tensile modulus [MPa]	3800
Tensile strength [MPa]	74
Elongation at break [-]	4%
Melting temperature [°C]	176

The tests conducted on the components are of different types. First and foremost, individual parts are tested, if necessary, to assess their stiffness and operational limits under working and breaking conditions. Subsequently, subassemblies are mounted and further tested to characterize their behaviour. If the results are considered satisfactory, prototypes are assembled to create a complete product. The types of tests conducted are diverse in nature and mainly include the evaluation of the following aspects:

- Coupling integrity under different stress conditions;
- stiffness of components and subassemblies;
- relative coupling smoothness;
- maximum deformations under specific loading conditions;
- variability of performance based on small variations in geometry (design robustness);
- behaviour of components and assemblies under high temperatures;
- behaviour of components and assemblies in the presence of humidity;
- behaviour of components and assemblies in the presence of marine salt;
- ease of subassembly mounting;
- ease of final product assembly;
- low rolling resistance during use.

Tests are carried out using various instruments and equipment commonly found in a laboratory, such as dynamometer and digital calliper. The nature of the testing process is inherently iterative: once the components are tested, geometries are redesigned, modified, and then prototyped again to test their new performances. This process occurs continuously, independently for the many subassemblies, therefore trying their different combinations.

Below are some of the most significant results obtained in this process for the main elements of the system. In particular, the lower carriage chain is visible in Figure 4.1, the upper carriage chain in Figure 4.2, the upper chain terminal in Figure 4.3, the telescopic cap in Figure 4.4, the lower and upper parts of the head-box head in Figure 4.5, and the head-box internal gasket in Figure 4.6.

-1-

-2-

-3- -4-

-5- -6-

Figure 4.1 – Geometry development of the lower carriage chains.

-1- -2-

-3-

Figure 4.2 – Geometry development of the upper carriage chains.

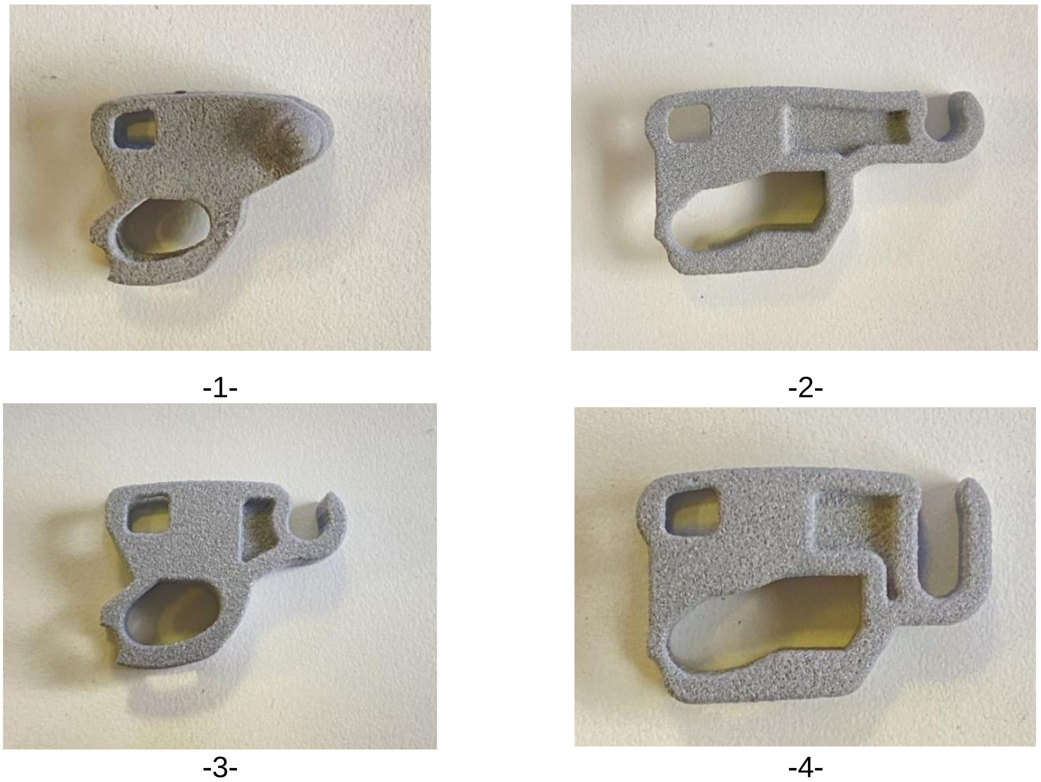


Figure 4.3 - Geometry development of the terminal element of the upper carriage chain.

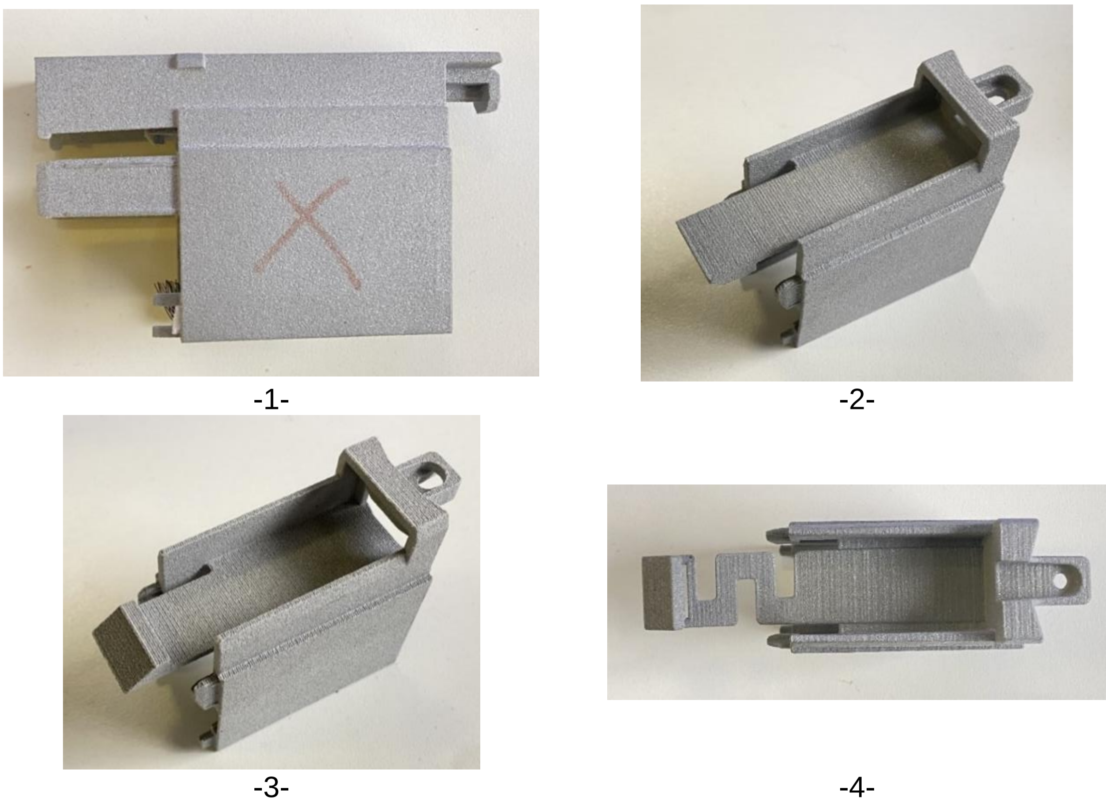


Figure 4.4 – Geometry development of the telescopic cap.

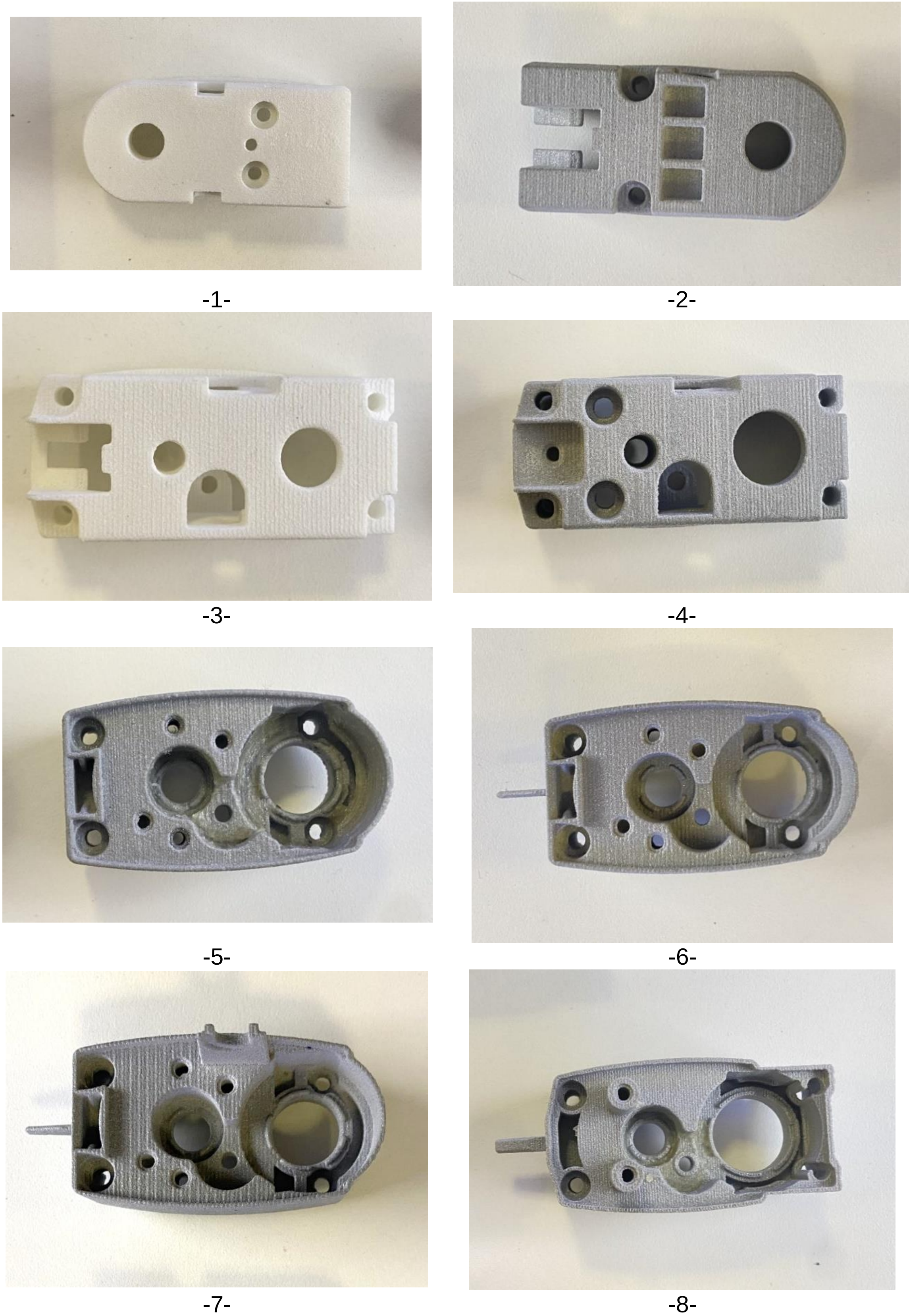


Figure 4.5 – Geometry development of the upper head-box head (part 1 and 2).

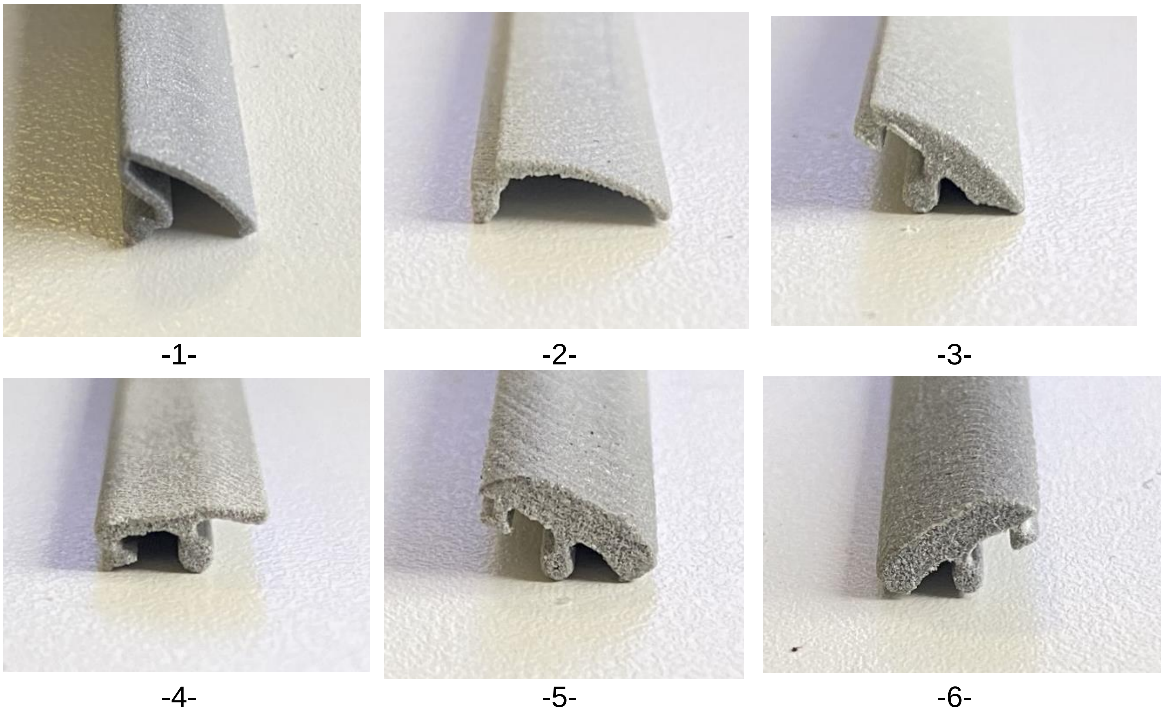


Figure 4.6 – Geometry development of the gasket located inside the head-box profile.

Entire mosquito net prototypes are also tested in different steps. First, the ease of assembly of the complete procedure is evaluated. If this is deemed acceptable in terms of time and complexity by a moderately experienced operator, the product is tested throughout an entire lifecycle. This is done by mounting the mosquito net on a frame: next to this frame, a double-acting pneumatic piston is horizontally mounted at a height of 120 cm from the ground. This pneumatic piston, connected to the handlebar of the mosquito net, moves the handlebar alternately from a closed position to an open one. The pneumatic piston is connected to a control unit with which it is possible to adjust the desired number of cycles and the waiting time between one movement and the next one. The equipment is visible in Figure 4.7 and Figure 4.8. The total number of cycles considered equivalent to a complete lifecycle for the product is 15,000. The objective of this type of test is to observe variations in the behaviour of components as wear increases and to ensure that there are no sudden breakages of parts subjected to higher loads than expected.

Figure 4.7 – Pneumatic piston employed for the moving of the handlebar during life tests.

Figure 4.8 – Electronic control unit for the setting of life tests.

Depending on the specific component requirements, lifecycle tests are conducted again in a climatic chamber, as seen in Figure 4.9, in which three infrared lamps increase the ambient temperature, simulating the heat of sunny summer days. The maximum temperature achievable in all external conditions is approximately 40°C, resulting in a temperature inside the aluminium profiles of 70 to 80°C. The plastics operating inside these profiles are therefore appropriately stressed. With this type of test, any excessive softening of plastic components is checked, which can lead to malfunctions or aesthetic defects in the product. An important example is the upper carriage chain, which operates inside the telescopic guide, that during high-temperature cycles tends to soften and, as a result, to become visible below it.

Measurements taken during these types of lifecycle tests mainly include:

- the sliding force required by the user to move the handlebar towards open and closed conditions;
- the extent of automatic retraction of the net into the box when the handlebar is released from the closed position;
- any functional or aesthetic defects that may arise.

Component wear and heat tend to make sliding the handlebar more difficult. Again, in case of issues, these are analysed, and the components are modified accordingly, if necessary. Once satisfactory results are achieved, without clear problems and with handlebar movement forces below 3.0 kg throughout the entire life, the last phase of prototype testing is carried out, which involves the installation of some test products in selected customers' homes. These field tests allow any issues that may have remained hidden during product handling in a controlled environment to appear.

Once all these phases are completed, the production of all necessary equipment begins, including injection moulds for plastic materials, dies for the extrusion of plastic profiles, and punches for aluminium. This operation is delayed until this development phase since it requires a significant investment and a very small margin of error. From this point forward, to reach the project's success, the geometry drawings should undergo only marginal changes. To proceed with this phase, all component drawings are prepared in advance, accompanied by the necessary dimensional and geometric tolerances.

Figure 4.9 – Climatic chamber for high temperatures testing.

The plastic components obtained are then validated through a new testing campaign, which includes the following main phases:

- measurements with caliper of the obtained dimensions and verification of compliance with the required geometry tolerances;
- assembly tests of subassemblies and preliminary assessments of functionality (checking for any clearance or unwanted interferences);
- assembly onto a complete product in the laboratory.

In practice, for each component, at least 2 or 3 stages of mould adjustments are necessary to obtain parts that conform to the required geometry. Subsequently, elements are examined again by subjecting them to new lifecycle tests. If no issues arise, the final check consists in the replacement of prototype plastics with the final ones in the products previously installed in customers' homes.

If unforeseen defects are identified due to the change of material from prototyping to moulding technology, further modifications of 3D and 2D drawings are required. The testing phases mentioned so far are then repeated until the final component is considered valid. Before starting production, the required technical documentation for the product is prepared, which includes the user and maintenance manual, declaration of conformity, technical datasheet, and technical dossier. Subsequently, all the relevant information is shared with the pertaining company departments. The final activities include the following:

- preparation of a 2D product drawing for customer communication;
- creation of article components codes;
- preparation of a complete and updated exploded drawing;
- definition of the various semi-finished products;
- updating of the complete bill of materials in the company database;
- final cost calculation;
- selection of components to include in the product box;
- procurement of components, with initial quotation requests;
- realization of production equipment;
- updating of working sheets for the productive department.

A DFD of the entire workflow is schematically represented in Figure 4.10.

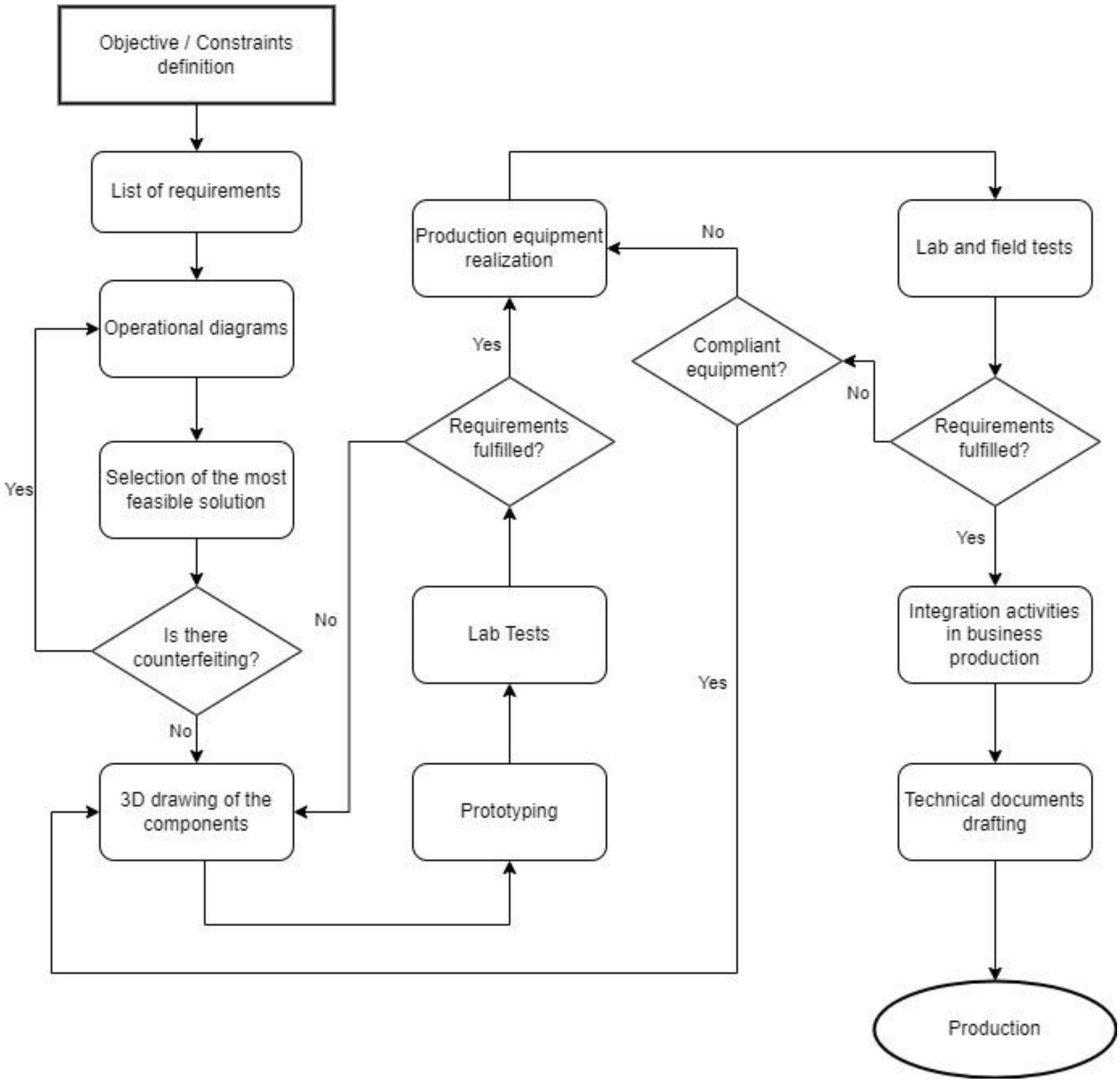


Figure 4.10 – Data flow diagram for the designing process.

4.2 - Methodological Approach for Identifying Reuse Strategies

The method retrieved from literature, which has been judged as the most suitable in the specific industrial context to support the search of alternative uses of exhausted mosquito nets (Fiorineschi et al., 2018), is presented in this section.

This method is based on the idea that the available information about the product can be exploited to extract potential useful hints for possible alternative uses. This is accomplished through specific searches using the international patent database (IPD). Indeed, as already stated by previous authors (Akers, 2003), the IPD can be considered a valuable source of information for innovation purposes. Once the functions and properties of the starting product are identified, a series of patent searches are conducted using different combinations of these terms. The Cooperative Patent Classifications (CPCs) are therefore extracted from the resulting patents. Hence, these should be taken as creative stimuli to generate alternative product applications. A brief description of the IPD search strategies is here provided, before presenting the detailed method description.

4.2.1 - Patent description and searching strategies

A patent is a document containing a complete set of information concerning the object of the invention that the applicant wants to be legally protected. It is divided into five main sections. For the purpose of this paper, it is important to know that the following elements are always present:

- Cooperative Patent Classifications (CPC): a hierarchical and alphanumeric classification of application fields in which the invention is located;
- abstract: a brief introduction containing the main aspects of the invention;
- description: a deep explanation of the invention and why it is different from the state of the art.

CPC codes are firstly used to categorize all possible invention fields in nine macro classes, with letters from A to Y. Then, a series of two numbers and one letter identifies the relative subclasses. For example, the macro class E corresponds to fixed constructions, and the subclass 06B refers to fixed or movable closures for openings in buildings, vehicles, fences, or like enclosures in general, such as doors, windows, blinds, and gates. Further subclasses exist with subsequent numbering for a more specific identification of the invention field, but this is not exploited in the present study. Additional information on this topic can be found in (Fiorineschi et al., 2018).

The so-called search queries must be carefully addressed to conduct a successful patent search. These consist of a set of words and/or numbers that are to be looked up, in specific text fields contained within the patent document. The search queries can also be combined in different ways, thanks to the logic operators AND, OR, NOT. Additionally, exact correspondence of a series of words can be found, as well as searches for words with a common root. Performing multiple searches with different combinations will potentially give a different set of patents as output. This will be very useful for carrying out the present work.

A patent search can be performed using a variety of tools. Some of them are available open source and consist of online patent databases such as *Google patent* or *Espacenet*. Other tools, like *Orbit* or *Matheo Patent*, require a payment license. The former allows for more complex and customized searches with respect to *Espacenet*. In addition, it provides the possibility of extracting the results in a quicker way to post-process them and retrieve specific information.

4.2.2 - Method details

The method described by (Fiorineschi et al., 2018) is characterized by nine different and well-defined steps. These are shown schematically in Figure 4.11.

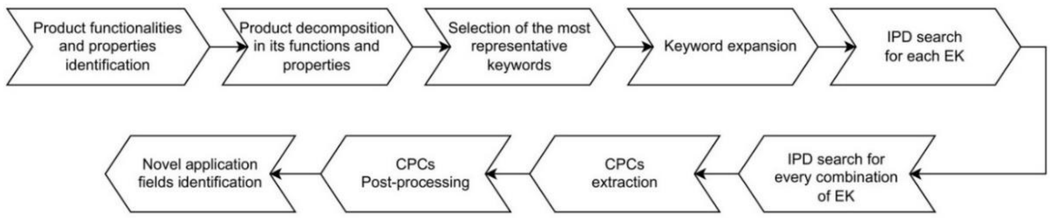


Figure 4.11 – DFD of the methodology proposed by (Fiorineschi et al., 2018).

First, a consistent set of product functionalities and characteristics must be found. This phase is very important as it will influence the following steps and the quality of the results. According to the authors, it is helpful to use ad hoc questionnaires or conduct exhaustive interviews with employees of the firm to gain a deep understanding of the product being analyzed. These questions can be preferably constructed with the guidance of some checklists or methods that can be found in the literature (Beitz et al., 1996; Bacciotti et al., 2016). For instance, some product characteristics that can be identified for a razor blade are “sharp”, “thin”, “lightweight”, etc.

Once the functionalities and characteristics are identified, the product has to be decomposed into its functions and properties. In this method, the definition of function is based on the one from Altshuler (Gadd, 2011). Taking the example of a dishwasher, the SAO structures “resistance heats water”, “mixture of soap and hot water cleans dishes”, “dishwasher racks hold dishes” indicate that, respectively, “heat up”, “clean” and “hold” are functions of the system. The authors point out that the list of functions must also include harmful ones, as they may be considered as useful, if not fundamental, in possible future product applications. Moreover, properties must be defined as a set of objective descriptors of the product, i.e., considered valid regardless of the person conducting the analysis.

A large number of terms should be obtained at this point. Consequently, to continue with the following steps, it is necessary to discard the ones that are considered less representative of the product by the firm staff. This is done to avoid the process to become cumbersome and to obtain more accurate results afterward. For example, in the case of a safety shoe, its primary functions and properties are “shielding the foot” and being “comfortable”, whereas a characteristic that may not be relevant is the option of having the possibility of different sizes.

Once the final terms are found, these can be used as input keywords to perform the IPD searches. Considering a single keyword, it is important to point out that the results obtained from that would be limited, as those obtained from input terms of similar meaning or with different endings would not be included. Therefore, for each individual keyword, the so-called expansion process is carried out by creating an expanded keyword (EK). It consists in the creation of a subgroup of synonyms and same words but with different endings, to be used as a single input. As an example, in Table 4.2 the expansion process of the words “humidify” and “paste” is reported. The searching process can now start.

Table 4.2 – Examples of keyword expansions

Keyword	Expanded keywords
Humidify	Humid, humidifies, humidity, humidification, humidifier, humidly, moisten, moistens, moistened, moistener, moistening, moist, moisture, moistness, moisturize, wet, wets, wetted, wetting, wetness, wettable, wettish, saturate, saturates, saturated, water, waters, watering, hydrate, hydrates, hydrated, hydrating, hydration, soak, soaks, soaked, soaking, drench, drenches, drenched, drenching, drenchingly, imbue, imbues, imbued, imbuing, imbuer, impregnate, impregnates, impregnated, impregnating, impregnation, impregnator.
Paste	Pastes, pasted, pasting, adhesive, adhesives, adhesion, adhesiveness, glue, glues, glued, gluing, gluey, bind, binds, binding, binder, rebind, bound, bounded, adherent, adhere, adheres, adhered, adhering, stick, sticks, sticked, sticking, sticky, stickiness, sticker, bond, bonds, bonded, bonding.

To this aim, a patent search is firstly performed for each expanded keyword. The search fields in which performing the search must also be established. The authors suggest to limit the research only to the title and abstract of the patent document (Fiorineschi et al., 2018). At this point, a huge amount of patent should be found with the consequence of rendering the process time consuming and hardly managed, due to the large number of outputs. Therefore, multiple expanded keywords are combined in the search query to reduce the amount of output obtained. It is not possible to establish a priori which are the best combinations, so the most correct thing to do is performing a patent search for every possible obtainable subgroup from the starting EKs. The total number of subgroups is expressed by **(1**:

$$N = \frac{n!}{k! \cdot (n-k)!} \qquad \textbf{(1)}$$

Where n is the total number of EKs, and k is the number of EKs considered for performing the combinations (it can be equal or less than n). For instance, if n = 4, the values that can be assumed by k for determining N are from 1 to 4, generating a total amount of 15 different combinations, as it is possible to see in Table 4.3 for a better understanding.

Table 4.3 – Combinations without repetitions generated by four expanded keyword (n = 4).

k	N	Combinations
1	4	1; 2; 3; 4
2	6	1 AND 2; 1 AND 3; 1 AND 4; 2 AND 3; 2 AND 4; 3 AND 4
3	4	1 AND 2 AND 3; 1 AND 3 AND 4; 1 AND 2 AND 4; 2 AND 3 AND 4
4	1	1 AND 2 AND 3 AND 4

Therefore, all the results are post-processed to obtain a list of CPCs codes and their percentage of occurrence for every EKs combination. In particular, the first four symbols are considered in this study. As the exam of all the CPCs obtained would be time-consuming, only the EKs subgroups best representing the starting product characteristics are considered. Then, if the CPCs number is still too high, a threshold value for the occurrence percentages is established for every EKs combination under which the results are not considered.

In the final step of the method, the user must try to extract useful stimuli for new product applications starting from the descriptions of the CPCs obtained. In fact, each CPC is associated with a particular application field, so the user is prompted to consider the starting product in a completely different context of use.

4.2.3 - Application to the mosquito net

For all the difficulties outlined in the introduction chapter in managing the end-of-life phase of the nets, the methodology (Fiorineschi et al., 2018) explained in the previous sub-section is applied here on this specific part of the product, since there is the potential to maximize the beneficial environmental effects achievable with such an approach.

The construction of a complete and correct list of product functions and properties was carried out in three successive steps. First, product descriptors were found with the support of Pahl and Beitz's requirement checklist (Beitz et al., 1996), taking care to also include negative product characteristics. Table 4.4 shows the results of this phase.

Table 4.4 – List of mesh descriptors obtained from the application of Pahl and Beitz checklist for functions identification.

Product characteristics	Terms
Geometry	Thin, fine, reticular, wide, long, extended, symmetrical, woven, flat, smooth, square meshes. **Harmful**: small, shattered, irregular, folded, crumpled
Kinematics	Stop, linear movement, translation
Forces	Tangential force, normal force, alternating forces, impulsive forces
Energy	Light absorption, heat exchange, moisture absorption
Material	Glass fiber: high mechanical strength, resilience, thermal insulation, acoustic insulation, soundproofing, non-combustible, impact resistance PVC: flexible, weather resistant
Signals	-
Safety	Glass fiber: Skin and eye irritation PVC: Chemical stability at ambient temperature
Ergonomics	Lightweight, obscuring, filtering
Production	Weldable, easily cuttable, flexible
Quality control	Uniform, regular
Assembly	Flexible, lightweight
Operation	Accumulates dirt, increases sliding resistance

Afterwards, an attempt was made to translate the concepts found into functions and properties, so as to obtain a single complete and non-repetitive set. The definition of function used was the one from Altshuler (Gadd, 2011). An example of how the correct terms for the function definition were found is shown in Table 4.5 for the descriptor "heat transfer". The complete list of functions and properties obtained is listed in Table 4.6.

Table 4.5 – Example of derivation of functions from the previously found mesh descriptor "Mesh exchanges heat".

Mesh exchanges heat	→	Air **warms** mesh
		Air **cools** mesh
		Mesh **warms** air
		Mesh **cools** air

Table 4.6 – Complete list of mesh functions and properties.

Functions	Properties
Filter (block)	Thin
Warm up	Reticulate
Cool	Planar
Humidify	Folded (HARMFUL)
Dehumidify	Uniform
Move (translate, rotate)	Regular
Attract	Light absorber (UV)
Irritate (HARMFUL)	Light
Darken (can be HARMFUL)	Flexible
	Resistant (shock resistant)
	Insulating
	Chemically stable
	Weldable
	Cuttable

As mentioned in the previous section, analysing a large number of terms with the present method would be cumbersome. Therefore, in agreement with the company, a screening of the most important terms was carried out to facilitate the method application. The final list of the most important functions and properties is reported in Table 4.7. From this set, keyword expansion is performed, and the outcome of this process is shown in Table 4.8.

Table 4.7 – Final list of mesh functions and properties selected in accordance with the firm staff.

Functions	Properties
Filter (block)	Thin
Move (translate, rotate)	Reticulate
Darken (can be HARMFUL)	Planar

Table 4.8 – Expanded keywords for the mesh.

#	Keyword	Expanded Keyword
1	Filter	Filter, filters, filtered, filtering, screen, screens, screened, screening, leak, leaks, leaked, leaking, permeate, permeates, permeated, permeating, penetrate, penetrates, penetrated, penetrating, stop, stops, stopped, stopping, block, blocks, blocked, blocking, contain, contains, contained, containing, separate, separates, separated, separating, divide, divides, dividing, divided
2	Move	Move, moves, moved, moving, movement, transfer, transfers, transferred, transferring, transport, transports, transported, transporting, transportation, roll by, rolls by, rolled by, rolling by, roller, roll, rolls, rolled, rolling, turn, turns, turned, turning
3	Darken	Darken, darkens, darkened, darkening, overshadow, overshadows, overshadowed, overshadowing, shadow, shadows, shadowed, shadowing, obfuscate, obfuscates, obfuscated, obfuscating, shade, shades, shaded, shading
4	Reduced thickness	Thickness, layer, sheet, coat, covering, shell, stratum, mantle, liner, reduced thickness, reduced layer, reduced stratum, reduced mantle, small thickness,

		small layer, small covering, small, low thickness, low layer, little thickness, little layer, thin, slim, narrow subtle, tight, compactness, fine, fines, fined, fining
5	Reticulate	Reticulate, reticulated, reticular, net-like, netlike, cross linked, cross-linked, crosslinked, meshy
6	Planar	Planar, plain, flat, flatty, regular, regularly, two-dimensional, two dimensional, bidimensional, two dimensionally, two-dimensionally

The patent search engine used in this case is *Google Patent* (Google, n.d.), as it allows the introduction of a high number of multiple terms simultaneously in the search query. The search process was performed by considering each EK singularly and then with all their possible combinations according to. **(1** For each search query, the results in terms of CPCs occurrence percentages out of the total patents were manually copied to an Excel file and stored, keeping track of the specific EKs input that generated them.

Then, thanks to a series of appositely designed VBA subroutines, the data were post-processed. A user interface, as shown in Figure 4.12 allows for the selection of the desired EKs combination, and the relative CPCs occurrences are shown in a graph. An example of such a graph is reported in Figure 4.13 for the combination "filter + reduced thickness + planar". The overall DFD of the procedure followed is shown in Figure 4.14, while the complete titles for each resulting CPC code are reported in Table 7.3 in Table 7.3 in the Appendix B.

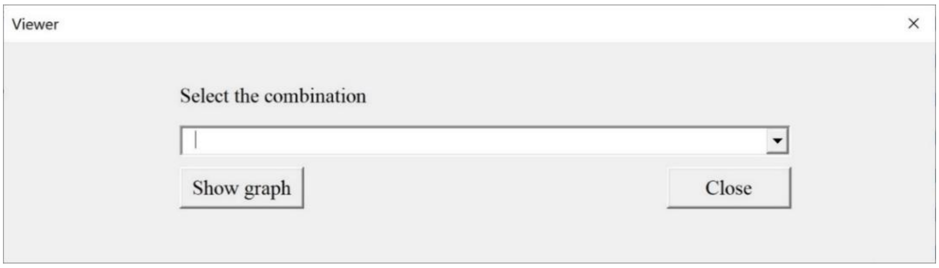


Figure 4.12 – User interface for the visualization of CPCs occurrence percentages.

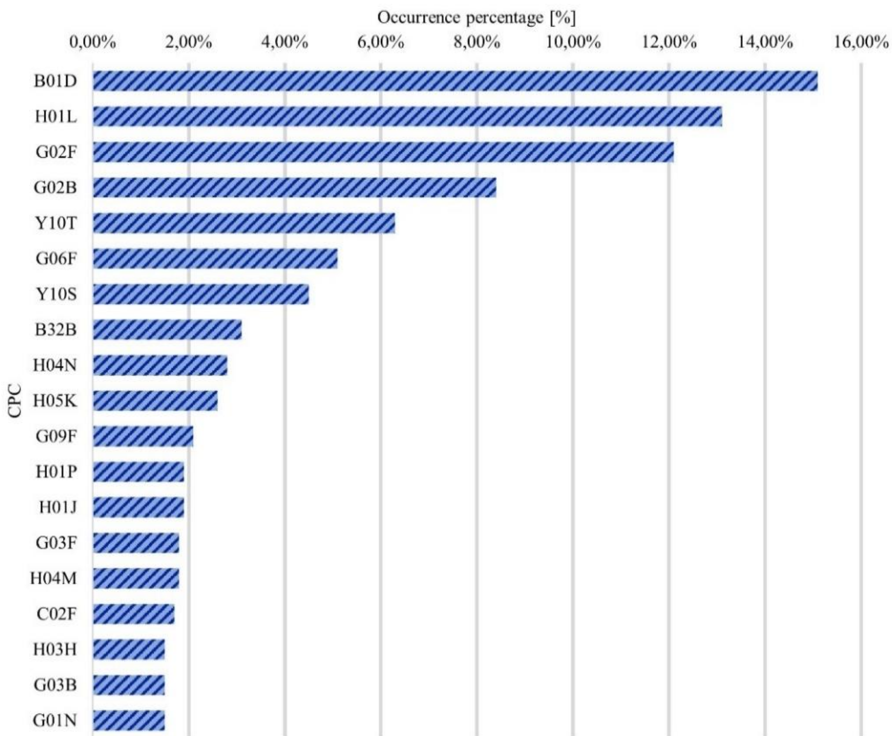


Figure 4.13 – CPCs occurrence example for the EK combination "filter + reduced thickness + planar".

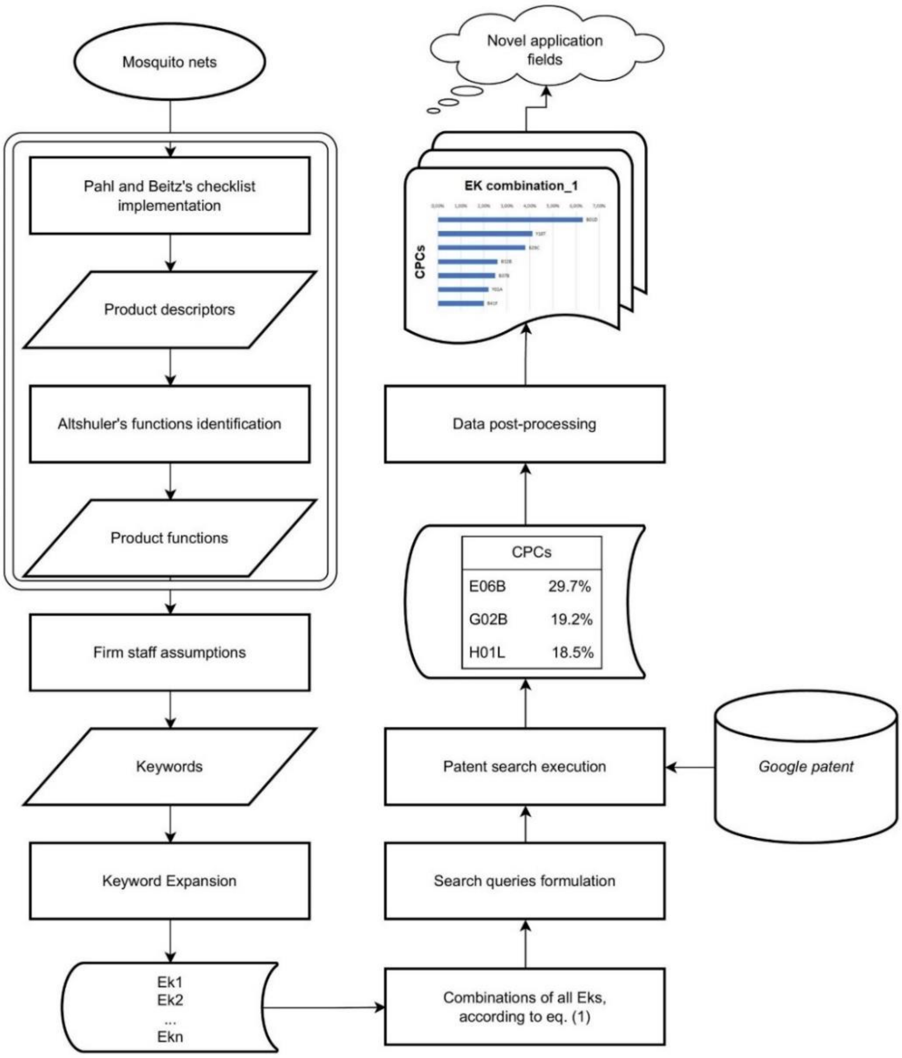


Figure 4.14 – DFD of the procedure followed for the identification of mosquito net alternative uses, according to the methodology proposed by (Fiorineschi et al., 2018).

4.3 - Textual Stimuli Effectiveness in Idea Generation Process

The objective of the final part of this study is to assess whether the administration of textual stimuli, such as those generated by the method previously described, produces noticeable differences in the outcomes of a general idea generation process when compared to not using this kind of stimulus. An experimental test involving two groups of students will therefore be performed. It has to be highlighted that the outcomes of this study do not directly infer a validity demonstration of the method applied, as the stimuli employed in the experiment are different from those obtained with the specific methodology in terms of quantity. However, the results will be able to determine whether this type of stimuli is generally effective, regardless of the methodology used to obtain them.

As widely reported in the literature, stimuli are in general information of different types and coming from different sources that can be useful during the conceptual design process (Blandino et al., 2023) to enhance the creativity performances. In most of the papers mentioned above the form of stimuli is of textual type, deriving from external sources such as patent descriptions and abstract, analysed with different tools and methodologies (Dewulf, 2011; Verhaegen et al., 2011; Yoon et al., 2015; Fiorineschi et al., 2018; Jia et al., 2018). However, other forms of stimuli exist, such as visual (Verhaegen et al., 2012) or mixed type.

Many attempts have already been performed in other studies to assess the role of stimuli, used in different context (Shah et al., 2000; Chulvi et al., 2012; Borgianni et al., 2020; Blandino et al., 2023). These consist in evaluating the performances of idea generation process, according to a set of metrics. The most recurring and recognized notions are those of quantity, quality, novelty, non-obviousness and variety of ideas generated (Shah et al., 2000). However, as stated in (Fiorineschi and Rotini, 2023), published studies in the past 20 years have employed a vast range of different definitions of these concepts, in particular for what concerns the novelty.

Generally speaking, novelty can be assessed “a priori” or “a posteriori”. The first option involves comparisons of the ideas obtained with already known and existing solutions, while the latter one only observes the outcomes, categorizing them in terms of frequency of appearance (Borgianni et al., 2020). The less recurring ideas are therefore considered the most original ones, according to the fact that they are more unexpected from a psychological point of view (Fiorineschi and Rotini, 2023). As stated in (Borgianni et al., 2020), both the approaches are commonly used in the literature, as it has been demonstrated that they are not correlated.

In this study, since the primary interest is to evaluate the relative performance differences between the test and control groups, irrespective of comparisons to reference solutions, only “a posteriori” novelty evaluations have been conducted. Moreover, due to the unavailability of a group of qualified experts to assess quality and non-obviousness of ideas, these metrics have been discarded, as valid results could not have been achieved. Therefore, only quantity, variety and a posteriori novelty will be taken into account.

4.3.1 - Ideas and metrics definition

Every idea obtained by the participants is classified and subsequently analysed in terms of its functions and field of application. The functions align with the S-A-O definition proposed by (Gadd, 2011). A maximum of four functions has been assigned to each idea, while the field of application is always unique. The categorization of the application fields corresponds to that provided by the Cooperative Patent Classification (CPC) subdivision. Consequently, a unique ID letter was given to each generated idea, following the rule that two different ideas would share the same ID only if they possessed the same set of functions and application fields.

It's important to note that only the ideas meeting the following criteria were considered:

- it was possible to assign a single CPC without ambiguity (non-vagueness).
- The application field was distinct from the original one.

Consequently, the valid ideas obtained have been analysed according to different metrics of quantity and originality, comparing the results of the control group with those of the treated group for both products. The metric of quantity involves different parameters: the selected ones are numbered from 1 to 9 in the following list, based on the available data. Originality metric and variety follow in the last two points:

1. Quantity of ideas per participant.
2. Quantity of different functions.
3. Quantity of each alternative function with respect to the total amount of alternative functions.
4. Quantity of alternative functions with respect to the ones pertaining to the original product application.
5. Quantity of functions per idea.
6. Quantity of functions per participant.
7. Quantity of different application fields, referring to them as the ones described by CPC.
8. Quantity of alternative application fields with respect to the ones provided as additional stimuli in the experiment.
9. Quantity of alternative application fields per participant.
10. Originality level of the ideas obtained.
11. Variety of the ideas obtained.

4.3.2 - Hypotheses formulation and research questions

Consequently, the following null hypotheses have been formulated, to be eventually rejected with statistical tests:

- H01a: the average value of ideas generated by each participant is not dependent on whether textual stimuli are used in the ideation process;
- H01b: the occurrence percentage of each function obtained out of the total occurrences of all functions is independent of whether textual stimuli are used in the ideation process. In other words, the quantity of functions and how they are distributed is not dependent on whether stimuli were employed or not;
- H01c: the occurrence percentage of each not obvious function obtained out of the total occurrences of all not obvious functions is independent of whether textual stimuli are used in the ideation process. Unobvious functions exclude those that were originally present in the starting product.
- H01d: the cumulative occurrence percentage of alternative functions with respect to the ones related to the original field of application is not dependent on whether stimuli were or were not employed.
- H01e: the average value of functions associated to each generated idea is not dependent on whether textual stimuli are used in the ideation process;
- H01f: the average value of functions generated by each participant is not dependent on whether textual stimuli are used in the ideation process;
- H01g: the occurrence percentage of each application field obtained out of the total occurrences of all application fields is independent of whether textual stimuli are used in the ideation process. In other words, the quantity of application fields and how they are distributed is not dependent on whether stimuli were employed or not;
- H01h: the cumulative occurrence percentage of alternative application fields with respect to the ones provided as stimuli in the experiment is not dependent on whether stimuli were employed or not.
- H01i: the average value of application fields proposed by each participant is not dependent on whether textual stimuli are used in the ideation process.

All these hypotheses refer to different aspects related to the metric of quantity. For what concerns “a posteriori” novelty or – from now on – rarity, the following null hypothesis is conceived:

- H01j: the rarity of the ideas obtained is not dependent on whether the stimuli are used or not during the ideation process.

Finally, the metric of variety must be obtained. This was first introduced by (Shah et al., 2003), with a detailed explanation of how to calculate it. However, the estimate is only valid for different ideas that fulfil the same main function. Therefore, this quantity cannot be estimated in this specific study, as the single group of generated ideas contains a wide range of different functions. To overcome this problem, the same strategy as in (Borgianni et al., 2020) has been replicated, calculating the number of distinct ideas in each group as a whole number. Therefore, no hypothesis has to be formulated.

In conclusion, the third research question of the study has been divided into four sub-questions, to answer which the metrics and hypotheses defined herein are used. The formulation of the research questions is presented in Table 4.9, along with the groups of metrics and corresponding hypotheses involved in answering each of them.

Table 4.9 – Summary of the formulated research questions, observed metrics, and related hypotheses involved.

Research question	Metrics	Hypotheses
Patent classifications can aid in identifying alternative functions for a product, that diverge from their original ones.	1; 2; 3; 4; 5; 6.	H01a; H01b; H01c; H01d; H01e; H01f.
Patent classifications might facilitate the discovery of new application sectors for the same product.	1; 7; 8; 9.	H01a; H01g; H01h; H01i.

Patent classifications enhance ideas originality.	10	H01j
Patent classifications enhance ideas variety.	11	-

4.3.3 - Design of experiment

To answer the four research questions of the final part of the study, an experiment has been designed with a class of students from the first year of master's degree course in mechanical engineering at the University of Florence (Italy). The participants were divided in two groups and a brief textual and visual description of the starting product was provided. Then, one group was asked to generate alternative application fields for employing the product at the end of its life, without any additional guidance. The other group was asked instead to generate the same outcome but with a set of given textual stimuli. These consisted of three cooperative patent classifications descriptions. extracted from the previous application of the method in (Fiorineschi et al., 2018). Afterwards, the exercise was repeated with another product, with the two groups switched: the group that had not previously received the supplementary textual stimuli now received them, while the other did not.

The total number of participants was 37, including 2 females and 35 males. Then, they were divided randomly, generating two groups as follows:

- Group A: 18 participants (17 males and 1 female);
- Group B: 19 participants (18 males and 1 female).

Thus, the individual gender distribution is optimized for maximizing equality. It was considered that any heterogeneity in terms of age and background knowledge was negligible for the purposes of the study, as all participants came from engineering academic backgrounds. Personal information of single participants was not registered, in line with the rules of the Institution. Therefore, no one was subjected to any form of judgment, neither during nor following the test. Besides, participation was entirely voluntary.

The products selection fell on the fly screen, subject of the previous phases of the study, and a wine barrel. The choice of two completely different products was performed to make the study's results independent from the type of product analysed, thus drawing conclusions having more general validity.

The description provided at the beginning of the exercise to both test and control group for the wine barrel follows:

The barrel-shaped cask, crafted from biodegradable wood, plays an essential role in wine preservation and enhancement. Its solid structure provides effective protection, creating a barrier against external environmental influences. The barrel shape, besides evoking tradition and grandeur, promotes the proper development of the wine inside, allowing for a harmonious and gradual flavour infusion. During the aging process, the wood interacts with the wine, imparting delicate layers of aromatic complexity, such as hints of vanilla, spicy notes, and subtle toasting.

The image is instead reported in Figure 4.15.

Figure 4.15 – Wine barrel image shown to the test and control groups.

The description of the fly screen is here reported, while the image is reported in Figure 4.16:

The mosquito net is an essential element for protecting indoor spaces from unwanted insects, such as mosquitoes, flies, and other flying pests. Various types are available, but the most commonly used ones are made of a compound of fiberglass coated with PVC. The net's mesh is designed to allow the passage of air and sunlight while keeping insects out. Depending on the material and thickness, it can also provide partial sunshade. Mosquito nets can be installed on windows, doors, and openings, both inside and outside of buildings. They are easy to cut and adapt to the desired dimensions, allowing for easy do-it-yourself installation.

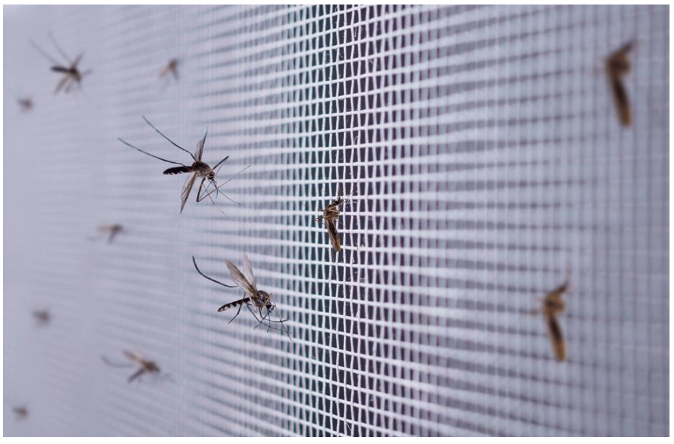


Figure 4.16 – Mosquito net image shown to the test and control groups.

The CPCs descriptions provided to the test group for wine barrel were:

A23L → foods, foodstuffs, or non-alcoholic beverages; their preparation or treatment, e.g. cooking, modification of nutritive qualities, physical treatment (shaping or working); preservation of foods or foodstuffs, in general.

A24B → manufacture or preparation of tobacco for smoking or chewing; tobacco; snuff.

A61H → physical therapy apparatus, e.g., devices for locating or stimulating reflex points in the body; artificial respiration; massage; bathing devices for special therapeutic or hygienic purposes or specific parts of the body (electrotherapy, magnetotherapy, radiation therapy, ultrasound therapy).

Instead, the CPCs chosen for the fly screen follow:

D06C → finishing, dressing, tentering or stretching textile fabrics.

A01G → horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops or seaweed; forestry; watering (picking of fruits, vegetables, hops or the like; propagating unicellular algae).

B32B → layered products, i.e., products built-up of strata of flat or non-flat, e.g. cellular or honeycomb, form.

The reason why these CPCs were chosen is that they are among those that proved to be most effective in generating new product applications in the second part of the study. The number was reduced to three as it was considered a suitable limit to avoid overexposing the participants to an excessive number of stimuli, given the limited time available for the test.

The participants were assigned the task of identifying the highest possible number of alternative application fields for the end-of-life phase of the products. An evaluation of the technical feasibility of the found solutions was not required to not limit the idea generation process and because this feature was not deemed relevant to answer to the research questions. The individuals were asked to concisely explain each concept with a brief textual description and, if desired, by including rough illustrations, sketches, etc. Besides, participants were explicitly told to refrain from any form of communication with one another and from the use of electronic devices for the whole course of the test.

The experiment duration was set to 30 minutes for each product, since this time frame represents a good balance between the requirement of maintaining high levels of focus of the participants and of promoting creativity, while also considering the necessities of organization and analysis.

The outcomes were subsequently collected, with the division of the two groups maintained for each product. To keep the results separate without referencing personal information, the individual sheets provided by the participants were numbered. Two examples of sketches are here reported, in Figure 4.17 and Figure 4.18 for the barrel and in Figure 4.19 and Figure 4.20 for the insect screen.

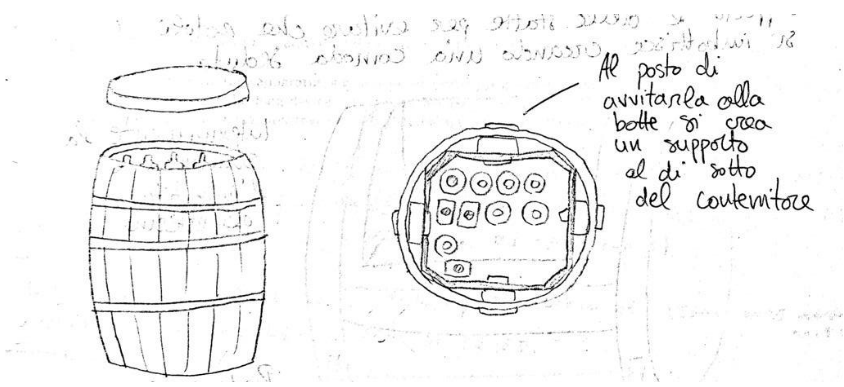


Figure 4.17 – Example of generated alternative product application for the barrel (1).

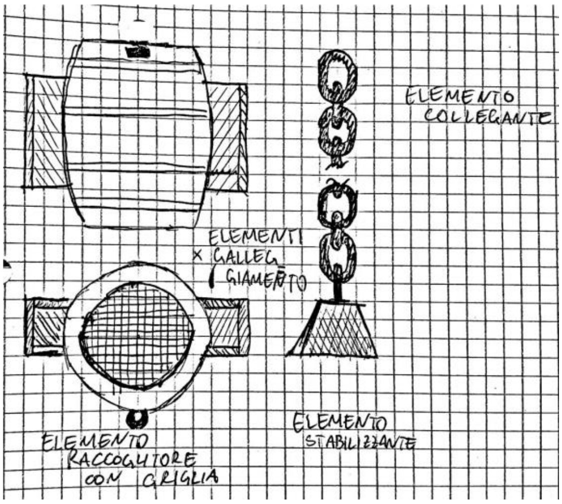


Figure 4.18 – Example of generated alternative product application for the barrel (2).

Figure 4.19 – Example of generated alternative product application for the fly screen (1).

Figure 4.20 – Example of generated alternative product application for the fly screen (2).

5 - Results

In this chapter, the final outcomes of the design process for the new mosquito net product will be presented. Detailed explanations of the constructive solutions will be provided, with a focus on the innovations addressing well-known design challenges in comparison to existing products on the market. Subsequently, the newly identified application fields for end-of-life fly screens used in the product will be discussed, along with an explanation of the methodologies that led to these results. Additionally, an exemplary application in the haute couture field, in particular for the creation of a rigid corset, will be showcased. Finally, the results of the experimental test conducted with a group of students, aimed at understanding the advantages of incorporating textual stimuli during the ideation process, will be reported.

5.1 - *Nano Sintesi* Product

The product comprises a headbox, extended vertically along one of the two sides of the frame, which defines a hollow volume at its interior, and a support structure, shown in Figure 5.1, characterized by the following parts:

- an upper guide, divided in two elements; a first one fixed at the upper wall of the opening (called from now on upper fastening profile) and a second one capable of being moved in a range for the perfect horizontal positioning (called from now on upper guide profile);
- an handlebar, that holds one edge of the fly screen, allowing the movement of it from an open to a closed configuration, thanks to the sliding connection with the upper guide;
- an abutment profile, of C-type, opposite to the headbox, that accommodates the handlebar when the net is extended and enables the proper closure of the opening;
- a lower guide, that permits the lateral constraining of the handlebar in its lower portion;
- a second abutment profile, again of C-type, interposed between the lateral wall and the headbox, allowing the correct registration of it in a perfectly vertical position.

The main structure of the mosquito net also includes the mechanism for synchronizing the horizontal movement of the handlebar, partially visible in Figure 5.1. Additionally, there are important mechanisms for adjusting the correct height of the upper telescopic guide and for securing the handlebar to the abutment profile. The following sections will describe the various subassemblies.

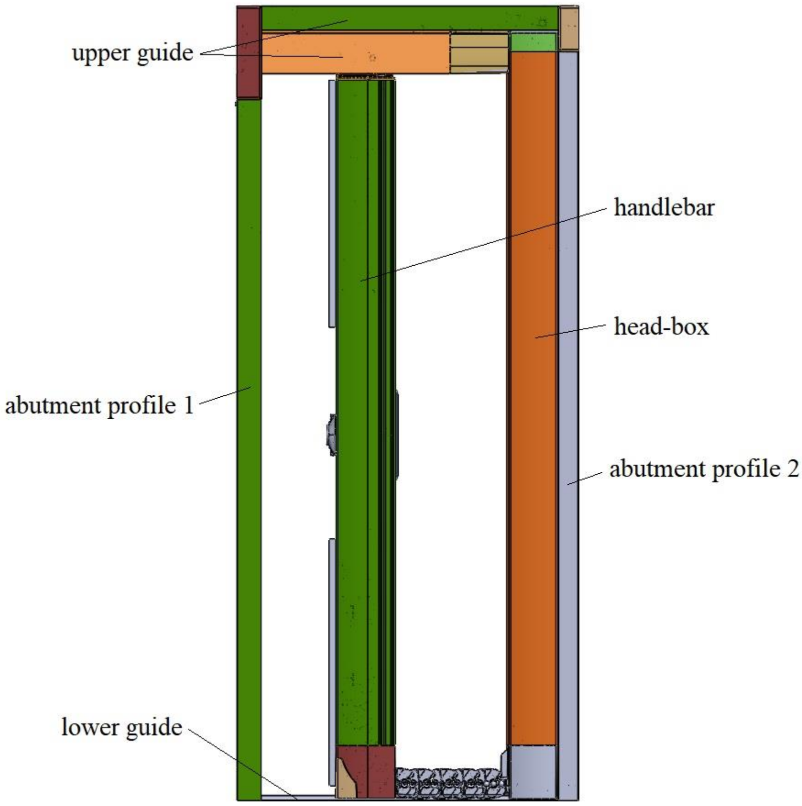


Figure 5.1 – Overall view of the developed model of mosquito net *Nano Sintesi*.

5.1.1 - Net container assembly

The winding tube is rotatably supported within the housing volume of the head-box, around a first axis R, as it is shown in Figure 5.2. A section of the headbox profile is instead reported in Figure 5.3. As it is possible to note, the final shape of the profile guarantees the separation between the net and the tensioning system with a physical obstacle given by the two overhanging aluminium walls. Moreover, the opening where the net exits is only 5 mm wide, according to the initial requirement that the unwound screen must be positioned centrally with respect to the product footprint. This also increases the protection of the net when it is wound around the take-up roller, preventing insects, other animals, or similar, to enter inside the head-box volume.

The net tube is extended for the entire length of the box profile. At the openings, two plastic heads are fixed to close the sub-assembly: a lower one, positioned on the lower guide, and an upper one, partially inserted in the upper guide.

Both heads are attached to the aluminium box through commercial screws with cylindrical head, placed in dedicated slots in the material, as shown in Figure 5.4. Four screws are used to secure the upper cap, and other

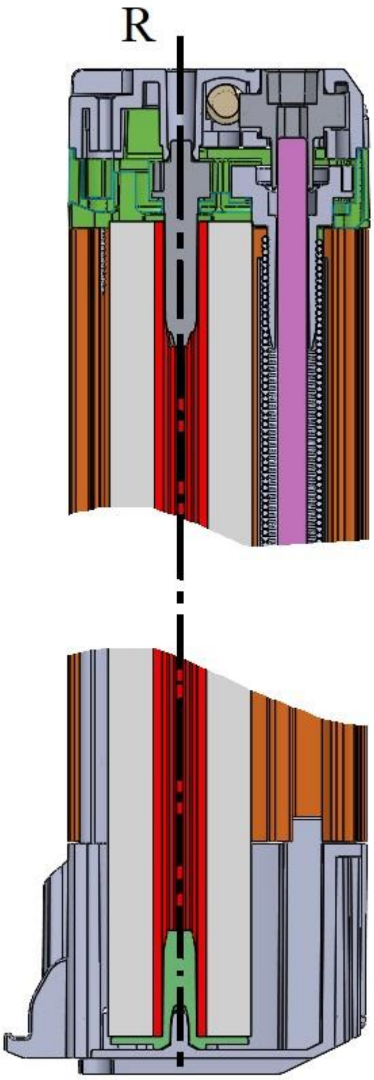


Figure 5.2 – Vertical section of the head-box assembly.

four for the lower cap. Figure 5.5 illustrates the final constructive solution. In particular, four holes are present in each of the two plastics, aligned with the first fixing holes on the aluminium section.

A torsional spring is located inside the head-box, with its main axis parallel and adjacent to the rotation axis of the net tube. One end of the spring is positioned at the upper exit of the profile (as visible in Figure 5.5) and is free to rotate relative to it, while the lower end is locked during the product's operation. However, to enable the spring to be loaded and, thus, permitting the relative rotation of the two ends, it is possible to rotate the lower end from the outside, transferring the desired movement.

The complete characteristics of the spring are listed in Table 5.1.

Table 5.1 – Geometry characteristics of the torsional spring employed.

Quantity	Values [mm]
Total length	1000
External diameter	11,4
Wire diameter	1,2
Pitch	1,2
Winding	Right-handed

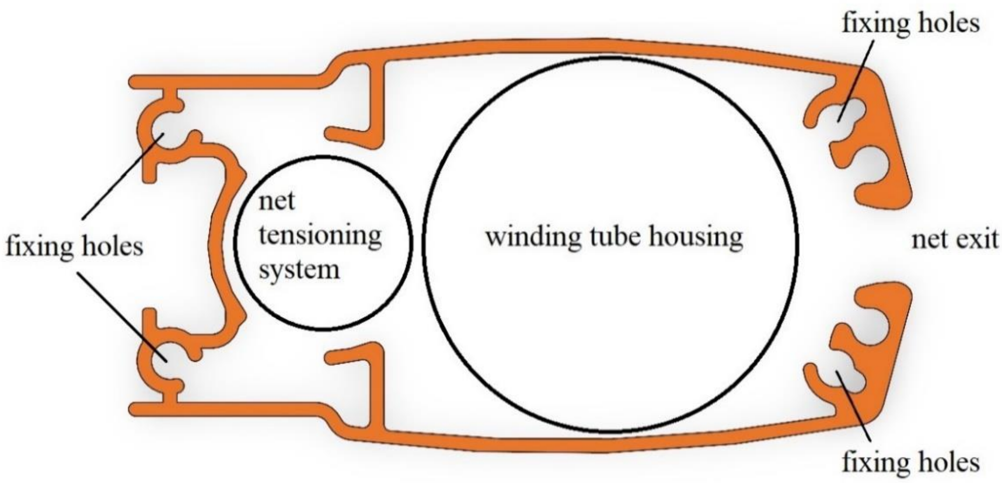


Figure 5.3 – Section of the final head-box profile.

To transmit the elastic torque to the net, there are transmission means, as shown in Figure 5.6, located in the upper head of the head-box, connecting the top ends of the winding tube and the spring. These are accompanied by additional support means, visible in Figure 5.7, located inside the head-box and coaxial with the spring.

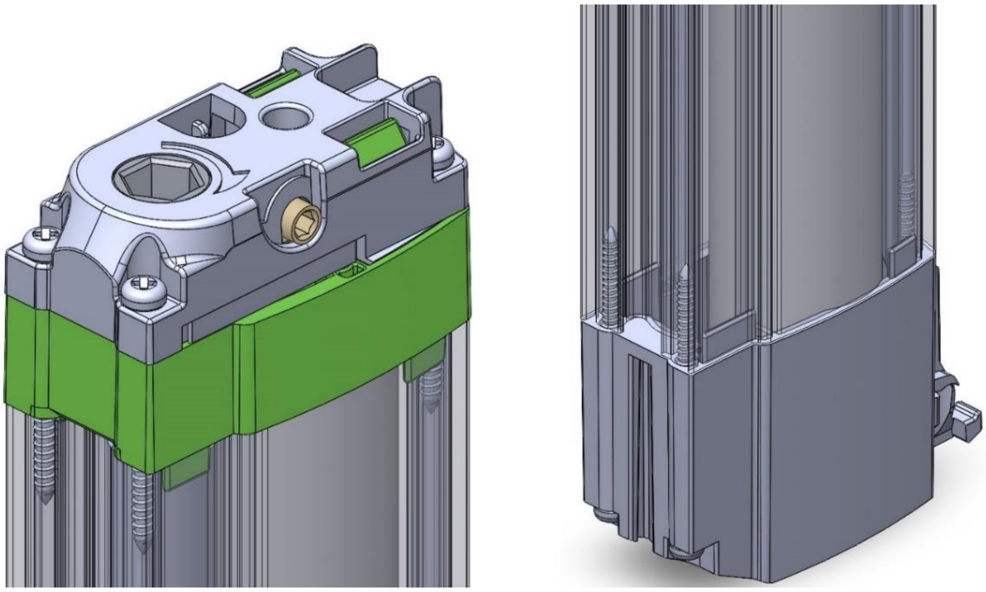


Figure 5.4 – Positioning of the upper and lower head-box heads.

In particular, these means consist of a hexagonal cross-section rod, locked in rotation relative to the headbox, and two plastic components at the ends: a lower dragger and an upper loading toothed wheel. The dragger has a substantially T-shaped form, including an elongated cylindrical portion along which the spring is partially wound, as visible in Figure 5.8. To prevent the disengagement, circumferential ribs are present on the piece's surface, allowing them to cooperate with the spring coils, preventing their axial movement. Inside the dragger, there is a cavity that extends the full height, in which the hexagonal rod is partially housed. The configuration of the rod and its seat ensures that the two elements are rotationally coupled. There is also a protruding surface, orthogonal to the main axis, which provides a limit stop for the spring. This is particularly useful during assembly as it serves as a definite reference point for the proper winding. Lastly, the dragger also features another protruding surface portion located in the internal hole, against which the hexagonal rod exerts contact, acting as a stop. In this way, every axial movement of the rod is also transferred to the dragger.

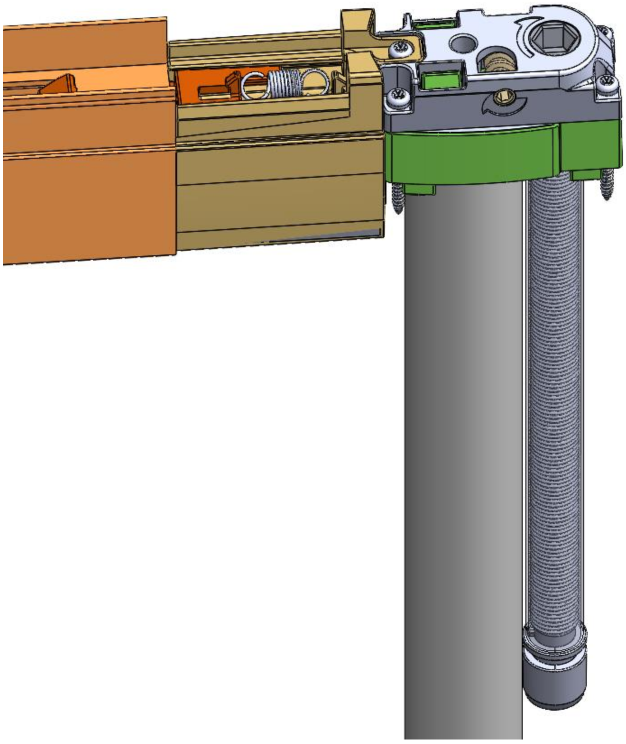


Figure 5.5 – Final assembly of the complete spring group.

To facilitate product installation and ensure better performance, the spring is also covered by a plastic tube, which serves the additional function of containing any excess oil with which the spring's steel is coated.

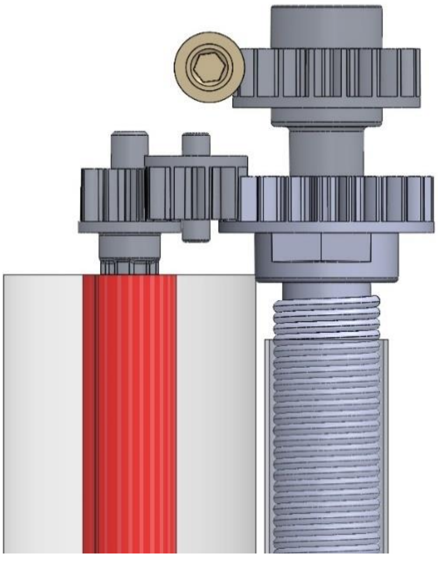


Figure 5.6 – Transmission means located inside the head-box head.

The transmission means include a first toothed wheel, integral with the winding tube of the net, and a second toothed wheel integral with the upper end of the spring, to which it is attached. The outer diameters of the first and second wheels are 11 mm and 23 mm, respectively. This results in a reduction ratio close to 0.5.

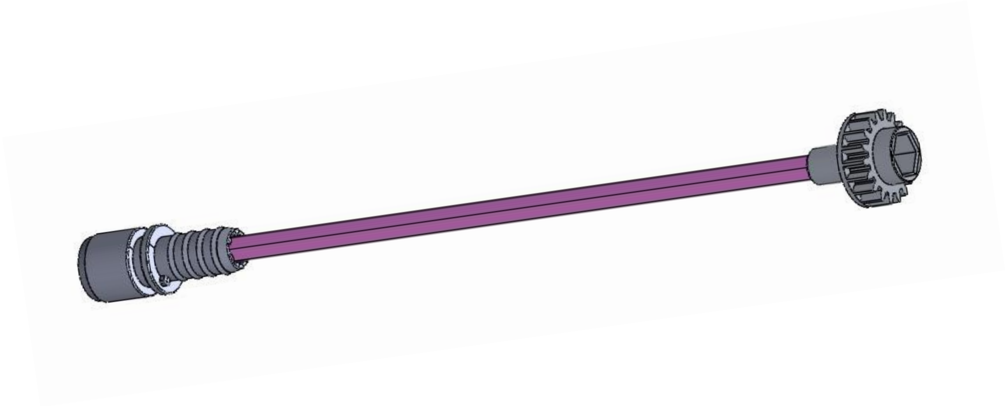


Figure 5.7 – Spring support means.

This brings a significant advantage: the number of turns the spring must withstand during the movement of the mosquito net between the two extreme open and closed positions is approximately half of what is required for other products more commonly available in the market, given a fixed number of net tube turns. This results in a lower variation in the spring's retention force, which remains more constant during use, enhancing the user experience.

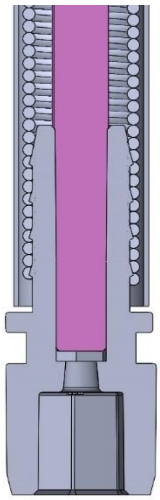


Figure 5.8 – Spring dragger.

What has been explained is even more beneficial in this product because, due to the reduced diameter of the aluminium tube, the number of turns the take-up roller must perform between the fully open and fully closed positions is greater than that of other products with larger winding tube diameters. This would have resulted in an excessive number of turns for the spring in the case of a 1:1 ratio. The variation in the spring's returning force is also reduced by using a relatively long at-rest spring, as mentioned earlier, measuring 1000 mm.

The transmission means also include a third idle gear, situated between the other two mentioned, characterized by an outer diameter equal to that of the first wheel. This component was introduced to allow the first two wheels to maintain their reduced diameters while simultaneously ensuring the necessary interaxial distance, which must be maintained because of the spatial encumbrances of the wound net and the adjacent torsional spring. In this way, it was possible to fulfil the overall product thickness constraint at 30 mm.

The cross-section of the net tube is shown in Figure 5.9, along with the gear to which it is coupled, in Figure 5.10. As it is possible to note, an insertion seat is present on the tube, within which the connection stem of the first gear is inserted. The shape is of polygonal type, with four lobes, and the lower part of the plastic has been tapered in order to facilitate the mounting. In the upper portion of the gear a support stem is instead created, to allow the correct rotation of the element.

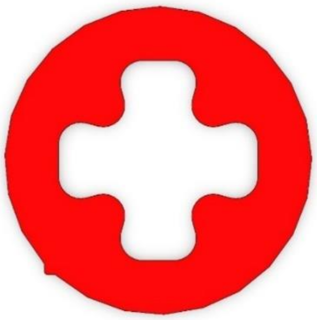


Figure 5.9 – Cross section of the net tube.

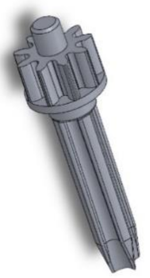


Figure 5.10 – First gear co-axial with the tube.

The upper head of the head-box is constituted by two main bodies: a lower portion (in Figure 5.11) and an upper portion (in Figure 5.12). The lower body is provided with two L-shaped retention tabs, extended towards the second body, in order to mechanically connect the two. To ensure the locking, two openings are present in the upper part, to snap-house the aforementioned tabs. As it is possible to see on the right view of Figure 5.12, two support seats of circular shape are present: a first one for the aforementioned support stem of the first gear, and a second one for the same portion of the idle gear.

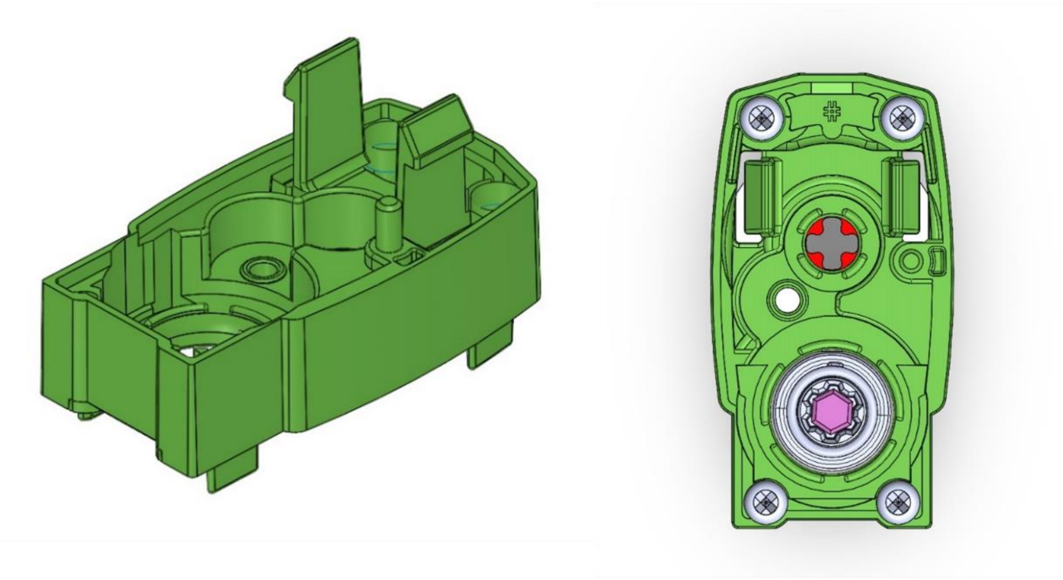


Figure 5.11 – Lower portion of the upper head-box head.

The lower portion of the upper head is provided with two additional support seats: one placed above the take-up roller, and one aligned with the torsional spring. In each one, a bottom wall against which the respective gears are placed in abutment is present. Moreover, these walls are characterized by a central hole, that allows the connection of the gears respectively with the insertion seat of the take-up roller and the edge of the elastic mean. Two support shoulders, extended projecting from the bottom walls of the seats, are present in order to reduce the friction between the gears and the plastic head during the rotation. In particular, they are visible on the right of Figure 5.11 and are placed circumferentially with respect to the holes.

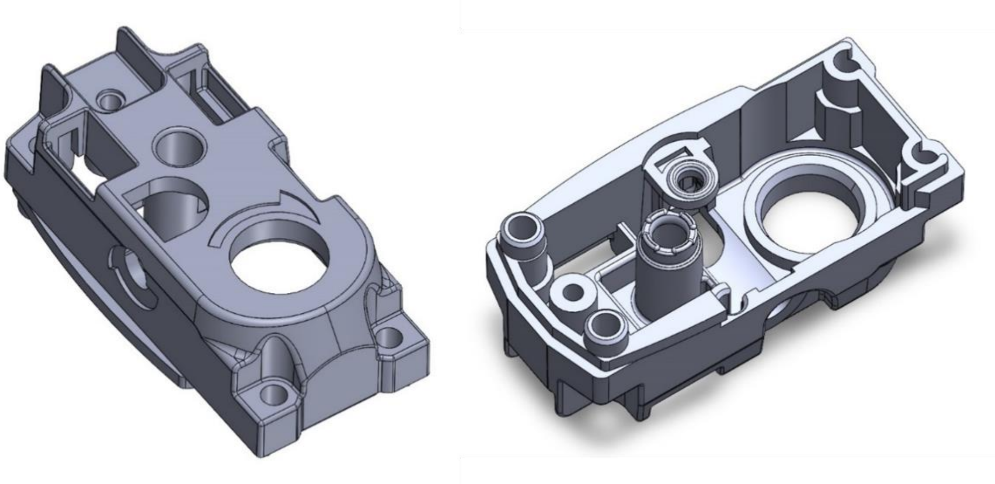


Figure 5.12 – Upper portion of the upper head-box head.

A detailed representation of the second gear is reported in Figure 5.13. It is characterized by an upper toothed portion and a lower stem portion. The part is provided with a through housing hole in which the support means of Figure 5.7 are partially housed, free to rotate within it. The upper end of the spring is wound on the stem portion and kept in position, thanks to the circumferential engagement protuberances that are present along the external surfaces of the stem. These cooperate with the torsion spring wire, in the same way as the dragger does.

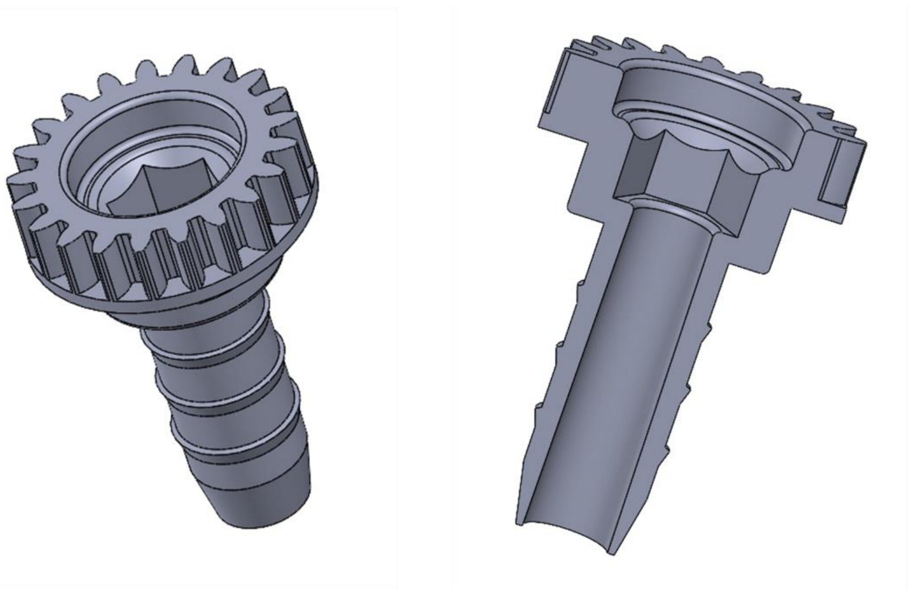


Figure 5.13 – Second gear, co-axial with the spring and connected to it.

The support means previously mentioned and reported in Figure 5.7, have the important function of adjusting the spring tension, when the headbox is already assembled. The upper loading gear, integral in rotation with the hexagonal rod, is housed in the upper cap of the upper head, aligned with the second gear. As it is possible to see in Figure 5.14, an adjustment opening is present where the user can act with an hexagonal tool to rotate the gear, while in the lower part a constraining and counter-shaped opening houses the upper end of the hexagonal bar, that is therefore fixed in rotation with the gear. Between the adjustment and the constraining openings an abutment wall is present, against which the hexagonal bar is in opposition, in order to transfer the constant upward thrust of the rod to the loading gear.

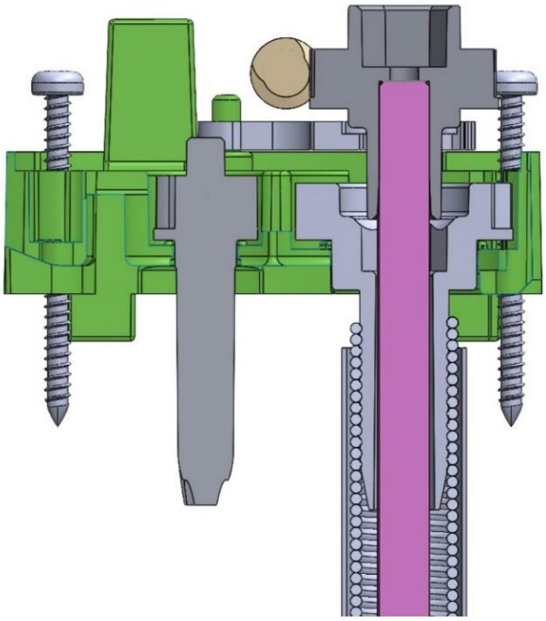


Figure 5.14 – Relative positioning of the transmission gears housed in the head-box head.

As it is possible to see in Figure 5.15, the external diameter of the lower stem of the loading gear is partially inserted in the central hole of the second gear with a radial clearance, in order to prevent the mutual coupling between the two gears. In this way, a rotation of the loading gear allows the angular movement of the lower end of the torsional spring, while the upper end of the elastic component remains locked. The configuration of the components described so far has been protected in the patent by (Ostuni and Melani, 2023).

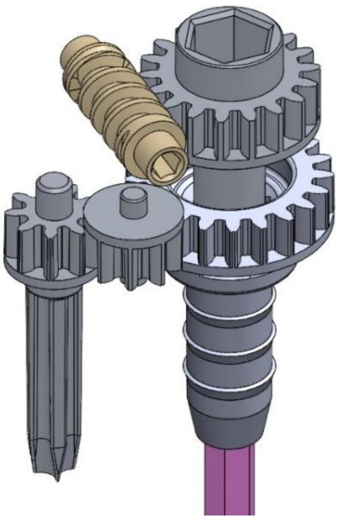


Figure 5.15 – Alternative view of transmission and supporting means.

The loading means also comprise a worm screw, rotatably mounted in the upper head and mechanically connected to the loading gear. This coupling is well visible in Figure 5.15. The external diameters of the two wheels are equal to 20 mm and 7,5 mm. The number of teeth is equal to 18 for the wheel, while the screw principle is one. The worm screw is actuatable by the user in order to rotate the loading gear and is configured for preventing the rotation of it in a direction opposite the loading sense. In fact, as it is known, the efficiency of this type of coupling does not allow retrograde motion, which in this case would lead to lose the spring tensioning.

In particular, the worm screw is housed in the upper cap of the plastic head and is extended orthogonally with respect to the rotation axis of the tube, for the entire width of the head-box. Two actuation openings are present on the two sides of the case, in order to allow the insertion of a specific tool to actuate the worm screw, and therefore to modify the spring tensioning, even when the product is already installed on the frame, without removing it.

For the characteristics outlined above, the reduction ratio of the coupling is equal to 1/18. In other terms, eighteen rotations of the screw are needed to give the spring one more turn. This allows a very precise regulation of the net tensioning, up to the desired value.

In order to directly rotate the loading gear, as previously described, the coupling with the worm screw has to be interrupted by the user. To this end, the gear is able to move axially, between a lifted position, in which is coupled to the worm screw, and a lowered position, in which it is uncoupled from it.

The axial movement of the gear also implies the downward displacement of the hexagonal rod and the dragger, thus stretching the spring. The axial force required to overcome the spring resistance is directly exerted by the user during the loading gear rotation phase.

To ensure an adequate level of axial force under all operative conditions of the system, the torsional spring is shorter than the hexagonal rod, thereby providing an initial tension force to the system. Specifically, the rod is 1100 mm long, which is 100 mm more than the length of the spring at rest. When the spring is loaded, the diameter of the coils tends to decrease, causing an axial elongation of the spring. The difference in length between the two components is capable of maintaining a minimum level of axial force for the proper repositioning of the loading gear in place.

If at the end of the loading phase, the gear teeth are not perfectly aligned with the thread of the worm screw, the elastic return force does not guarantee alone the correct returning of the gear in position. In this case, it is sufficient that the user slightly rotates the gear in order to correctly realign the external toothing, and the coupling is automatically restored. The double loading system described for the spring tensioning adjustment has been protected in the patent by (Rossi and Melani, 2023a).

To prevent accidental disengagement of the worm-gear coupling, especially during product handling from the factory to the final installation site – primarily due to impacts experienced by the product – there is a safety lever on the head assembly that prevents the gear from moving axially downward. This lever remains open during the fast spring-loading operations in the factory, as shown in Figure 5.16 and Figure 5.17. Subsequently, it is closed, clipping onto a specially shaped portion of the upper plastic head. The lever (as visible in Figure 5.17) has a hole into which a pin, located in the lower part of the head, is inserted, allowing it to pivot around it. The semicircular surface on the lever then fits underneath the plane of the loading gear's teeth, thereby locking it axially (as visible in Figure 5.18) after the tensioning phase. If there is a need to quickly load the spring again, the lever can be easily opened using a specific tool (slotted screwdriver) on the closure portion.

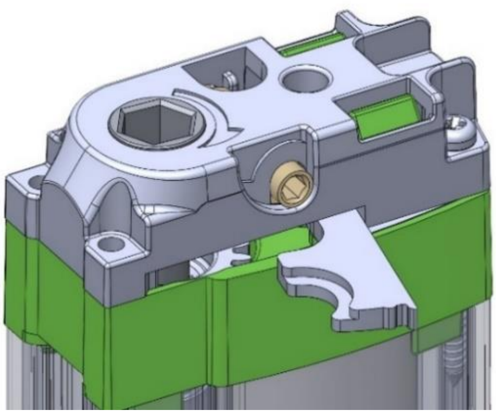


Figure 5.16 – Upper head-box head assembly with open safety lever.

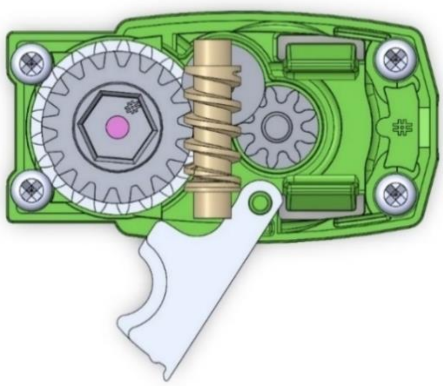


Figure 5.17 – Upper view of the upper head-box head with gears visible.

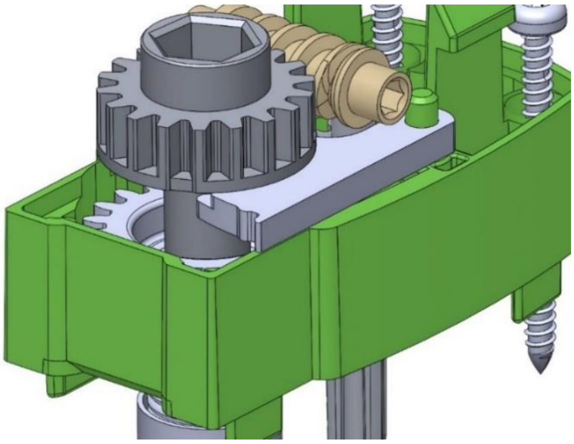


Figure 5.18 – Upper head-box head assembly with safety lever closed.

5.1.2 - Handlebar and synchronization mechanism

The final aesthetic result of the developed lower chain is shown in Figure 5.19. As it is possible to note, one end is connected to the lower head of the head-box profile, while the second end is slidably associated with the handlebar, remaining inserted within the axial cavity of the profile, for all the operating conditions.

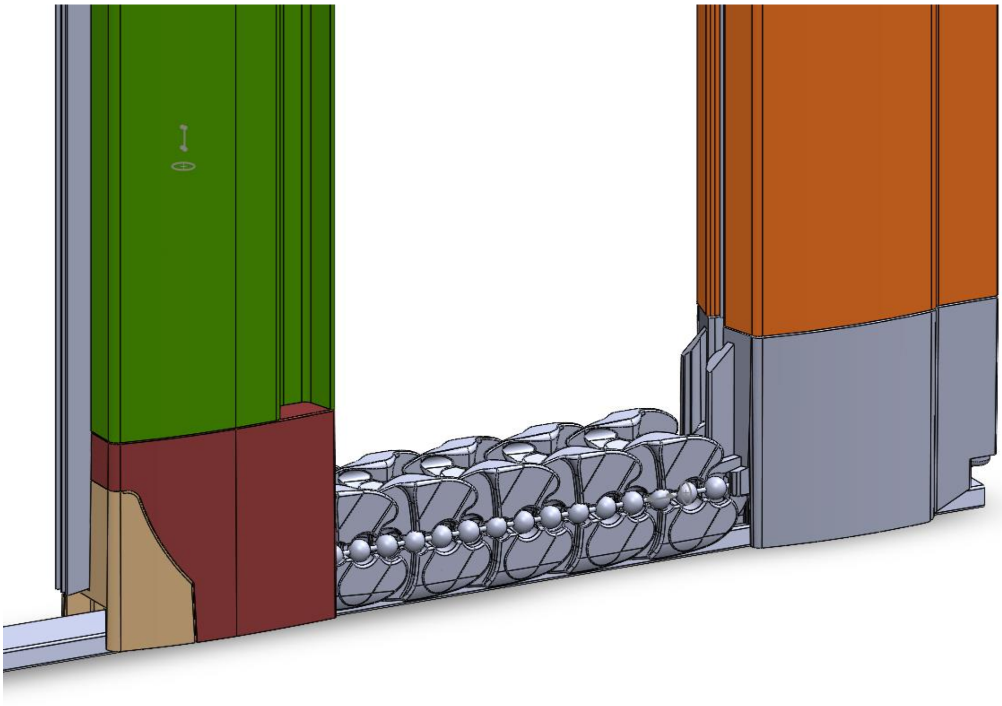


Figure 5.19 – Final assembly of lower carriage mounted on the product.

The lower termination of the handlebar is provided with a plastic head, divided in two parts, visible in Figure 5.20: a main body and a support slide. The slide is characterized by a curved surface, that brings the single chains of the carriage to rotate with respect to each other, allowing them to enter and exit from the cavity. Therefore, when the handlebar is in open position, the guide chain is housed vertically along the bar; when the mosquito net is closed the carriage elements are horizontally aligned, below the screen.

A front view of one chaining element is reported in Figure 5.21. As it is possible to note, each element is characterized by two lateral walls, connected with a central body. These define a groove open on the upper part, which passes along the extension line of the chain. This volume houses the lower edge of the fly screen when the mosquito net in closed. Besides, two upper walls are present on each side. If retention brushes are employed, these can be inserted in dedicated slots created under the mentioned walls, which in turn create abutment surfaces for the bristles during retention.

On the external surfaces of each lateral wall, three housing seats are made, as it is possible to see in Figure 5.22, placed side by side along the extension line of the carriage. Two connection elements are present: they are constituted by a commercial nylon wire, with a plurality of spherical portions displaced on it, at a given pitch of 6 mm. Each of the engagement portion is inserted in a corresponding housing seat on the external chain surfaces, in order to facilitate the assembly.

Each lateral wall can be subdivided into two parts: a recessed portion A and a prominent portion B. In this manner, the unit A is inserted in the part B of the adjacent chain, thus limiting the range of relative translation of the two elements and preventing from rotations around different axes from the expected one.

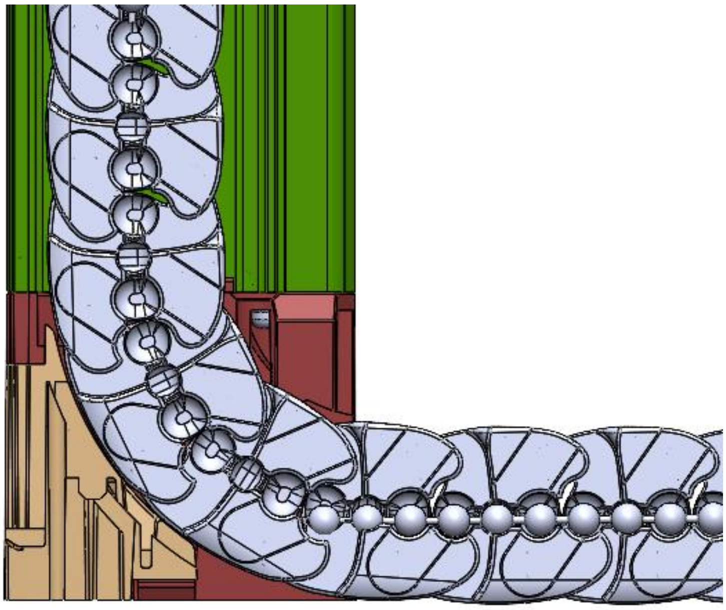


Figure 5.20 – Lower handlebar head and interface with the lower chain.

When the carriage is completely straight, the extra-rotation of the chains is prevented by two abutment portions, elongated parallel to the extension line, that go in contact with two other surfaces placed on corresponding cavities on the adjacent chain, as it is highlighted in the square C in Figure 5.23. Another limitation on the extra-rotation of the chains when they are tilted is provided by the abutment of the upper fin - visible in the square D of Figure 5.24- against the surface that delimits the upper cavity of the adjacent element.

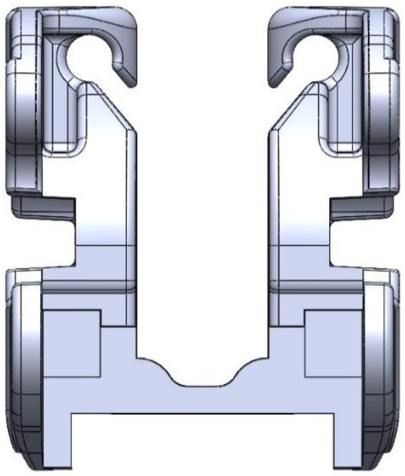
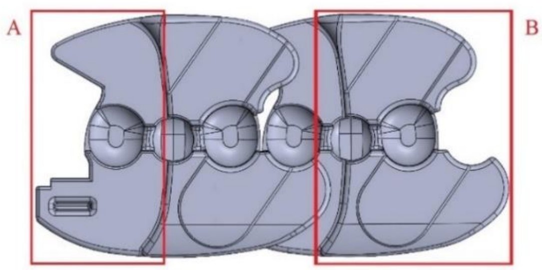


Figure 5.21 – Front view of a chain element.

Together with the lateral walls, the presence of connection elements allows the limitation of undesired swinging movements of the chain, since they maintain it tensioned, increasing its global flexional rigidity. In particular, in the event in which an impact against the lateral walls occurs, the shape of the guide chain tends to be modified, forming a concavity. Therefore, the connection elements, engaged within their seats, stretch the flexible portions of the wire, which then absorb the impact energy and return to their original shape thanks to their elastic properties.

As can be better seen in Figure 5.25, each wall of a single chain element is characterized by a central housing seat, to size with respect to the corresponding engagement sphere, that ensures a good mechanical connection between them. Adjacent to that, two additional housing seats are present on the same piece, that carry the corresponding spheres but in a slidable way. In particular, as it possible to see in Figure 5.25, these lateral seats have an elongated shape along the X directions, orthogonal to the rotation axis of the chains. This ensures the sliding movement of the spheres inside their location and an easier roto-translation of the guide elements with respect to each other, thus reducing the connection wires wear and the overall friction.



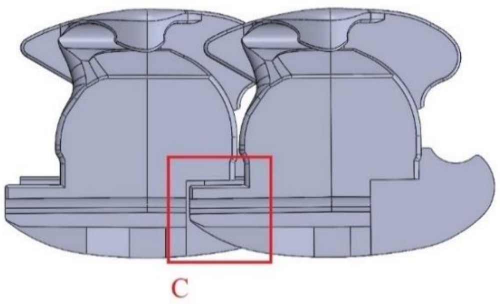


Figure 5.22 – Housing portions located on the side view of two adjacent chains.

Figure 5.23 – Abutment portions located in the lower part of the chain.

Another advantage of this solution is that the distance between two adjacent spheres can have a less precise realization tolerance, with respect to other solutions already on the market. Indeed, the tension generated between two adjacent chain elements does not depend on the individual distance between only two contiguous spheres but on the entire portion of the filament between two to-size seats of adjacent carriages. In this constructive solution, this means that the tensioning error is averaged over three adjacent flexible portions, which can be bent during the relative movement of two carriages.

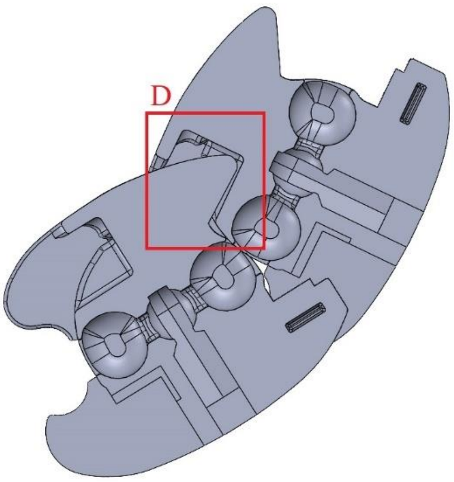


Figure 5.24 – Abutment portions located in the upper part of the chain.

The square E in Figure 5.26 shows the particular conformation of the passage opening of the chain, placed in correspondence of the prominent portion B, that has an elongated shape along the X direction, greater than that of the external housing seats. This, in order to allow the free movement of the connecting wire in all the possible relative positions of two adjacent chains.

Towards the internal portion of each lateral wall, two cams are present along the edges, highlighted in Figure 5.27 in squares F and G. These are constantly in contact during the relative movement of two adjacent chains, rolling one over the other, allowing the motion of the two elements between the aligned and tilted positions.

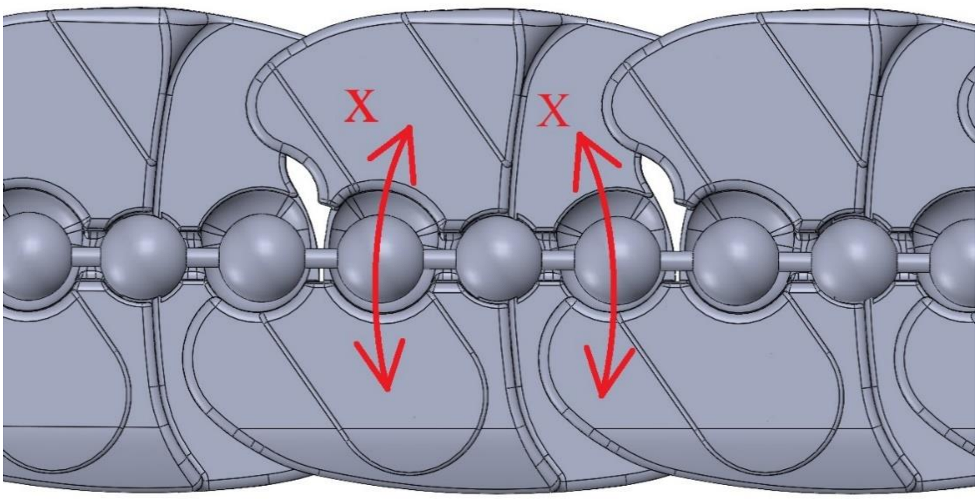
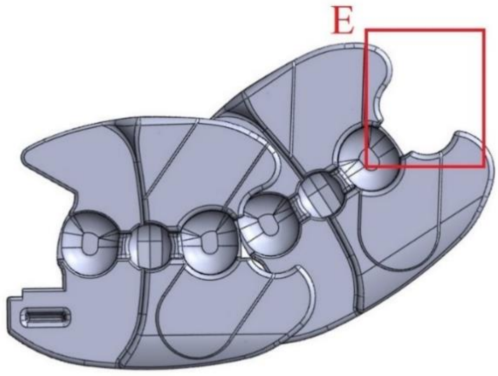


Figure 5.25 – Details of the spheres' housings, with free directions X for the transversal movement of the elements.

In particular, they are specifically shaped to either move away from or approach the to-size housing seats of two adjacent chains during the roto-translation. More specifically, an intermediate position exists between the aligned and tilted positions, which creates the maximum distance between the housing seats. This causes the connecting wire to elastically elongate during the movement, thus exerting an elastic returning force that aims to reposition the chain in either an aligned or completely tilted configuration. In this way, the intermediate positions are unstable, while the extreme ones are stable.



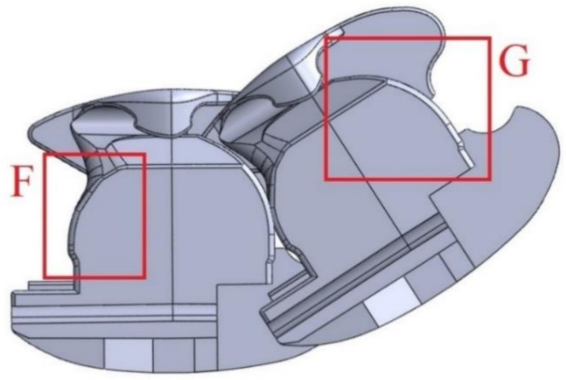
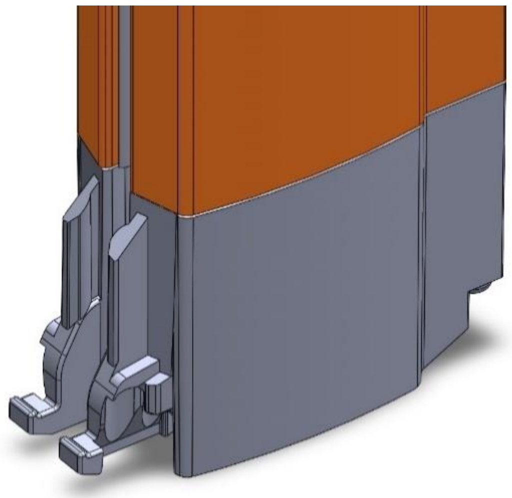


Figure 5.26 – External passage opening of the chain.

Figure 5.27 – Internal cams where two adjacent chains roll.on each other.

In this manner, when the handlebar is moved towards the closed or open position, the carriage elements are forced by the elastic return stress to pass from an aligned position to a completely tilted position and vice-versa, without the possibility of remaining in an intermediate, not desired, position.

In order to maintain the guide chain connected to the lower part of the head-box, a lower plastic head, reported in Figure 5.28, is provided in the bottom part of the profile. As it is possible to see, two abutment portions are present, projecting along the extension line of the guide chain. On each of the protrusions, a retention seat is present. Both are characterized by two hollow semi-spheres, directed downward, so as to house the last two engagement portions of the connecting wires, as it is possible to see in Figure 5.29.



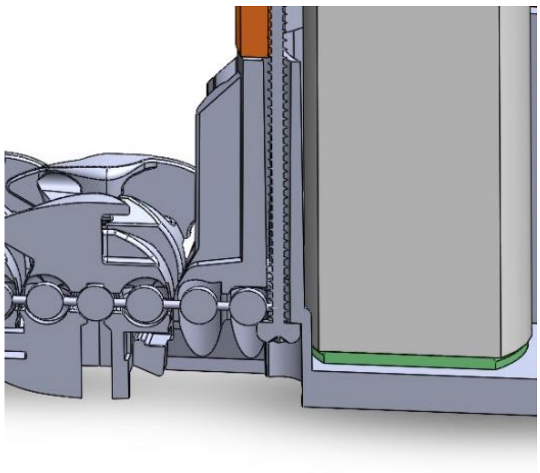
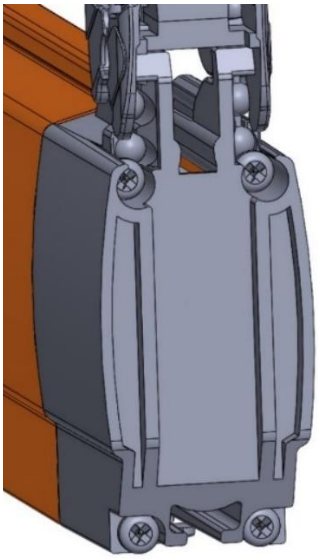


Figure 5.28 – Lower head-box head with protruding fins.

Figure 5.29 – Housing of external spheres on the dedicated seats of the head.

The spherical elements are retained in position thanks to two screws inserted in dedicated slots on the plastic cup, in such a way that the screw heads partially close the retaining seats, as it is visible in Figure 5.30.

The protruding portions of the lower headbox head have also the function of limiting extra-rotations and oscillating movements of the guide chain with respect to the net container, thanks to the appositely shaped hook visible in Figure 5.31 that goes in contact with the wall of the lower cavity of the chain, on both sides of the element.



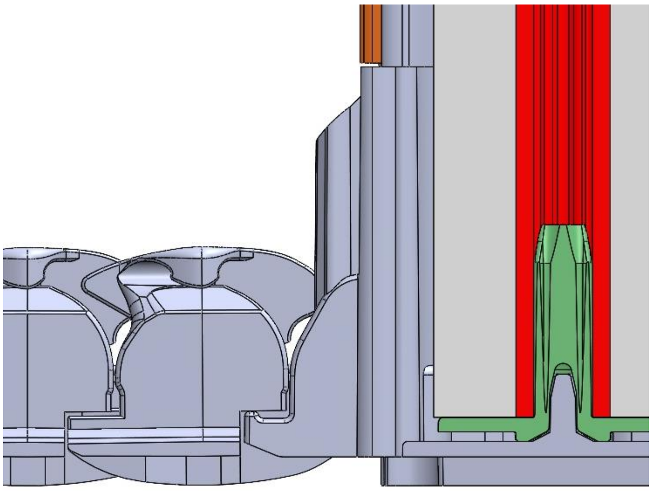


Figure 5.30 – Retention of spherical elements with the screw heads.

Figure 5.31 – Abutment portion of the head box head for the prevention of the chain extra-rotation.

Finally, two tabs are present on the lower head-box head, visible in Figure 5.28, which are extended parallel to each other and placed above the previously mentioned abutment portions. Such elements have been design to prevent the undesired detachment of the handlebar from the head-box profile when the system is open, cooperating with the lower plastic termination of the handlebar profile. This ensures a better aesthetic performance of the product even after several cycles of use. The lower guide chain and its connection system to the lower head-box head has been protected in the patent by (Ostuni et al., 2023).

5.1.3 - Telescopic guide regulation

As previously mentioned, the upper rail consists of two profiles: an upper fastening profile, which opposes the upper wall of the frame, and an upper guiding profile enclosed within the former. This upper guiding profile can be adjusted in height to restore a perfect horizontal alignment in cases of out-of-square situations.

Figure 5.32 shows a cross-section of the upper guide profile. As can be observed, the upper end of the handlebar is located in the lower section of the guide. More specifically, there is a plastic head with a reduced overall thickness in the transverse direction, allowing it to smoothly slide along the primary direction of guide development. This is made possible by two rolling bearings positioned on the lateral walls, as depicted in Figure 5.33.

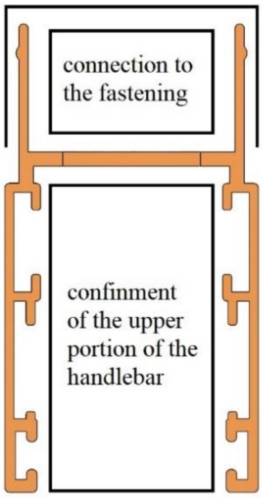


Figure 5.32 – Section of the final upper guide profile.

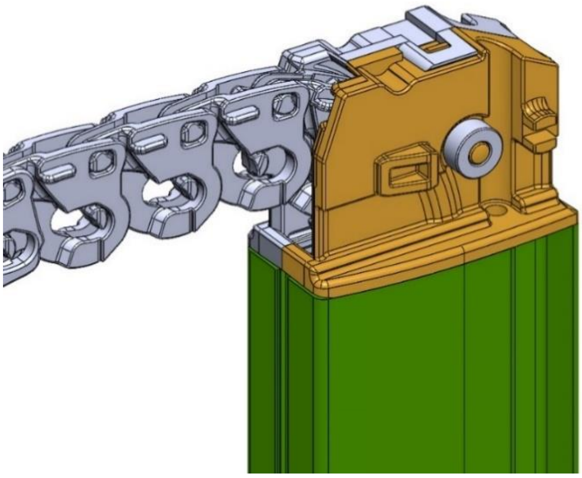


Figure 5.33 – Upper handlebar head with rolling bearings installed.

Each bearing is attached to a protruding pin, which is directly integrated into the side wall of the tapered plastic head. This design minimizes the number of components required. On the other hand, both sides of the upper guide's housing section feature two projecting fins, labelled as A and B in Figure 5.34. These fins create a pathway for the bearings to roll along. Specifically, the lower fins bear the weight of the handlebar under normal conditions. If there is an impact on the handlebar, pushing it upward, the upper fins serve to limit its vertical movement, preventing the plastic head from colliding with the upper guide's horizontal wall. To ensure a secure connection with the guide, the protruding pins on the head partially enter the rail section defined by the fins.

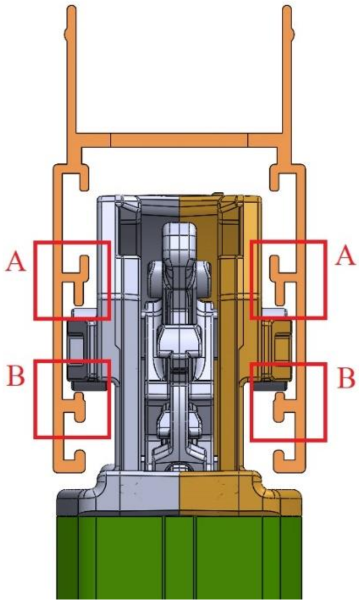


Figure 5.34 – Protruding surfaces internal to the upper guide.

The upper guide's height adjustment is ensured through regulation mechanisms located in its upper section, adjacent to the fastening profile. These mechanisms consist of a regulation block, which houses a nut with a threaded seat, and a regulation screw. It is possible to see them mounted in Figure 5.35. The nut is inserted into the regulation block through a specifically designed side opening. To prevent accidental release, two protruding elements within the housing are employed. These elements elastically deform as the nut passes through and then promptly return to their original shape.

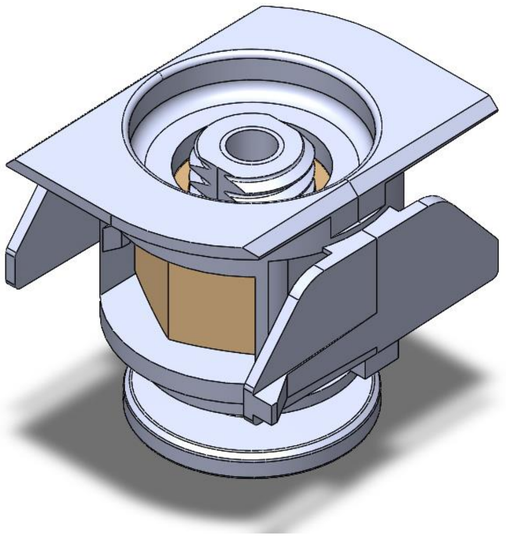
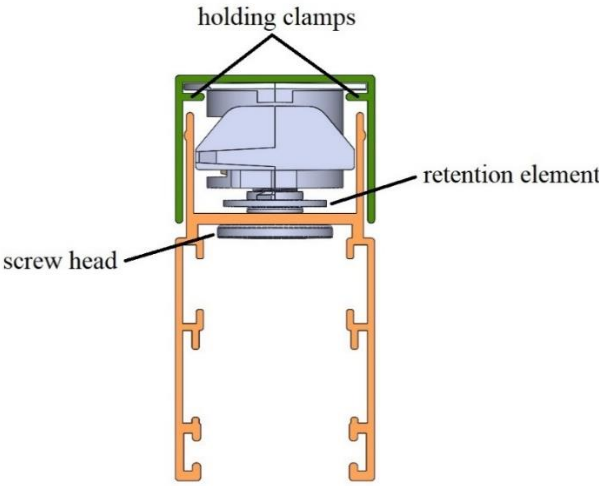


Figure 5.35 – Regulation means for the height control of the upper guide.

A hole is created in the horizontal wall of the upper guide, from which the screw is inserted from below. The screw head, of a flat design, has a larger external diameter than that of the hole. This ensures that there is a continuous contact surface between the two elements, preventing the upper guide from falling down during installation. Additionally, there is an extra retention element, as shown in Figure 5.36 and Figure 5.37, fixed in relation to the screw's shaft. Its purpose is to restrict the upper surface of the horizontal guide wall in an upward direction, effectively securing it in place.



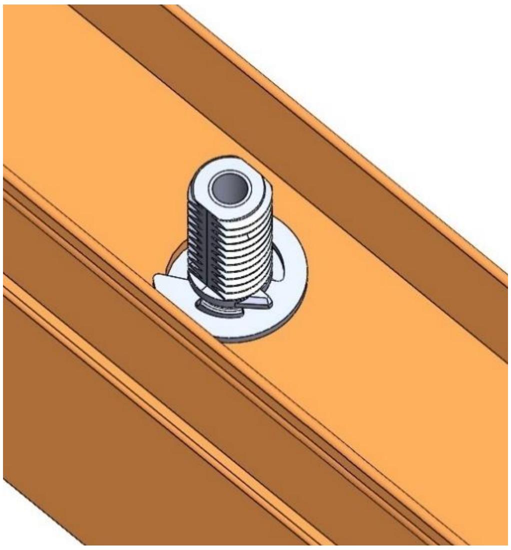


Figure 5.36 – Front view of the upper rail assembly.

Figure 5.37 – Regulation screw mounted on the upper guide.

The retention element consists of a Seeger ring that is partially seated on the screw shaft, aligning with a groove of reduced diameter. This configuration axially secures the two components. Figure 5.38 illustrates that an opening is present in the ring to facilitate its insertion, and three thicker segments are located circumferentially. During the insertion phase, two out of the three segments on the opposite side of the opening undergo elastic deformation, to then return to their original shape, thus effectively locking the Seeger ring in position.

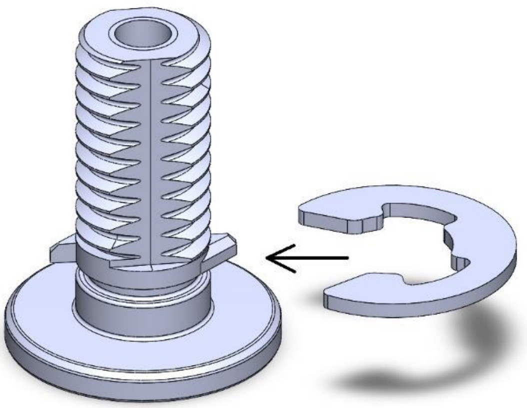


Figure 5.38 – Installation of the retention element on the regulation screw.

The fastening profile features an inverted 'U' shape, as depicted in Figure 5.36, and houses two internal holding clamps. To reinforce the assembly, the two upward-protruding lateral walls of the guide profile are aligned internally with the side enclosures of the fastening profile.

In Figure 5.39, it is possible to see that the regulation block has a rectangular upper portion. At the ends of the longer side, two supportive fins are positioned to be secured to the fastening profile by the previously mentioned holding clamps. This coupling is achieved through a simple form-fitting mechanism, which is better illustrated in Figure 5.36. Therefore, no additional elements are necessary.

To ensure the connection, there is no need to insert the regulation block from one end of the fastening profile and slide it into the correct position. In fact, the length of the shorter side of the upper part of the block is smaller than the remaining clearance between the two holding clamps of the guide. This allows the adjustment means to come into direct contact with the upper surface of the U-profile. Then, rotating the block by 90° brings the supportive fins into contact with the clamps, as shown in Figure 5.36.

Notably, at the base of the screw stem of Figure 5.38, two opposing teeth are present, diametrically opposite with respect to the longitudinal axis. Simultaneously, on the lower opening of the retention block, two similar teeth can be found, projecting from the circular wall as visible in Figure 5.39. When the screw is fully threaded inside the block, the opposing faces of these protrusions, extending radially, come into contact with each other. Therefore, further rotation of the screw causes the entire block to rotate solidly.

The external smaller side edge of the rectangular upper portion of the regulation block has both a straight and a smoothed section to facilitate its movement and subsequent locking in its final position. During the rotation, the bevelled part is designed to glide along the internal sides of the fastening profile's lateral walls. Once the block is constrained, the straight portion becomes parallel and engages with the two sides of the fastening guide, preventing any further rotation of the regulation block.

In this way, it is possible to first assemble the screw on the upper guide, securing it with the Seeger ring. Then, the regulation block is directly thread onto the screw, ensuring it is in the correct position with the longest sides of the rectangular upper portion parallel to the main profile development. Afterward, the upper guide is inserted into the fastening profile. To lock them together, the regulation screw is adjusted to its end position, causing the regulation block to rotate. At this point, it is possible to rotate it in the opposite direction to move the teeth of the screw away from those on the regulation block, allowing for adjustment between the two aluminium profiles.

Additionally, two flexible flaps, as seen in Figure 5.39, are located laterally to the main body. They can bend during the transition from the free to the constrained position when they come into contact with the side walls of the upper guide. When the block is engaged with the fastening guide, these two elements return to their non-deformed state abruptly. This produces an audible sound, detectable by the installer, indicating that the component is securely fastened. This also prevents excessive rotations of the screw that could result in damage to the elements.

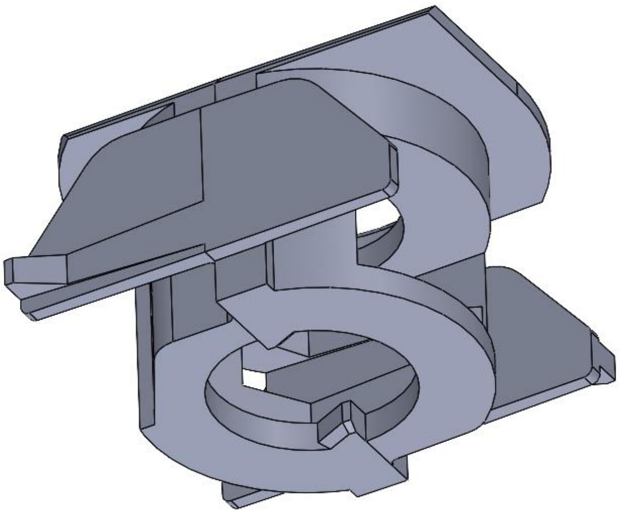


Figure 5.39 – Downer view of the regulation block, with protruding teeth projecting into the central opening.

Both flaps have two ends. Notably, one of these ends is provided with a locking tooth. In the constrained position, this tooth is aligned with the lateral wall of the upper guide. Consequently, these two teeth work together with the rectangular upper portion to ensure that the adjustment means stay in the correct position, as depicted in Figure 5.40.

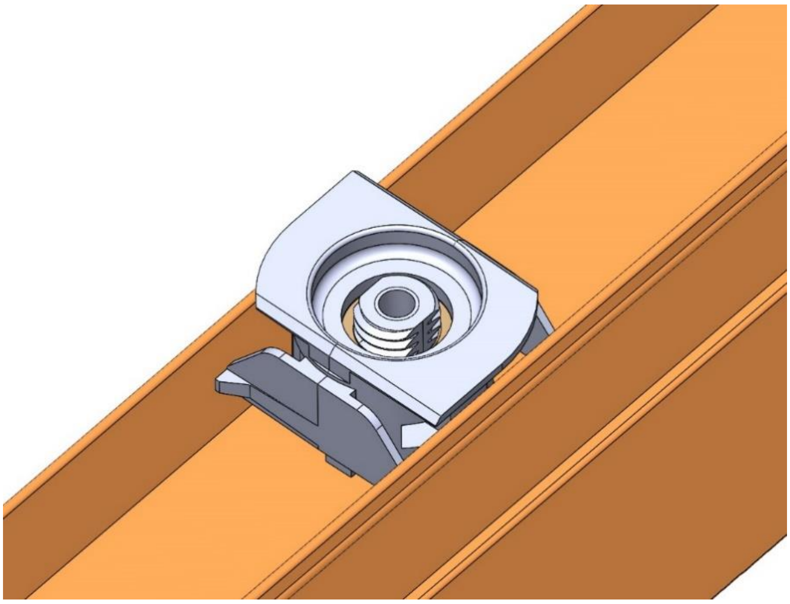


Figure 5.40 – Final position of regulation means on the upper guide when the system is in operation.

The regulation means are positioned off-centre with respect to the guide's development, approximately 20 cm away from the abutment profile. This positioning allows the regulation screw to not only raise and lower the telescopic profile but also to tilt it, achieving the desired level of horizontality.

On the side of the winding tube, an attachment device is positioned between the upper guide and the headbox head. This device comprises a cap equipped with a retaining strap that extends in the main direction of the guide's development. This assembly can be observed in Figure 5.41. A tension spring is situated between these components, exerting an elastic force to retract the strap.

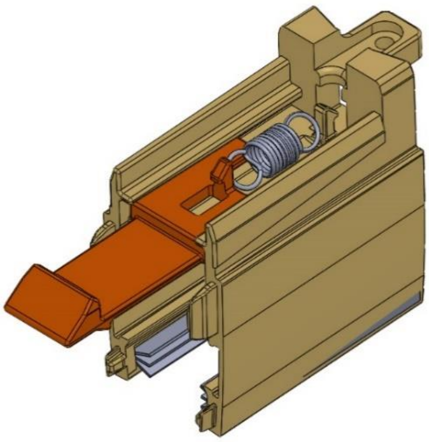


Figure 5.41 – Upper telescopic cap assembly.

A rectangular hole on the edge of the upper guide, located on its horizontal surface, is positioned in correspondence of the strap. Therefore, the side of the hole closest to the cap engages with the vertical wall found at the end of the protruding element, securing the guide in place towards the headbox.

Two rails are integrated into the internal walls of the cup, extending continuously from the ones found on the guide. This arrangement allows the rolling bearings to move on them when the handlebar is in the open position. Additionally, four insertion wings are situated on the lateral surface to engage with the slots located on the edge of the upper guide. The full assembly is depicted in Figure 5.42, while the entire regulation system has been protected in the patent by (Rossi and Melani, 2023b).

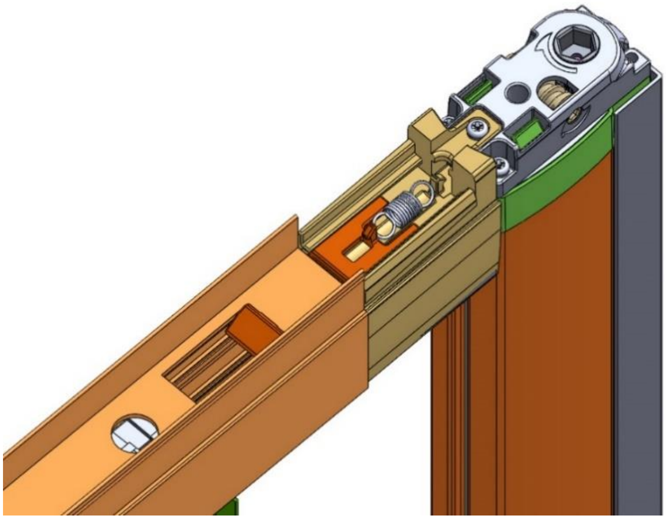


Figure 5.42 – Final assembly of upper guide connected to the head-box through the telescopic cap.

5.1.4 - Assembly and Installation phases

The assembly times for the semi-finished products of *Nano Sintesi* are reported in Table 5.2.

Table 5.2 – List of semi-finished assemblies and execution times for the new product.

#	Description	Time [s]
A	Spring group	180
B	Net tube	277
C	Elastic connector	60
D	Lower guide	90
E	Accessory box	75
F	Regulation block with threaded nut	20
G	Telescopic cap	48
H	Upper handlebar head	45
I	Magnet case	15
J	Abutment profile metal plate	17
Total		827

As for the *Sintesi* reference product, the final assembly phase is entirely carried out manually, following similar standard procedures. The necessary processes for punching the aluminium profiles are reported in Table 5.3.

Table 5.3 – Processing to be performed on the aluminium profiles of the new product and execution times.

#	Description	Time [s]
1	Drilling of the first abutment profile (3 steps)	27
2	Drilling of the second abutment profile (3 steps)	27
3	Drilling of the upper guide (2 steps)	18
4	Realization of the rectangular groove on the upper guide (1 step)	12
5	Realization of the circular hole for the regulation screw insertion (1 step)	12
Total		96

The workstation tools employed for the assembly operations are reported in the following list:

- screwdriver;
- scissors;
- special scissors with built-in jig;
- special clamps for the separation of upper chains;
- customized tool for facilitating the net tube positioning;
- flathead screwdriver;
- hexagonal insert.

The operations required for the final preparation of frame aluminium profiles are reported in Table 5.4, while Table 5.5 reports the final assembly phases for the rest of the product.

Table 5.4 – Steps for the final preparation of aluminium profiles of the new product and execution times.

#	Description	Time [s]
6	Insertion of three clips along the first abutment profile	60
7	Insertion of the metal plate along the second abutment profile and fastening	31
8	Insertion of the regulation screw in its hole and locking with the seeger ring	18
9	Screwing of the regulation block in position on the guide	25
10	Insertion of two brushes along the upper guide and cutting	24
Total		158

Table 5.5 – Final production phases of the new product.

#	Description	Time [s]
11	Gasket insertion in the headbox and cutting	30
12	Positioning of the tool for the correct net insertion	8
13	Net tube insertion	30
14	Removing of the tool for the correct net insertion	5
15	Cutting of the lower portion of the net gasket	8
16	Positioning of the bushing in the lower end of the tube	10
17	Positioning of the lower head-box head	15
18	Fastening of the lower head-box head with the first two screws	35
19	Insertion of the handlebar along the net gasket	25
20	Insertion of the upper spring group	16
21	Fastening of the upper head-box head with three screws	35
22	Spring tensioning	32
23	Closing of the safety lever	5
24	Insertion of the elastic connector on one end of the lower chain	5
25	Fastening of the elastic connector on the chain with the clip	7
26	Insertion of the lower chain with the elastic connector in the handlebar	19
27	Insertion of the magnetic block along the handlebar	15
28	Screwing of the magnet on the magnetic block	15
29	Insertion of the upper part of brush on the handlebar	10

30	Cutting of the brush to the correct length	5
31	Positioning of the upper handlebar head	7
32	Fastening of the upper handlebar head with two screws	18
33	Positioning of the lower handlebar head	11
34	Fastening of the lower handlebar head with two screws	25
35	Insertion of the two wires ends into their seats on the lower head-box head	21
36	Fastening of the lower head-box head with the remaining two screws	22
37	Insertion of the lower part of brush on the handlebar	11
38	Cutting of the brush to the correct length	5
39	Positioning of the downer handlebar support	12
40	Upper chain construction at the right length	50
41	Positioning of the final component of the upper chain	5
42	Insertion of the upper chain in position and snap fastening	18
43	Positioning of the telescopic cap assembly on the head-box upper head	13
44	Fastening of the telescopic cap on the head-box head with one screw	11
45	Product testing	150
46	Product packaging with stretch film	100
Total		809

It is possible to conclude that the total amount of time is of 1890 seconds, given by the sum of 827 s for the semi-finished assemblies preparation and 1063 s for the final operations. This value is 25% higher than that of *Sintesi* and it is mostly due to the double number of semi-finished parts. In fact, final assembly takes only 5,4 % more than the reference.

Final production costs are reported in Table 5.6, divided for different types of materials and labour costs.

Table 5.6 – Final estimation of new mosquito net model production costs.

Resume	
Aluminium [€/product]	€ 29,0
Plastics [€/product]	€ 21,9
Accessories [€/product]	€ 4,5
Assembly [€/product]	€ 9,45
TOTAL [€/product]	€ 64,85
TOT [€/m^2]	€ 22,33

As can be seen, the final production cost is 16.7% lower than that of *Sintesi*. In comparison to the initial estimation, the cost of accessories has been reduced, while the costs of aluminium and plastic components have increased. The increase in aluminium costs can be partially attributed to initial errors in estimating the final price of the bars. This is because the costs do not always decrease with a reduction in weight, as painting costs may rise for lighter items. The other two trends are explained by the fact that many parts initially thought to be accessories have been produced through plastic moulding.

The final installation phases of the product are divided into 14 steps, that are reported in a detailed manner in Table 7.2 in the Appendix A.

5.2 - Mosquito Net End-of-Life Alternative Applications

From the post-processing of the data obtained with the method described in Section 4.2.2 - above (Fiorineschi et al., 2018), a set of expanded keyword combinations (EKs) has been derived. The occurrence percentages for all the relative cooperative patent classifications (CPCs) descriptions associated with the outcome patents is also retrieved. To expedite the obtaining of the results in an industrial context, EKs that not only described the product effectively but also contained a subset of CPCs with higher recurrence rates compared to other options have been selected. This process was made in collaboration with the company.

Moreover, to provide an alternative instrument for restricting the CPCs to be considered, a cumulative graph with the occurrence percentage of the most frequent categories has also been found. The results are shown in Figure 5.43. For the CPC titles, the reader is referred to Table 7.3 in Appendix B.

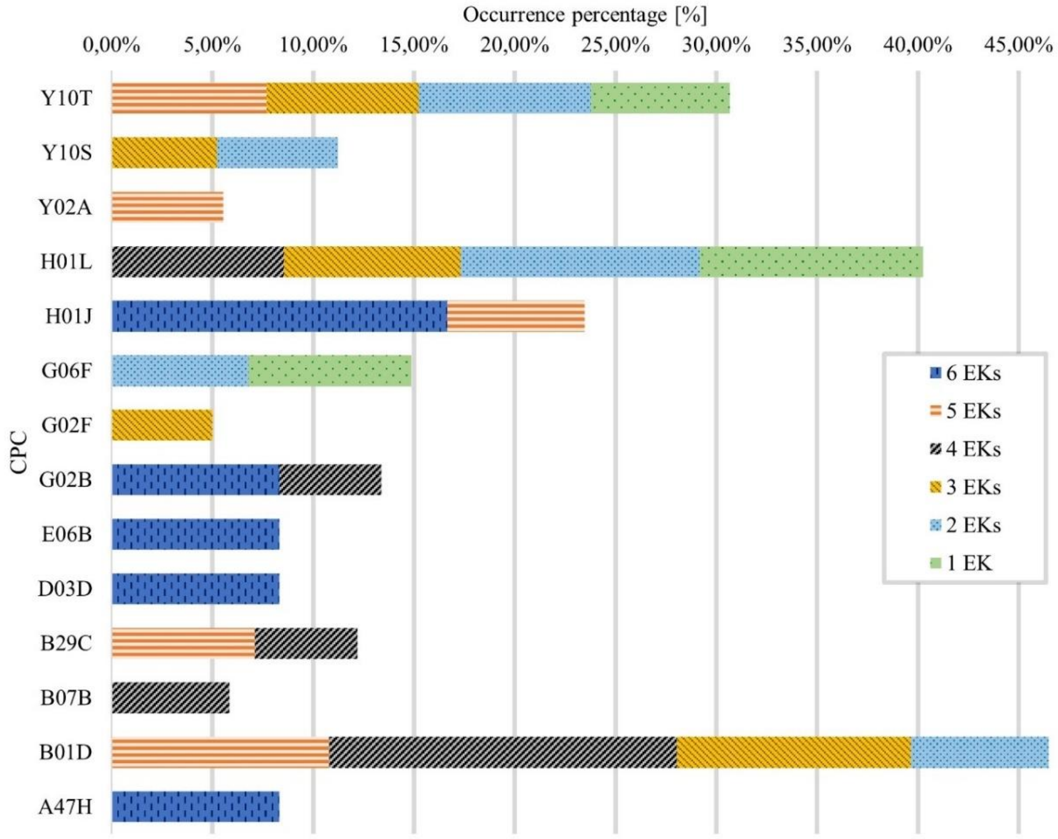


Figure 5.43 – Cumulative graph of the most recurring CPCs.

In particular, each colour represents the percentage of the CPCs occurrences out of the total occurrences of all CPCs, for each group of EK combinations characterized by the same number of terms (equal k). Therefore, in this case, six colours are present (n=6). To avoid penalizing combinations where there were few absolute patents produced, this has been done separately for each group of equal numerosity. It is worth to point out that among the most recurring CPCs, the category E06B, related to the mosquito nets, is also found as expected.

The description of each selected CPC has been used as an external stimulus in brainstorming sessions that have been executed both by the firm's staff alone and, on some occasions, with the participation of external groups of collaborators. Then, with those stimuli that did not generate any relevant idea, further patent searches are performed by introducing the specific CPC among the search queries, in addition to some of the most representative keywords, and analysing the resulting patents. Therefore, through the utilization of this empirical method outlined, additional ideas are generated. In particular, brainstorming sessions have been beneficial in four cases, while patent searches in 2 cases.

The constrained set of CPCs that has been successfully employed to derive relevant results in terms of possible new mesh applications is provided in Table 5.7. It derives from the graph of Figure 5.43, in combination with the firm's restriction on the EK combination options. The other CPCs that have been analysed without having obtained satisfactory results are not explicitly reported. Therefore, the list of Table 5.7 is neither exhaustive nor the only one possible. In fact, it represents the result obtained from the specific firm staff, according to all the hypotheses and restrictions made.

Table 5.7 – Final set of CPC classes and corresponding ideas generated of possible new applications.

CPC	Short description	Exploited EK combination	New possible application	Methodology
D06C	Finishing, dressing, tenting or stretching textile fabrics	Filter + move + darken + reduced thickness + reticulate + planar	Base for embroidery or carpets	Brainstorming session
D03D	Woven fabrics; methods of weaving; looms	Filter + move + darken + reduced thickness + reticulate + planar	Geogrids	Brainstorming session
B32B	Layered products, i.e., products built-up of strata of flat or non-flat, e.g. cellular or honeycomb, form	Reticulate + planar	Reinforcement elements for the plaster; Reinforcement elements for resin moulding	Brainstorming session
A01G	Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops or seaweed; forestry; watering	Darken + reduced thickness + reticulate + planar	Bird aviary; protective device for harvesting fruit trees	Patent searching
Y02A	Technologies for adaptation to climate change	Filter + move + darken + reduced thickness + planar	Possible reuse of individual threads of coated glass fibre to be mixed with sponge / cement in the construction of artificial corals	Patent searching
B01D	Separation	Filter + move + reduced thickness + reticulate + planar	Internal reinforcement element of bags and backpacks, suitcases	Brainstorming session

The EK combination reported in the third column of Table 5.7 is the one that has been exploited during the process of CPC identification. Nevertheless, it is worth to point out that a single CPC can be found in more than one combination. As an example, the exact number of EKs combinations in which the CPCs of Figure 5.43 can be observed is reported in Table 5.8 for the sake of completeness.

Table 5.8 – Total amount of EKs combinations in which the most recurring CPCs of Figure 6 can be observed.

CPC	Total amount of EK combinations involved
D06C	7
D03D	14
B32B	31
A01G	24
Y02A	40
B01D	22

Six new possible application fields have been identified. The results are summarized in the fourth column of Table 5.7, together with the specific methodology for which the stimulus has been exploited, in the fifth column. As can be seen, patent search has been beneficial in two cases. For these two cases, the keywords and the patent examined (Roth, 2002; 雷明龙 and 雷彩霞, 2020) are reported in Table 5.9.

Table 5.9 – Examined patents for the identification of alternative uses, starting from the retrieved CPCs.

CPC	New possible application	Keyword(s)	Patent examined
A01G	Bird aviary; protective device for harvesting fruit trees	Glass fibre	(雷明龙 and 雷彩霞, 2020)
Y02A	Possible reuse of individual threads of coated glass fibre to be mixed with sponge / cement in the construction of artificial corals	Glass fibre + PVC	(Roth, 2002)

Some of the alternative applications are more readily feasible than the others, in terms of different costs and additional processing that would be needed. Geogrids, found from the EK combination "filter + move + darken + reduced thickness + reticulate + planar", are routinely used in the civil sector for reinforcing the soil and must meet certain standards of mechanical properties. Thus, a test campaign would be needed to understand if such properties are fulfilled by the net. In addition, it is possible to imagine that net scraps, which are therefore available in small pieces, are more difficult to use in a sector such as this, where the areas to be covered with the material can be very large.

The latter rationale makes the use of nets for vegetable or fruit tree protection crucial. To obtain a large single element when needed, it would therefore be necessary to perform at least one additional processing of joining individual scrap pieces.

The application identified by category Y02A, concerning the use of individual net threads to be mixed with cement in the construction of artificial corals, also seems difficult to apply. On one side, it would be necessary to have available individual net threads as scraps, which it is not the case. In addition, the type of application seems to be quite niche, although one might think of extending the use to similar types of components, such as decorative elements in general.

On the contrary, the possible uses as a fixing element during plaster application or as a reinforcing element for resin moulding seem to be more promising. Depending on the waste used, however, additional processing may be required as well, to remove welded elements such as seals and/or plastic retaining buttons.

The other applications identified for the textile/manufacturing field, such as use as a reinforcing element for bags and backpacks or as a base for the creation of embroidery or carpets, also appear to be interesting and worthy of further investigation. In this regard, a fashion Maison located in Prato, Italy, has carried out a trial use of net scraps for the creation of a rigid corset, which is typically used in haute couture, formal wear, and lingerie. The bodice consists of seven garment pieces made of net (see Figure 5.44), joined together inserting a corset boning (see Figure 5.45) in every seam and a satin edge (see Figure 5.45) for refinement. Once the entire bodice is assembled, a silk tulle is positioned and sewn onto the centre part to create a ruffle (see Figure 5.45). An invisible zip is finally added at the centre back to create the bodice opening. The dress is completed with a skirt made of the same tulle previously employed, attached at the bottom part of the corset. The result is visible in Figure 5.46.

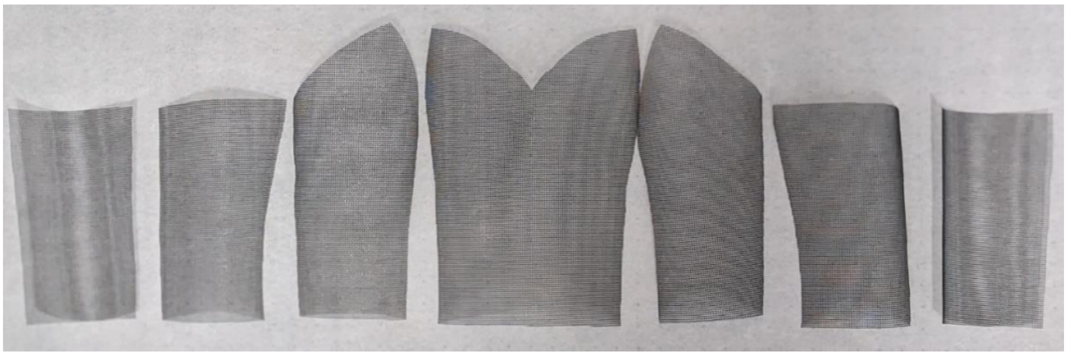


Figure 5.44 – Seven garment pieces obtained from the net scrap.

-1- -2- -3-

Figure 5.45 – Seven garment pieces obtained from the net scrap (1); Corset boning employed to strengthen the bodice shape (2); Bodice assembling phase. It is possible to observe the silk tulle positioning around the centre part of the corset (3).

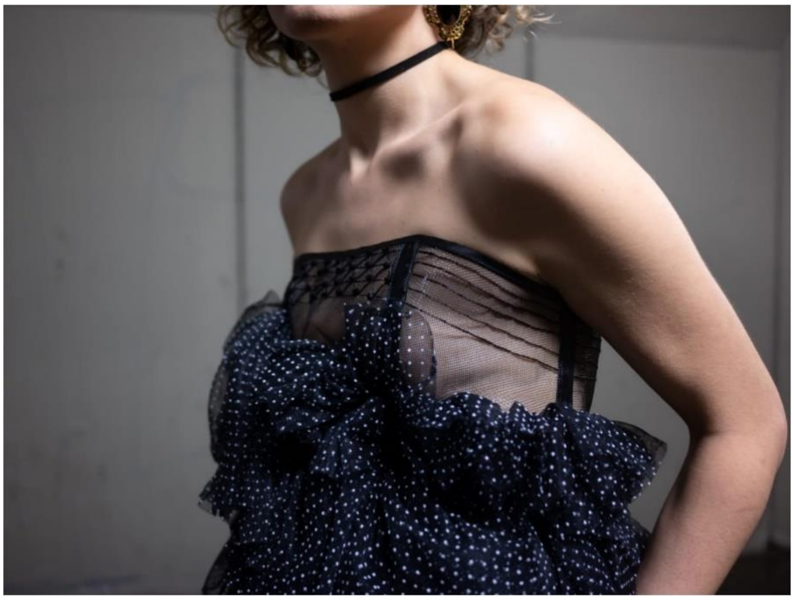


Figure 5.46 – Final representation of the completed bodice.

According to experts in the field, the material has proven to be excellent for this type of use, and possible alternative uses have also been suggested, such as a hardening structure in clothing and accessories or in the creation of hats, thanks to the material stiffness that allows it to maintain the desired shape once pressed on a specific mould. Additionally, due to its reticular structure, it is also considered an excellent base for creating embroidery, as previously supposed. The results of this study are also reported in (Melani et al., 2023a) and (Melani et al., 2023b).

5.3 - Effectiveness of Textual Stimuli in the Design Process

The ideas generated during the experimental test, which was conducted in the final part of the study with the two participating groups from the University of Florence, are detailed in this subsection. The setup of the experiment, along with the definitions of the metrics and hypotheses used to analyze the results, can be found in subsections 4.3.1 -4.3.2 -and 4.3.3 -. The distribution of stimuli to the two groups, in relation to the products, is presented in Table 5.10.

Table 5.10 – Allocation of products and stimuli to the two groups of participants.

	Group A	Group B
Product 1 – Barrel	With CPCs descriptions assigned	No stimuli
Product 2 – Mosquito Net	No stimuli	With CPCs descriptions assigned

The total numbers of ideas obtained in the four cases is reported in Table 5.11. After a screening, performed according to the rules defined in 4.3.1 -the non-compliant ideas were discarded, arriving to the final number of ideas per group visible in Table 5.12.

Table 5.11 – Total numbers of ideas generated by the two groups for product 1 and product 2.

	Product 1	Product 2
Group with CPCs	45	78
Group without CPCs	54	57

Table 5.12 – Total number of valid ideas generated by the two groups for product 1 and product 2.

	Product 1	Product 2
Group with CPCs	44	71
Group without CPCs	49	57

The following metrics need to be assessed: quantity, novelty (rarity), and variety. To address the hypotheses formulated in Section 4.3.2 -, the first nine hypotheses pertain to different aspects of quantity, while the tenth one concerns rarity values. No hypothesis has been formulated for variety.

5.3.1 - Ideas generated by participants

The t-student statistical test has been employed to evaluate the collected data, specifically focusing on the validation or rejection of the formulated H01a null hypothesis. Mean values, standard deviations and skewness are reported in Table 5.13 for product 1 and Table 5.14 for product 2. The p-value results are instead reported in Table 5.15.

Table 5.13 – Mean, standard deviation, and skewness values of the “ideas per participant” metric for product 1.

Metric	Test Group (A)			Control Group (B)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Quantity – ideas/participants	2.444	1.504	0.0615	2.579	1.895	0.630

Table 5.14 – Mean, standard deviation, and skewness values of the “ideas per participant” metric for product 2.

Metric	Test Group (B)			Control Group (A)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Quantity – ideas/participants	3.737	2.621	0.796	3.167	1.689	-0.128

Table 5.15 – Results of the t-student statistical tests performed for the "ideas per participant" metric of product 1 and product 2.

Metric	Hypothesis test	Type of test	p-value Product 1	p-value Product 2
Quantity – ideas/participants	H01a	t-student	0.812	0.435

As it can be observed, the p-values are far from the alpha threshold level commonly established at 0.05, indicating that there is no statistically significant difference between the number of ideas obtained by the participants with and without external stimuli.

5.3.2 - Functions results

Regarding the functions, the total quantity obtained by the two groups is provided in Table 5.16. As it can be observed, the overall trends are in opposition to each other, with a greater number of functions generated with stimuli in product 2 and without stimuli in product 1.

Table 5.16 – Total numbers of valid functions obtained by the two groups for product 1 and product 2.

	Product 1	Product 2
Test group	86	168
Control group	102	141

The functions distribution among participants is reported in Table 5.17 for product 1 and Table 5.18 for product 2.

Table 5.17 – Functions distribution obtained for product 1.

Function	Test Group (A)	Control Group (B)
Support*	29	34
Contain*	16	21
Beautify	16	26
Flavor*	3	4
Season*	3	1
Dry	1	0
Smoke	3	2
Refrigerate	2	1
Insulate	5	7
Cook	2	0
Entertain	1	2
Treat (physically)	3	1
Amplify	1	1
Generate	0	1
Degrade	1	0
Separate	0	1

Table 5.18 – Functions distribution obtained for product 2.

Function	Test Group (B)	Control Group (A)
Protect*	28	16
Beautify	7	8
Block*	29	34
Collect	9	2
Support	32	22
Darken	5	3
Filter*	13	20
Separate*	11	18
Dampen	1	1
Contain	25	14
Remove	3	3
Isolate	3	0
Cool	1	0
Mix	1	0

As can be observed, the total amount of retrieved functions follows an opposite trend for the two products, with a greater number of functions obtained in the control group for product 1 and in the test group for product 2. However, trivial functions related to the original application fields of fly screens and wine barrels can be retrieved in both groups. These come from previous decompositions of the starting products, performed both in the previous steps of the study (for the fly screen) and during the preparation of the experiment (for the wine barrel). In particular, they are remarked with a "*" symbol in Table 5.17 and Table 5.18, and they will be excluded for analysing H01c hypothesis.

Based on this criterion, the functions can be further divided and analysed to determine whether textual stimuli can promote the discovery of new functions that were not present in the product's original intended use. The aggregate data in Table 5.19 are therefore obtained.

Table 5.19 – Total number of functions obtained from the two work groups for product 1 and product 2, categorized into new functions and trivial functions, the latter being attributable to the application sector from which the two products originate.

	Product 1		Product 2	
	Test Group (A)	Control Group (B)	Test Group (B)	Control Group (A)
Trivial Functions	35	60	81	88
New Functions	51	42	87	53

Despite the opposite trends observed in Table 5.16, the number of new functions turns out to be greater in the test group compared to the control group for both products. The statistical significance of the results has been analysed in these cases with Chi-squared tests, as they aim to examine the frequencies of function occurrences in the two groups. Table 5.20 reports the results.

Table 5.20 – Results of the Chi-squared statistical tests performed to verify H01b, H01c and H01d hypotheses. The p-value of H01d for product 1 has been corrected according to Yates formulation, because of the limited numerosity of the sample.

Metric	Hypothesis test	Type of test	p-value Product 1	p-value Product 2
Quantity – functions	H01b	Chi-squared	0.715	0.105
Quantity – less obvious functions	H01c	Chi-squared	0,432	0,188
Quantity – cumulative functions	H01d	Chi-squared	1.000	0.013

While it is possible to observe that the H01b and H01c hypotheses cannot be rejected for both cases, the occurrence percentages of aggregate new functions with respect to trivial ones show contrasting results in the two products. Indeed, it is possible to reject the hypothesis H01d only in product 2.

Regarding the metrics related to the distributions of functions generated per idea and functions per participant, the results in terms of mean, standard deviation, and skewness are reported in Table 5.21 and Table 5.22, respectively for Product 1 and Product 2. The p-value results obtained with the t-student test are instead reported in Table 5.23.

Table 5.21 – Mean, standard deviation, and skewness values of the "functions/idea" and "functions/participant" metrics for product 1.

Metric	Test Group (A)			Control Group (B)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Quantity – functions/idea	1.955	0.888	0.509	2.082	0.954	0.282
Quantity – functions/participant	4.778	3.078	0.249	5.368	3.451	0.775

Table 5.22 – Mean, standard deviation, and skewness values of the “functions/idea” and “functions/participant” metrics for product 2.

Metric	Test Group (B)			Control Group (A)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Quantity – functions/idea	2.366	0.866	0.291	2.474	0.734	-0.467
Quantity – functions/participant	8.842	5.699	0.531	7.833	3.746	-0.420

Table 5.23 – Results of the t-student statistical tests performed to verify H01e and H01f hypotheses for product 1 and product 2.

Metric	Hypothesis test	Type of test	p-value Product 1	p-value Product 2
Quantity – functions/idea	H01e	t-student	0.508	0.449
Quantity – functions/participant	H01f	t-student	0.586	0.527

The preliminary findings indicate a general reduction in performance metrics associated with the employment of CPC descriptions for these two parameters. Conversely, a marginal increase in the quantity of functions generated per participant is observed for Product 2. In terms of statistical significance, it is, however, not possible to generalize the derived outcomes, given that the obtained p-values are well above the threshold level. Consequently, the null hypotheses cannot be rejected.

5.3.3 - Application fields results

With regards to the application fields, the total quantities obtained are reported in Table 5.24. It is possible to observe an opposite trend in the two products, similarly to what has already been highlighted for the functions in Table 5.16.

Table 5.24 – Total number of valid application fields obtained by the two groups for product 1 and product 2, in terms of CPCs.

	Product 1	Product 2
Test group	44	71
Control group	49	57

The complete results are reported in Table 5.25 for the wine barrel and Table 5.26 for the fly screen.

Table 5.25 – CPCs distribution obtained for product 1.

CPC	Test Group (A)	Control Group (B)
A47B	7	10
A47F	2	1
A47C	3	2
A47G	5	5
A47J	1	1
A47K	1	0
A63G	1	0
A99Z	1	0
F21V	1	2
B65H	1	0
C11B	2	3

A24B	3	0
A23L	4	3
A01G	3	7
B65D	2	3
A61H	3	1
E04B	1	1
E04F	1	0
C11D	1	0
G10K	1	0
A01K	0	2
G10D	0	1
E04H	0	1
B63B	0	1
A63J	0	1
C12J	0	1
F24S	0	1
F03B	0	1
B32K	0	1

Table 5.26 – CPCs distribution obtained for product 2.

CPC	Test Group (B)	Control Group (A)
A41B	1	0
A42B	6	3
A41D	6	3
A45C	1	1
A01G	12	3
A01D	6	1
A01K	4	6
F21V	1	0
B29D	4	1
E04F	2	1
A45B	1	1
B01D	2	3
E03C	1	1
D07B	1	1
A63B	2	3
E01F	2	2
F01M	1	3
G10H	1	1
B33Y	1	1
B60H	1	4
B65D	3	3
B08B	3	1
A23L	1	0
F24S	1	0
F25D	1	0
A47J	4	2
B01F	1	0

H01B	1	0
D05C	0	1
A43B	0	1
F21S	0	1
E03F	0	1
B09B	0	2
A22C	0	1
A47C	0	1
A01M	0	1
F41H	0	1
A44C	0	1
A47G	0	1

It is observable that, as one might expect, some of the Cooperative Patent Classification (CPC) codes retrieved in the test group were also present among those provided as stimuli. For what concerns category A01G for fly screens and all three categories (A24B, A23L and A61H) for the barrel. The cumulative results in Table 5.27 are grouped based on whether the CPCs were included in the stimuli or not.

Table 5.27 – Total number of CPCs obtained from the two work groups for product 1 and product 2, categorized into CPCs coming from additional stimuli and others.

	Product 1		Product 2	
	Test Group (A)	Control Group (B)	Test Group (B)	Control Group (A)
CPCs from stimuli	10	4	12	3
Other CPCs	34	45	59	54

As one might expect, the quantity of CPCs obtained that belong to those provided as stimuli is greater in the test groups compared to the control groups for both products.

The statistical tests performed to reject hypotheses H01g and H01h are, respectively, the chi-squared test and the Fisher exact test. The latter was chosen due to the small sample size, with the number of occurrences in each cell being less than 5. The results of the p-values are reported in Table 5.28.

Table 5.28 – Results of the Chi-squared and Fisher statistical tests performed to verify H01g and H01h hypotheses.

Metric	Hypothesis test	Type of test	p-value Product 1	p-value Product 2
Quantity – application fields	H01g	Chi-squared	0.663	0.549
Quantity – cumulative application fields	H01h	Fisher	0.0795	0.0787

It can be concluded that the null hypotheses cannot be rejected. Therefore, the occurrence percentages of each application field are not influenced by the given textual stimuli, and the use of these does not focus the research on applications in the patent areas from which the definitions originate.

For what concerns the metric of CPCs identified per participant, the values describing the obtained results in terms of mean, standard deviation, and skewness are presented in Table 5.29 and Table 5.30, respectively for Product 1 and Product 2. The p-value results from the t-student test are instead reported in Table 5.31.

Table 5.29 – Mean, standard deviation, and skewness values of the “application fields/participant” metric for product 1.

Metric	Test Group (A)			Control Group (B)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Quantity – application fields/participant	2.222	1.478	0.186	2.368	1.640	0.683

Table 5.30 – Mean, standard deviation, and skewness values of the “application fields/participant” metric for product 2.

Metric	Test Group (B)			Control Group (A)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Quantity – application fields/participant	3.579	2.364	0.623	3.056	1.589	-0.102

Table 5.31 – Results of the t-student statistical tests performed to verify H01i hypothesis for product 1 and product 2.

Metric	Hypothesis test	Type of test	p-value Product 1	p-value Product 2
Quantity – application fields/participant	H01i	t-student	0.777	0.433

As it is possible to note, opposite trends between the two products can be observed in the mean values. However, the results are not generalizable, based on the outcomes of the statistical tests. Therefore, the null hypothesis H01i cannot be rejected in this case either.

5.3.4 - Originality results

The originality metric was calculated using the previously known total and distinct numbers of valid ideas. Consequently, the frequency of occurrence for each idea is the primary variable of interest to study this metric. Mean values, standard deviations, and measures of skewness for the two groups are presented in Table 5.32 for product 1 and Table 5.33 for product 2.

Table 5.32 – Mean, standard deviation, and skewness values of the originality metric for product 1.

Metric	Test Group (A)			Control Group (B)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Originality	1.375	0.660	2.290	1.885	1.728	2.510

Table 5.33 – Mean, standard deviation, and skewness values of the originality metric for product 2.

Metric	Test Group (B)			Control Group (A)		
	Mean	S.D.	Skewness	Mean	S.D.	Skewness
Originality	1.972	1.594	2.198	1.677	0.976	1.131

Within the scope of this analysis, it is observed that elevated mean values signify a higher incidence of recurring ideas. This recurrence suggests a diminished level of originality, as it indicates a tendency towards the repetition of similar concepts rather than the introduction of unique ones.

The outcomes of the statistical analyses conducted for the validation of the null hypothesis is reported in Table 5.34. Notably, the skewness value exceeding 2 necessitated an alternative approach to the analysis; hence, the Mann-Whitney test was utilized instead of the t-student test for both products.

Table 5.34 – Results of the Mann-Whitney statistical test performed to verify H01f hypothesis.

Metric	Hypothesis test	Type of test	p-value Product 1	p-value Product 2
Originality	H01j	Mann-Whitney	0.521	0.670

These p-values are well above the conventional levels of statistical significance, which indicates that there is no difference between employing or not such textual stimuli for generating more original ideas. Therefore, the null hypothesis H01j cannot be rejected.

5.3.5 - Variety

As mentioned in Section 4.3.2 - above, the assessment of variety was conducted collectively, rather than on an individual participant basis. This was determined by calculating the quantity of unique ideas generated by each entire group. The results, expressed as percentages of the total number of ideas (as shown in Table 5.12), are reported in Table 5.35.

Table 5.35 – Variety results for the two groups and the two products.

	Group with CPCs descriptions	Group without external stimuli
Product 1 – Barrel	72,7 %	53,1 %
Product 2 – Mosquito Net	50,7 %	59,6 %

Notably, the variety index is higher when CPC descriptions are used compared to when they are not, only in the case of the barrel product. In the mosquito-net case, the trend is the opposite.

6 - Discussions

The development of the new mosquito net model, subject of the first goal of the study, began with the initial definition of objectives and design constraints. As seen in Table 2.1, many elements on that list are characterized by rather general guidelines, which were taken into consideration during the development, especially when making specific decisions regarding the constructive solutions to adopt. Among the constraints, those that had the greatest influence on the entire development process were the need to keep the overall product dimensions within 30 mm, to use a flat type of net, and to maintain high standards of reliability. These in fact led to the search for innovative solutions to be able to wrap the mesh in a confined space, without incurring malfunctions or considerable losses in the smoothness of the product during its service life.

In the market, other products exist with similar or even smaller dimensions, such as pleated mosquito nets or the Bettio Picoscenica model. However, the former, besides being expensive, are characterized by visually impactful nets that are often not well-perceived by customers. Moreover, their reliability is poor due to the presence of visible wires, which often leads to blockages caused by dirt or accidental impacts. Instead, the latter model is characterized by complex assembly and the need for frequent maintenance, including lubricating moving parts and tensioning wires, which are also present. The value profile of the *Nano Sintesi* mosquito net is, therefore, entirely innovative in the market, meeting the needs of those with limited installation space – a common condition – while maintaining ease of assembly and high visibility through the net.

To ensure a high level of reliability, it was chosen to use a torsional spring for net tensioning, as is commonly done in the majority of products available in the market. Therefore, this is a widely tested solution that decreases the risk of malfunctions. Due to the reduced thickness of the product and the space occupied by the net tube, however, it was not possible to insert this spring inside the winding tube, as is typically done. To overcome this issue while keeping the assembly easy to install in its final position, it was decided to house the spring inside the headbox, but externally to the net tube, parallel to it. The transmission of the elastic energy of the spring to the net tube is therefore guaranteed by a three-gear wheel transmission system located within the head-box head. In this way, the installer will not perceive any additional assembly difficulties for this aspect, as the entire mechanism is confined within the aluminium profile of the head-box.

The choice to adopt gear wheels for transmitting torque is also based on the need to create a system with a high degree of reliability, ensuring constant coupling between the elements even in the case of reduced dimensions of the various components, as in this case. In particular, the use of three elements, including an idle wheel, was necessary to meet the maximum space requirements while maintaining the needed centre distance between the net tube and the spring. Additionally, this choice was also guided by cost considerations, as it is possible to manufacture the components directly through plastic injection moulding, a technology that allows for very low unit production costs after an initial investment in equipment. Specifically, the cost of each gear is €0,15/piece. If an alternative type of coupling, such as belts or chains, had been used, they would not have been readily available in the market (due to their small size), thus increasing costs. Furthermore, additional studies would have been required to assess the suitability of these solutions in terms of reliability.

During the initial phases of prototype testing, particularly in the life tests, the gearwheels occasionally experienced breakages. These primarily occurred at the base of the teeth and at the base of the connecting pins that engage with the head-box casings. Indeed, excessive heat and inconsistent lubrication of the gears led to the components weakening excessively, resulting in part failure.

Based on calculations made during the design phase, assuming a constant movement speed of the handlebar at $v = 1,15$ m/s, the rotational speed of the net tube and – consequently – the first gear with a smaller diameter, falls within a range of 920 to 2200 rpm. This variation is due to the changing of the winding diameter, which ranges from approximately 24 mm to 10 mm as the net is moved. Therefore, the higher speed will be reached when the handlebar is in the closed position, especially for products of maximum width in which the net is almost completely unwound. At the same time, the torsional spring employed, with the assigned level of preload, considered sufficient for tensioning the net during the product's use, exerts a variable torque ranging from 0,18 to 0,24 N·m. This torque is higher when the handlebar in the closed position, and lower when the mosquito net is open (equal to the preload provided during assembly). Therefore, the power involved ranges from an upper limit of 56 W to a lower limit of 17 W. On the other hand, an analysis of the power to be impressed on the handlebar for its movement, obtained by means of a simple laboratory test, yields an average value of about 34 W, with a handling force of about 29 N.

By conducting a verification under maximum stress conditions on the smaller-diameter gearwheel coaxial to the net tube, which is subjected to greater stress, using the Lewis formula in reverse, it is found that with the use of the Alumide prototyping material, the tooth profile can withstand the applied force with a very low safety factor, equal to 1,06. The calculation performed is the one of (2) and the numeric values are reported in Table 6.1.

$$S.F. = \frac{\sigma_R \, m \, b \, y \, \eta_d}{F_{t\,amm}} \tag{2}$$

Table 6.1 – List of data employed for the safety factor calculation.

Quantity	Value
Module [mm]	1
Pressure angle [deg]	20
Axial length [mm]	5,6
Number of teeth [-]	9
Reference diameter [mm]	9
Shape Factor (y) [-]	0,161
Peripherical velocity [m/s]	1,04
Velocity coefficient (η_d) [-]	0,852
Failure stress [N/mm2]	74
Admissible force [N]	53,6

Considering the uncertainty of the mechanical properties data of the material, the variability of its characteristics for the individual printed part and the temperature increase due to the frictional force of the gears in their housings, it is possible to justify the failures that initially occurred during the life tests. In order to eliminate this problem, the housings have been optimised so as to minimise sliding surfaces and the resistant section of the wheel centring pins has been increased as much as possible.

With regard to increasing safety during assembly and making it easier for the installer to adjust the tension of the net, the solution found involving a double external spring loading system ensures that the operation can be carried out once the box is fully assembled. Hence, the operator only has to press down on the loading wheel to disengage it from the worm gear and then turn it. The number of preload rotations has been chosen constant regardless of the size of the product and is equal to 35. Next, the safety lever on the plastic head must be closed. This ensures that the loading gear cannot accidentally fall down as a result of an impact, causing the spring to lose its charge. This became necessary as a result of malfunctions related to the sudden loss of spring tension that occurred in the latter stages of the design.

On the other hand, once the product is installed, the adjustment of the spring load is done by means of the worm screw, which can be operated from both sides of the product. For aesthetic reasons, the access hole has been positioned below the vertical flap of the fastening profile. Therefore, in order to be able to load the spring, it is necessary to unhook the head-box from the side profile, tilting it slightly until the hole is visible. This was considered a good compromise solution between aesthetic and functional requirements.

The choice of using two retention wires to connect the lower carriage chain is a solution that has also been widely used by other competitors, and several patents had already been filed to this regard. However, it was decided to use the same concept in this project as well, since it has proven to be the only reliable technology that guaranteed the correct sliding of the handle and at the same time the necessary transverse rigidity to the assembly. The need to achieve this last characteristic is dictated by the fact that a further version of this product without the use of a ground rail is expected to be released in the future. The handlebar must therefore not be excessively labile in this direction.

Despite the various already patented solutions, the developed chain still manages to distinguish itself thanks to the fact that it has two filaments with only some of the retaining elements attached to the carriage elements, thus allowing a greater radius of curvature of the component and less concentrated stresses. In addition, this requires less stringent machining tolerances for the relative positioning of the individual spheres side by side, as the clamping distance is composed of three contiguous portions of wire. Finally, the specific conformation of the cams on which two adjacent chains roll allows their controlled closing and distancing, so that preferential positions are established for the carriage, preventing it from remaining in intermediate bending positions.

In order to maximise the transversal rigidity of the chain, it was decided to house the filaments on the outer side walls of the carriage, in distal positions with respect to the neutral axis. This also facilitates assembly operations, which are carried out using a specially designed automatic machine.

As already seen in Section 5.1.3 -above, the handlebar moves between the extreme positions thanks to two rolling bearings constrained within a track in the upper telescopic guide. Therefore, the aluminium profile is, under nominal conditions, entirely suspended. This solution was chosen in accordance with the company staff and based on what appeared to be a prevailing trend on the market. Additionally, in the absence of a bottom guide, this concept was considered the most promising one for providing adequate constraint for the handlebar. However, in hindsight, this choice is thought to have caused a design fixation problem, which hindered the investigation of alternative options, such as a mixed guidance or a purely lower guidance, in case of the presence of a bottom guide.

The height adjustment required for the top rail is achieved by a few simple steps performed by the installer. In fact, during the alignment of the upper guide to the fastening profile, no centring of components is necessary for the engagement, but it is sufficient to bring the two profiles to a stop and turn the adjustment insert with a standard screwdriver. Compared to other commercially available and patented solutions, which require the centring of holes between the two guides and the action by means of two different adjusting elements, this alternative proves to be advantageous.

Regarding the production assembly process, the total time has increased by 25,6% compared to the reference product, *Sintesi*. However, this increase is mainly related to the preparation of semi-finished components, which are in greater numbers. In particular, for this category, the time increment is 66.4%, while for the final production, it is only 5.5%. The latter value can be considered acceptable compared to the initial objectives of keeping production times unchanged with respect to *Sintesi*. Indeed, the additional semi-finished components production can be managed with greater flexibility, having them assembled by the staff during periods of lower workload or delegating their production to external companies.

On the other hand, the final installation phase involves a total of 14 steps, whereas for *Sintesi*, this number is 12. The total number of common operations to both processes, as shown in Table 7.1 and Table 7.2 in Appendix A, is 8, while the new operations amount to 6. Of these, 4 are related to the presence of the double upper telescopic guide that needs to be positioned and adjusted in height, while the remaining 2 concern the adjustment of the metal plate on the abutment profile and the possible modification of the spring load. The required time increases compared to the reference product. However, it has been considered globally acceptable by experienced installers when compared to other models of this size range, which require much more complex operations.

Finally, the overall production cost is 22,33 € per square meter, which is 16,7% lower than *Sintesi.* In fact, although assembly times are higher (+25,6 %), there is an overall cost reduction due to the miniaturization of the components. The aluminium weight – and cost – is indeed reduced by 33,2 %. In contrast, the cost of plastics and accessories shows only a slight reduction of -1,8%. This is because, unlike *Sintesi*, there is a higher number of these components, despite their small size.

Analysing the project objectives and constraints established during the product's early design stages, it is possible to assess if they have been fulfilled by the final product. Table 6.2 summarizes the outcomes in these terms, for each objective/constraint.

Table 6.2 – Product objectives and constraints list, with the indication if they have been met or not at the end of the detailed design.

Objective/ Constraint	Description	Outcome
Constraint	The mosquito net must be equipped with an upper and lower chain, similarly to the *Sintesi* product	The constraint has been fulfilled.
Constraint	The product must be of lateral type	The constraint has been fulfilled.
Constraint	The product must be installed in an in-light frame	The constraint has been fulfilled.
Constraint	The overall footprint must not exceed 30 mm	The constraint has been fulfilled.
Constraint	The maximum feasible dimension must be: 140 x 280 cm	The constraint has been fulfilled.
Constraint	The product functioning must be guaranteed for 10 years of use	The constraint has been fulfilled.
Constraint	The maximum height of the lower guide must be of 5 mm	The constraint has been fulfilled.
Constraint	The maximum manageable out-of-square values on the headbox must be of 8 mm (+/- 4 mm up or down)	The constraint has been fulfilled.
Constraint	The maximum manageable out-of-square values on the abutment profile must be of 4 mm (+/- 2 mm up or down)	The constraint has been fulfilled.
Constraint	The stiffness of the lower chain must be such that if a force of 1 kg is applied at the center of 1 meter of chain (chain hinged at the ends), the deformation of the chain must not exceed 3.5 cm	The constraint has been fulfilled.
Constraint	The net must exit centrally with respect to the headbox	The constraint has been fulfilled.
Constraint	No retention elements are required inside the lower chain	The constraint has been fulfilled.
Objective	Maintain a simple phase of installation	The objective has been fulfilled. Despite two additional steps needed for the installation, the result has been considered globally acceptable by experienced installers.
Objective	Increase the aesthetic appeal of the aluminium parts	The objective has been fulfilled, according to first customers interviews.
Objective	Maintain the reliability of the product	The objective has been fulfilled.
Objective	Increase simplicity during maintenance	The objective has been fulfilled.
Objective	Increase safety for the operator during the assembly phase	The objective has been fulfilled.
Objective	Maintain assembly times unchanged	This objective has not been fulfilled, due to the presence of a higher amount of semi-finished assemblies. However, the result has been considered acceptable.
Objective	The out-of-square recovery capabilities must be maintained	The objective has been fulfilled.
Objective	Minimize assembly and material costs	The objective has been fulfilled.

As per the company's request, raised during the product development phase, the study thus focused on identifying possible strategies for mitigating the environmental impacts associated with the production of this new mosquito net model. Due to the project's constraints related to product costs, which had to be kept within a certain limit, and the need to integrate production into the company's established processes, reusing the nets was evaluated as the primary action to reduce one of the main sources of impact. Indeed, this part is completely disposed of in landfills and can hardly be recycled today due to its bi-component structure.

This offered the opportunity to adopt a methodological approach to the specific design problem, thereby identifying in a systematic way new possible application fields for the exhausted nets. After a literature search, the method (Fiorineschi et al., 2018) deemed most suitable for the specific case under examination was identified, both because it was more immediately implementable and because it did not require the use of specific ad-hoc software. Therefore, the starting product has been decomposed in its functions, according to the S-A-O definition scheme and, after a screening, the set of EKs has been defined.

The implementation of the method provided six main alternative areas of use. These were obtained from five different combinations of EKs, among those considered by the company staff to be most representative of the net product. The CPCs descriptions exploited as stimuli belonged two to the 'textiles; paper' sphere, two to 'performing operations; transporting', one to 'human necessities' and one to 'technologies for mitigation or adaptation against climate change'. Three of these, in particular categories D03D, Y02A and B01D, are also found among the most recurring of all the combinations of EKs searched.

Although various stimuli were identified for possible alternative mosquito net uses, even promising ones, it is important to note that the results obtained largely rely on the assumptions made during the method's implementation. The initial function identification phase was carried out as objectively as possible, by utilizing supporting tools such as Pahl and Beitz's checklist, in combination with Altshuler's function definition scheme. To obtain a more exhaustive description of the product in terms of properties and functions, other checklists that can be found in the literature (Bacciotti et al., 2016) can also be adopted. However, in order to speed up the process, the list of functions and properties was subsequently narrowed down to only the most representative ones. At this stage, the firm staff, who possesses a deep understanding of the product and its strengths and weaknesses, were chosen as the decision group. It is noteworthy that the selection of a different set of keywords would result in a different set of CPCs, and hence, different stimuli. Therefore, it is probable that some suggestions may be missed during this screening process, potentially resulting in the exclusion of some valuable opportunities. Moreover, a significant number of CPCs obtained as output were discarded influencing again the results, due to two other assumptions: the selection of a more representative set of EK combinations and a threshold value in terms of recurrence rates, below which the CPCs were not considered. Thus, the CPCs frequency in each patent search strongly influences the output.

The need for these assumptions in the method's application arises from the challenges of managing a massive amount of information produced while performing a thorough search campaign in the patent database using all the starting keywords. According to (1), the total number of queries needed to perform the search with all the functions in Table 4.6 would have been over 133,000 times greater than that of the functions in Table 4.7. This difficulty primarily results from the method's implementation. Conducting such an extensive analysis using the available tools would require a significant amount of time with only minimal benefits to the results. In fact, the freely available patent search engine does not permit the automatic extrapolation of results in terms of CPCs, thus making it necessary to manually copy CPC occurrence values onto a worksheet and divide them correctly into cells for each search. This limitation proved to be a significant hurdle during the implementation phase. The use of an alternative paid search engine would most likely have simplified this task, allowing both the search with the various EK combinations and the extraction of the desired data to be automated.

The stimuli obtained were employed in the ideation process during brainstorming sessions and in additional patent searches, bringing, respectively, to four and two new ideas. The feasibility analysis of use in textiles was first carried out, as it was considered the most promising one, while the other sectors require further investigation. Although the application of the method shown in this work does not in itself differ in the steps performed compared to those already present in the original literature contribution, the implementation in a real industrial context was never previously addressed. Therefore, the outcomes obtained in this specific case provide new indications on the possible effectiveness of this method.

The subsequent and final part of the work aimed to assess the capability of CPC descriptions to enhance idea generation outcomes in terms of quantity, originality, and variety. Therefore, it does not seek to directly demonstrate the effectiveness of the method (Fiorineschi et al., 2018) employed but rather the efficacy of the stimulatory means utilized by the methodology itself, at a first preliminary stage.

As observed in chapter 5.3 -the experimental activity conducted to this end, has revealed contrasting outcomes for the various parameters evaluated when comparing the two products under investigation. Specifically, with respect to the mosquito net, the aggregate trend data of the metrics assessed suggest that the test group outperformed the control group. This was evident in almost all the metrics under investigation, translating into an enhanced ability to generate a higher quantity of ideas characterized by broader diversity in functionality, application fields, and innovation. In contrast, for the wine barrel case, the textual hints provided did not yield any notable advantageous effects. All the parameters involved in the study are here analysed singularly.

For what concerns the average number of ideas generated per participant, the mosquito net product has recorded a value of 3.737 in the test group and 3.167 in the control group, indicating a potential, although modest, influence of the textual stimuli on the volume of idea generation. Conversely, for the wine barrel, the test and control group averages were 2.444 and 2.579, respectively, suggesting no benefit from the use of such textual descriptions.

For the metric related to the functions generation, the test group associated with Product 2 exhibited a more extensive array of functions and a greater cumulative count of novel functions, suggesting that the textual stimuli may have fostered a more expansive exploration of functional possibilities among participants. Conversely, the total number of functions formulated by the test group for Product 1 was lower than that of the control group (86 versus 102). Nevertheless, it is noteworthy that also in this case there was a relative increase in the proportion of non-obvious functions within the group exposed to the stimuli, as opposed to functions that were directly tied to the original domain of application, suggesting a potentially beneficial influence of the textual descriptions even in this context.

In addition, the characteristics of the ideas obtained in terms of the amount of functions that can be associated with each of them shows in both products a slight deterioration in average performance when the additional textual stimuli are administered. This could be a symptom of more detailed and more application-specific ideas being favoured using such descriptions.

The analysis of potential application sectors once again suggests, as evidenced by the larger number of application fields identified by the test group for Product 2 (71 versus 57), that CPC descriptions may facilitate this objective. However, the results for Product 1 do not exhibit a similar trend. From the standpoint of application sectors that are different from or similar to the descriptive stimuli, it is observed instead that these stimuli have influenced the number of ideas associated with the given CPCs for both products, as could reasonably be expected.

With regard instead to the performance of the individual participants in terms of the functions and application fields generated by each of them, again opposite trends are noted in the two products under test. In fact, for the fly screen, there is a higher average value for both parameters in the test group, while the opposite is true for the wine barrel. It is also true that these parameters also depend closely on the absolute quantity of ideas generated, which in fact shows the same variations between the two products.

Despite these observed trends, statistical analyses revealed a more uniform reality. While the generation of functions and application fields matched expectations from an indicative point of view only for one of the two products, statistical tests have shown that in no case these differences result to be significant, with p-values well above the threshold of 0.05. The sole exception lies in the cumulative number of aggregate new functions, which seems to be notably influenced by the CPC's textual stimuli, but only for product 2. This was manifested in the significantly greater number of novel functions produced by the test group, leading to the rejection of the null hypothesis in this regard (with a p-value of 0.013). Considering these observations, the preliminary investigation does not provide a clear answer to the relative sub-question of the study, given that the statistical outcomes differ between the two products.

For what concerns the hypothesis that textual definitions from patent classifications facilitate the discovery of new application sectors, the p-values obtained do not support this outcome. Indeed, the test groups did not demonstrate a statistically relevant ability to identify a wider range of application fields for both products compared to the control groups. Therefore, the answer to the second sub-question is negative.

In examining whether originality of ideas is enhances by the use of CPCs descriptions, the study provides a negative response. Specifically, the test group of product 2 also exhibited a slight rise in the frequency of repeating ideas, indicating a fixation problem caused by the stimuli. However, this observation lacks statistical significance, as indicated by p-values of 0.521 and 0.670 respectively for product 1 and 2. This result implies that any differences in idea originality between the test and control groups could be attributed to random variation, and the answer to the corresponding research question cannot be positive.

With regard to the variety values, intended as the percentage of distinct ideas over the total number of retrieved ideas, once again, a difference in behaviour for the two products is observed. In the first product, a higher variety is obtained in the group with stimuli, while in the second product, there is greater variety in the group without stimuli.

It is worth to note that the results may have been influenced by several factors. First and foremost, the specific descriptions used: for the purposes of the study, it was indeed chosen to employ descriptions corresponding to the 4-digit CPCs. This decision was intentionally made to strike a balance between offering hints that were not overly abstract and vague, and avoiding those that were excessively detailed and descriptive of the technologies. However, this choice certainly influenced the process of generating ideas, thereby affecting the type of outcomes produced.

Furthermore, the intentional restriction to just three descriptions has been taken to prevent overwhelming participants, although this decision may have consequences for the range and variety of ideas generated as well. Moreover, the choice of mosquito nets and wine barrels as the subjects of analyses was significant, suggesting that the findings might be product specific.

Another important aspect is related to the characteristics of the participants. For the purposes of the study, they were divided randomly into the two groups, considering that they had the same type of background and that any more talented individuals were equally distributed. In accordance with the university's ethical regulations, participants were not asked for any personal information. Therefore, these aspects could not be checked. However, it was considered that, as they all belonged to the same university course and were all around the same age, they could be regarded as a homogeneous group. A more critical characteristic is that of numerosity. In order to carry out statistical analyses, the larger the sample available, the more reliable the results will be. Compared to other studies in the literature (Borgianni et al., 2020), in this case the sample available was smaller, with a total number of participants between the two groups of 37.

Another source of potential influence on the results lies in the assumptions made in the assignment of functions and CPCs descriptions to the various ideas, which was carried out by the authors as rigorously as possible, but still without any comparison with a broader group of experts. Furthermore, the choice of how these ideas were grouped to obtain a set without repetitions can certainly be reconsidered. In this case, all ideas with the same functions and the same field of application were considered to belong to the same idea. However, it could also have been chosen to consider other parameters such the only application fields, thus modifying the results. Lastly, it is necessary to note that the textual and visual descriptions provided to both groups for the two products might themselves have created an underlying fixation problem for the ideas generated, similarly to what has been observed because of the CPCs.

Summarising, the following aspects may have generally influenced the results of the experimental study:

- type of stimuli provided;
- quantity of stimuli provided;
- type of products to be analysed;
- possible differences in participants' backgrounds;
- possible presence of more talented participants;
- size of groups;
- time available for the test;
- assignment of functions to the individual ideas;
- assignment of fields of application to the individual ideas;
- judgment of the validity of the ideas obtained (excessive generality);
- categorisation of ideas into related groups.

The retrieved results should therefore be considered as preliminary and preparatory to further studies in order to generalize the findings obtained so far. Table 6.3 and Table 6.4 summarize the considerations discussed above, presenting the answers to the sub-questions formulated to achieve the third objective of the work. Table 6.3 is based on the indicative outcomes, while Table 6.4 on the statistical tests performed.

Table 6.3 - Answers to the research questions of the final part of the study, based on the indicative outcomes.

Research question	Answer
Patent classifications can aid in identifying alternative functions for a product, that diverge from their original ones.	The absolute quantity of functions obtained is not clearly influenced by the provided textual stimuli, with opposing results between the two products. However, in percentage terms, the new product functions generated compared to the obvious initial ones are greater in the test groups for both products.
Patent classifications might facilitate the discovery of new application sectors for the same product.	The absolute quantity of application sectors obtained is not clearly influenced by the provided textual stimuli, with opposing results between the two products. However, in both cases, a fixation phenomenon generated by the CPC stimuli is observed, with more ideas related to the provided patent classes retrieved in the test groups.
Patent classification definitions enhance ideas originality.	The originality of the generated ideas is not clearly influenced by the provided textual stimuli, with opposing results between the two products.
Patent classifications enhance variety of ideas	Ideas variety is not clearly influenced by the provided textual stimuli, with opposing results between the two products.

Table 6.4 - Answers to the research questions of the final part of the study, based on the statistical tests performed.

Research question	Answer
Patent classifications can aid in identifying alternative functions for a product, that diverge from their original ones.	The preliminary study does not provide a clear-cut answer to this research question, with conflicting results for the two products. Further investigations are necessary.
Patent classifications might facilitate the discovery of new application sectors for the same product.	The identification of new application fields is not statistically enhanced by the use of CPC descriptors as textual stimuli.
Patent classification definitions enhance ideas originality.	A posteriori originality level is not statistically influenced by the use of CPC descriptors as textual stimuli.

7 - Conclusions

In this thesis work, three main interrelated research activities have been pursued. The initial objective was to develop a new horizontal sliding mosquito net product for doors and windows, designed with reduced thickness. Simultaneously, during the development of the new model, investigations were conducted to identify potential improvements for reducing the environmental impact of these products.

One of the company's main focuses with regard to management control is to reduce and keep the production costs of the new models within certain limits, so as to be able to position the products in the market by earning a margin. Therefore, in order to meet this business need and facilitate the integration of the new model into existing production lines, no radical changes were made to the technologies in use. On the contrary, an attempt was made to reuse as many components as possible that already existed within the company, and also in terms of the materials used, these remained mainly the same, i.e., aluminium, plastics, steel and fibreglass and PVC mesh.

Efforts were therefore concentrated on reducing the amount of wastes and scraps. The most critical component among those present turned out to be the net, which is currently disposed of in landfills as waste from processed textile fibre. Based on previous studies, the recycling option is difficult to implement due to the two-component nature of the material. Therefore, efforts have been focused on identifying possible strategies for reuse. Reutilization in the same sector turned out to be economically and technically not feasible. For this reason, new alternative areas of use have been explored.

To this goal, the study adopted the methodology proposed in (Fiorineschi et al., 2018) to provide useful guidelines for generating appropriate creative stimuli that could be leveraged during the design process. The quality of these new applications was then assessed by testing the technical feasibility of a specific solution. The requirement for adopting a supporting methodology in the process of generating these ideas was dictated by the fact that the firm staff had not previously faced the problem and were unsure of how to approach it. Therefore, in this specific case, employing a supporting method has proven to be beneficial for the firm goals of both reducing the net environmental impact and creating new business opportunities. At the same time, this study demonstrates how it was possible to concretely employ such a methodology in a real industrial context, with its advantages and disadvantages. This approach, as observed in the literature, has not been adopted previously in other documented cases. Therefore, the present work can be considered a precedent for those who intend to employ this methodology in the future, even in other sectors.

The method applied exploits the information obtained from the CPC codes to which patents belong, which were in turn obtained by performing specific searches with different combinations of the starting product functions. Consequently, several stimuli for possible new applications of mosquito net waste were generated. As already stated, many assumptions have been made during the method implementation. In particular, with regard to the selection of the starting set of functions and the choice of EK combinations to analyse, they have certainly influenced the results obtained in terms of new applications. For this reason, the method could benefit in future applications from alternative strategies of selecting CPCs. For instance, a cumulative graph of the most recurring CPCs could be obtained independently from which EK originated them. Alternatively, not only the most recurrent CPCs could be selected, but, for example, the less recurrent ones as well. Moreover, it would be valuable to observe results obtained with different sets of product functions and compare them according to different metrics. Further studies in these regards are needed to understand how the results would be influenced.

According to the manufacturer, some of the forecasted new uses are more difficult to realize than others, and further studies are needed to investigate. In particular, the utilization of mosquito nets in the geogrid field seems to be the most problematic. Assuming the product exhibits the appropriate mechanical properties for such purposes, it would be crucial to procure waste pieces that are as regular in shape as possible. This is particularly critical as the scraps always have different lengths. In addition, an analysis would be necessary to determine how to join the individual pieces without compromising the mechanical properties in the joining areas.

If the mechanical properties of the mosquito net were not suitable for the newly selected application, it would be necessary to make some adjustments to the net production process. Subsequently, tests would have to be carried out in agreement with the mesh manufacturer. As the company is fully equipped with its machinery for such production, it would be challenging to modify the basic materials. However, modest changes in the geometry could be considered, such as altering the thickness and size of the individual mesh elements. Two restrictions must be met for this to be viable: firstly, the mesh must not be too thick as it would limit the amount of mesh that can be contained in an aluminium profile, and secondly, the mesh must not have too large mesh elements as it would permit insects to pass through.

Instead, the most promising applications that do not require any modifications to the product are related to its use in fashion and craftsmanship. A preliminary test was carried out for making a dress and produced encouraging results. Furthermore, the textile industry already sees established collection hubs for waste material recovery, which could also benefit from the scraps of this application. Regarding the necessary cutting operations to remove any welded elements, these could be performed either using the existing machinery in the company or by the receiver of the product, as it is a simple operation that can be carried out with basic tools.

In the final part of the study, a preliminary investigation was conducted to assess whether the type of stimuli used so far in the present work to identify alternative application fields for the fly screen is effective in generating new reuse ideas for end-of-life products, in a more general sense. This inquiry was particularly focused on evaluating the extent to which these CPC-derived descriptions could potentially enhance the creative process of the designers. In particular, the objectives were to assess the influence of such textual stimuli on specific metrics of the ideation phase. Firstly, the quantitative increase in the number of functions and the range of Cooperative Patent Classifications associated with the ideas generated. Secondly, the enhancement in the originality and variety of ideas. This was carried out through a controlled experiment, which involved a group of students from the University of Florence, Italy. The exercise consisted in the generation of the maximum number of ideas for the reuse of two given products at their end of life. Students were divided in two groups: a control group and a test group. A series of stimuli derived from selected CPCs descriptions has been provided only to the test group and the results have been compared at a group level. Then, the same procedure has been repeated for the second product, switching the two groups. While the indicative research’s findings have shown opposite trends for the two products under investigation, statistical tests have revealed more coherent results. In fact, quite surprisingly, none of the formulated null hypotheses can be rejected, since all p-values from the statistical tests exceed the threshold for significance. The sole exception is represented by the hypothesis related to the identification of new functions, which appears to be effectively enhanced by CPCs descriptions only for product 2, indicating the necessity of further investigations.

Therefore, this experimental activity aimed to increase our understanding of how CPC descriptions contribute to the identification of alternative application fields for end-of-life products, in an uncovered manner with respect to existing literature. However, the preliminary nature of the investigation must be emphasised, remembering that various factors inherent to the experiment may have influenced the results. These include the limited set of products proposed, the specific CPCs provided and the characteristics of the participants. For these reasons, further studies would be required to generalise the results obtained. In particular, involving a larger sample of participants to better represent the population would reduce the uncertainty regarding these parameters. Furthermore, by making several groups analyse the same products with different stimuli, it is possible to see if there is variability in this case as well.

Apart from this, it is important to emphasise that this activity is not aimed at verifying the effectiveness of the method (Fiorineschi et al., 2018) employed. In fact, the groups of stimuli provided, although of the same typology, are not identical. In order to validate the method in place, it would therefore be necessary to provide the participants in the experiment with the same set of stimuli that were obtained from the methodology. In this case, the number of these, as far as observed in the present study, is an extremely high number, which cannot be comparable with the only three stimuli used in the experiment. This could therefore lead to different results to those observed. Such an activity may be considered of interest as one of the future developments to be undertaken.

The mosquito net model developed during the study has reached the final stage of the industrialisation process, after approximately three years of work. The dies for the extrusion of the aluminium profiles and gaskets have been realised, as well as the moulds for the plastic components.

On the basis of the discussed results, it can be concluded that the initial constraints and objectives of the project were almost entirely fulfilled. In fact, a new model of a compact lateral-sliding mosquito net with the following characteristics has been realized:

- overall thickness dimension of 30 mm;

- single head-box;
- suitable for in light installations;
- maximum size of 140 x 280 cm;
- presence of lower guide;
- presence of abutment profile;

From the non-infringement searches carried out in the preliminary stages, not only did no significant problems emerge with regard to the solutions identified in terms of counterfeiting, but it was also possible to deposit four new patents. The only case in which a partial issue was found lies in the system of the lower chain carriage with connecting wires, as a previous patent (Grützner, 2019) has prevented realization in one of the initially conceived embodiments.

Life tests carried out during the final stages of development ensured the use for an average lifetime of ten years, as required. On the other hand, field tests in private homes are still in progress to test the product under real conditions of use. The specifications regarding the recovery of out-of-square and flexural rigidity of the lower chain have also been respected.

Concerning the constructive solutions, the adoption of some of them was imposed by the firm for commercial reasons. In particular, with reference to the carriage of the upper and lower chains, the central mesh exit and the fact of supporting the handlebar at the top by making it suspended. It is believed that these constraints have partially prevented the design space from being explored, thereby excluding possible alternative, better performing solutions. At the same time, it is also true that it was not the aim of this study to realise a concept totally detached from traditional insect screens.

The objectives relating to ease of installation, assembly and maintenance, product reliability and assembly safety have also been considered achieved by the different company departments. On the other hand, the production time has increased, contrary to what was requested. However, considering an overall cost reduction due to the lighter weight of the product, this result was considered acceptable.

In order to reduce installation and assembly time, a possible future development could be to eliminate the double upper telescopic rail, creating a product with a handlebar supported at the bottom. If a lower guide is present, such a solution would in fact appear to be easily feasible.

Other possible product developments concern the realisation of optional extras such as the absence of a bottom rail and abutment profile, features that are required in some installations, and the realisation of a double head-box version. Alternative technologies for the quick coupling of the handlebar to the abutment profile can also be considered for possible developments to meet customer demands.

In conclusion, this work has successfully demonstrated the applicability of the methodology proposed by Fiorineschi et al. (2018) within an industrial context, for identifying alternative applications of a given product. Therefore, this study serves as a valuable example for those seeking to apply the same method in the future for other applications. While it is not possible to definitively validate the methodology itself, the value of the generated textual stimuli can be confidently affirmed, which may vary in quantity but have boundless potential for generating alternative applications. It is also important to acknowledge the limitations of this study in the initial assessment of environmental impacts of mosquito nets, as a complete Life Cycle Assessment (LCA) is lacking. Moreover, the demonstration of the effectiveness of using textual stimuli in the idea generation process has shown limitations in its generalization. Nevertheless, the findings of the study represent a significant step toward reducing environmental impact and driving innovation in the mosquito net industry, as supported by the results obtained in the design process of the new product model, with the filing of four different patents. Further research and development are needed to continue improving the study, addressing its weaknesses, and exploring new opportunities for the firm's economic growth.

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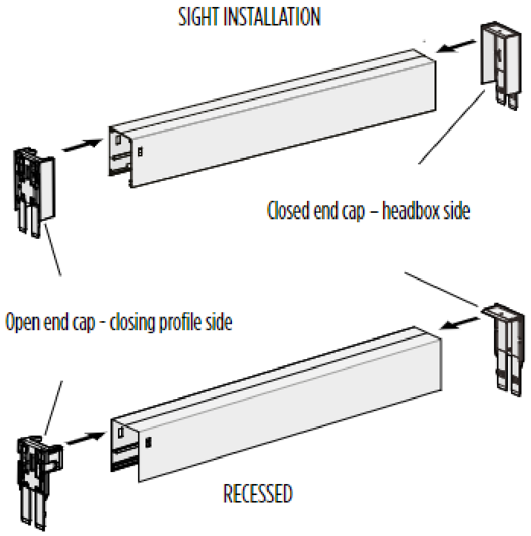
Appendix A

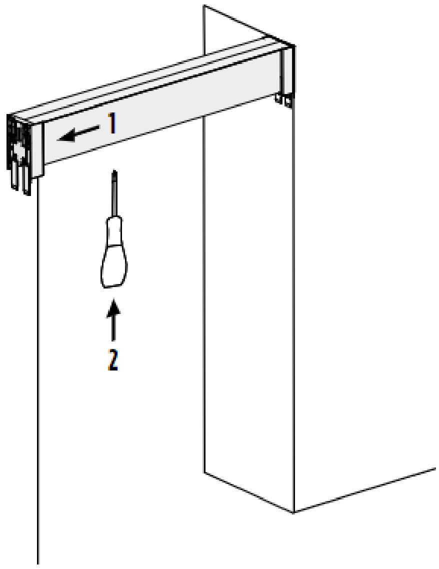
User manual of *Sintesi* product is here reported, in Table 7.1

Table 7.1 – Installation instructions for the *Sintesi* product

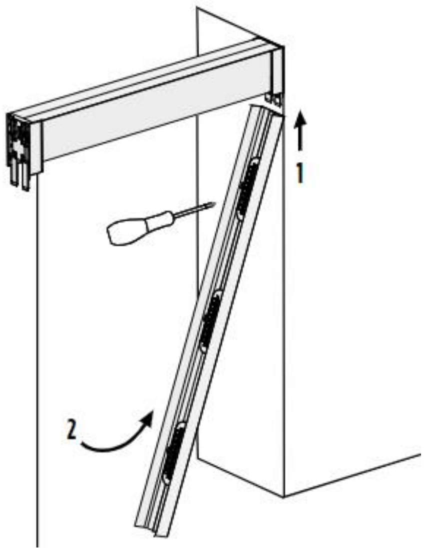
***Sintesi* installation instructions**



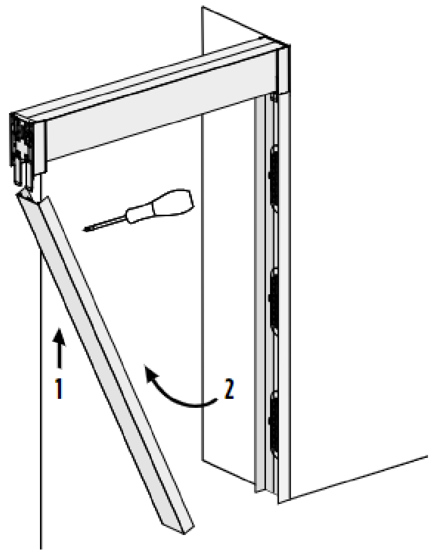
1. Assemble the upper track, inserting the two end caps. The closing side of the guide can be identified by a small rectangular window on each of the faces.



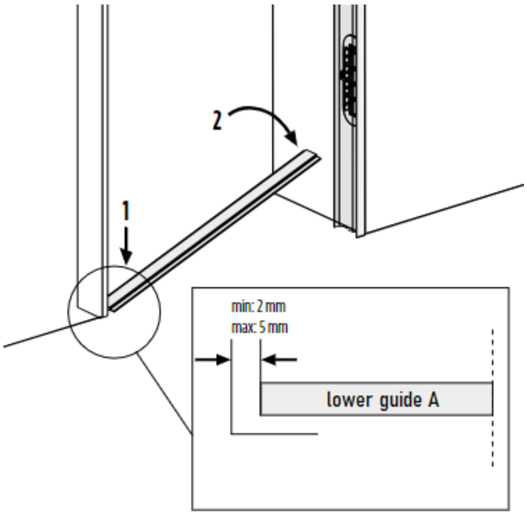
2. Position the upper track, taking care to put the end cap on the closing profile against the wall. Mark the holes and fix with screws and plugs. If using a self-supporting kit, this step can be skipped.



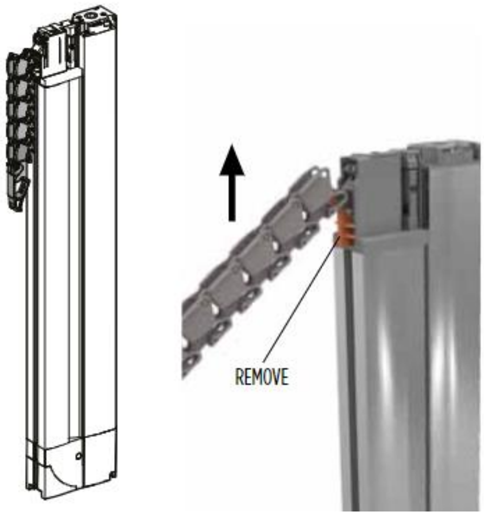
3. Position the lateral closing profile with the clips on the headbox side. Mark the holes and fix with screws and plugs. Check that the distance between the lower edge and the last clip is not less than 30 cm.



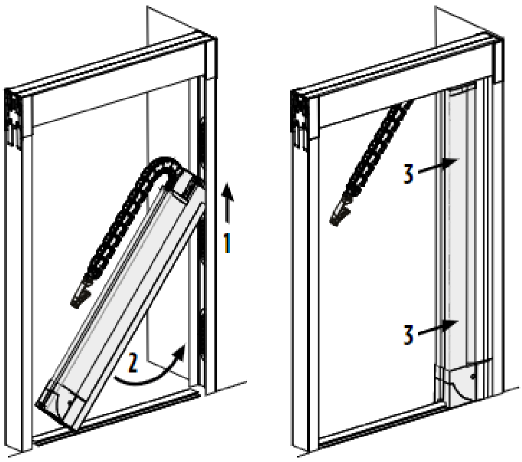
4. Position the closing profile with the magnet opposite the one with the clips. Mark the holes and fix with screws and plugs.



5. Thoroughly clean the threshold before applying the guide. Position the bottom guide A leaving a gap of between 2 and 5 mm from the closing profile with the magnet. Remove the double-sided tape and position the bottom guide in line with the other elements.

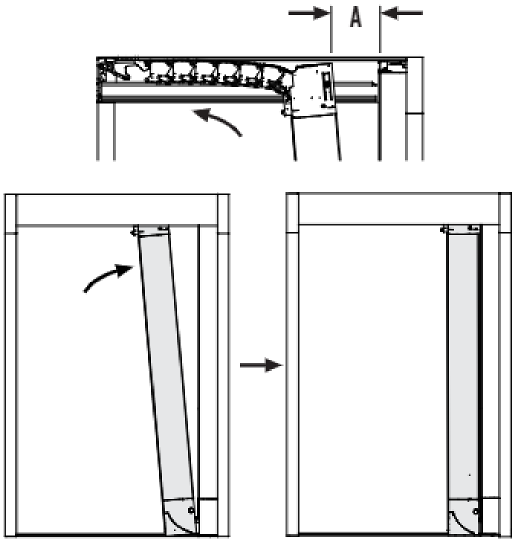


6. To restore the functionality and continuity of the upper chain, lift the protruding part until the track clicks.

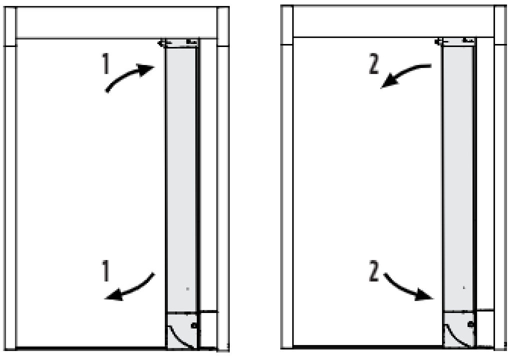


7. Position the lower part of the headbox on the bottom guide and the upper part inside the lateral closing profile with the clips. Slide it vertically and then clip the screen headbox to the closing profile as shown in figure.

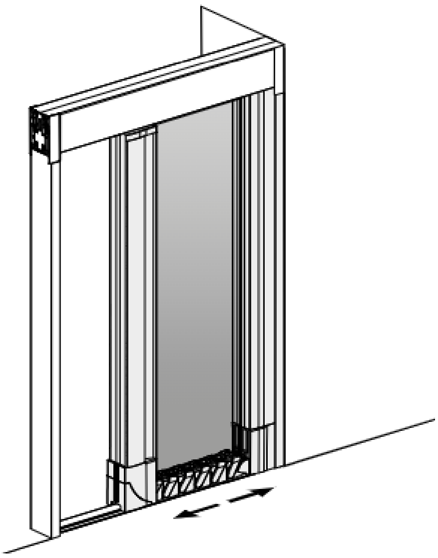
8. Insert the finger in the appropriate space on the first track element of the upper carriage track, hook the terminal into the slot located inside the end cap on the closing profile side.



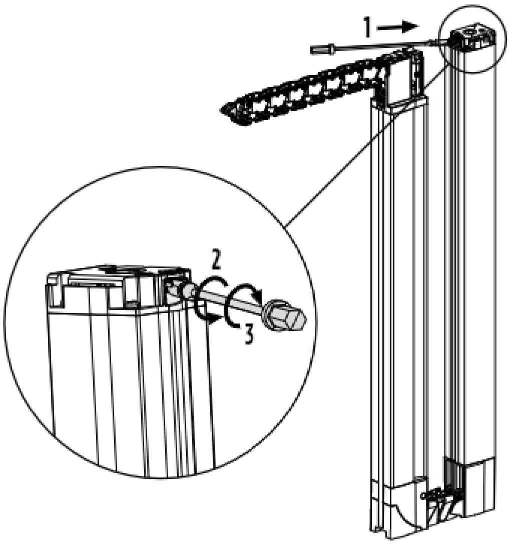
9. If there is a misalignment (A) in the upper or lower part of the rolled screen, hit the handlebar against the headbox with progressive intensity until it is realigned.



10. If there is a residual tilt, rotate the handle as shown in the figure. If the handle is still distant from the headbox, adjust the internal regulator by forcing the handlebar: push the handlebar from above and pull it from below (1) or vice versa (2), until the handlebar is completely adjacent to the headbox.



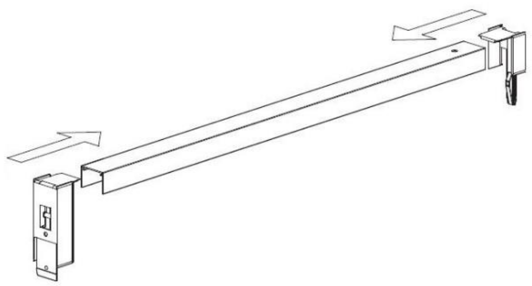
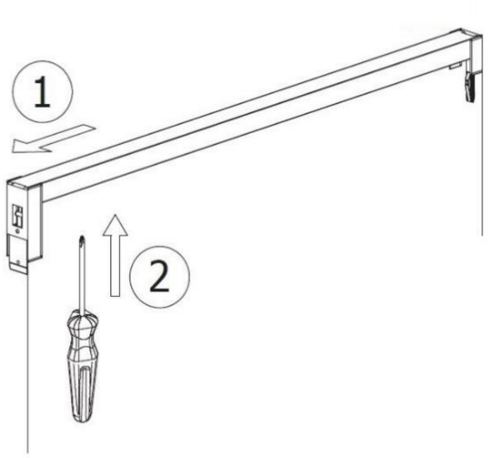
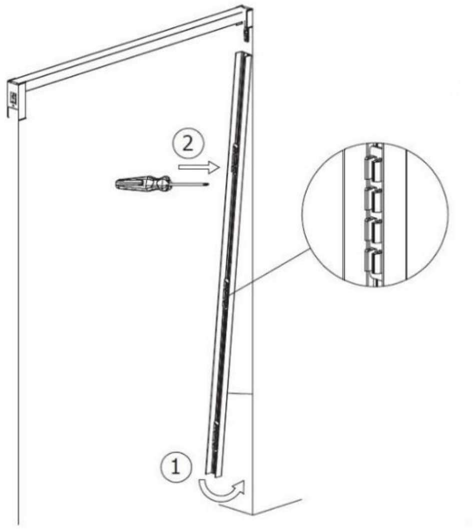
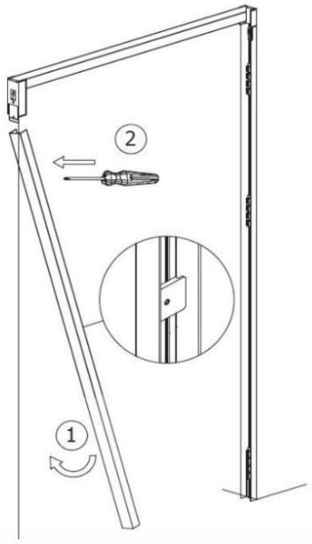
11. Test the insect screen by opening and closing several times. Rest the handlebar against the headbox and check that there is no gap between them.

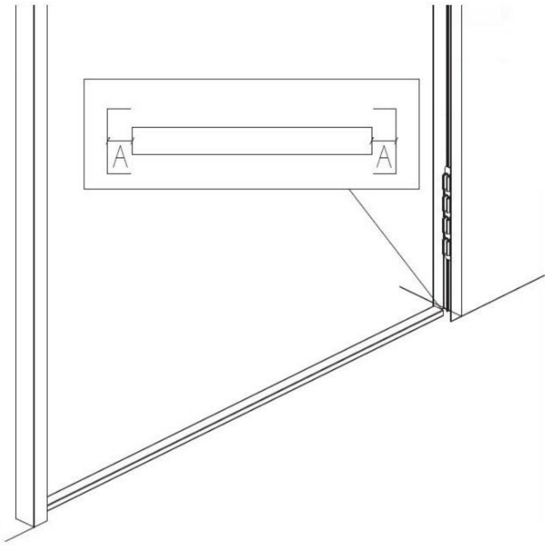


12. If necessary, adjust the spring load of the screen, insert the special key in the adjustment screw in the upper part of the headbox as shown in the figure. Turn anticlockwise to wind the spring or clockwise to loosen it.

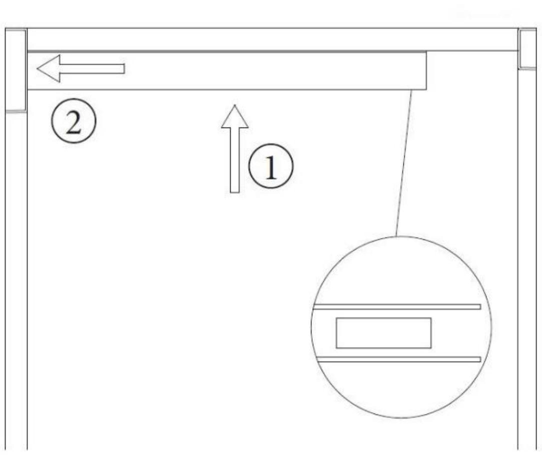
User manual of *Nano Sintesi* product is here reported, in Table 7.2.

Table 7.2 – Installation instructions for the *Nano Sintesi* product.

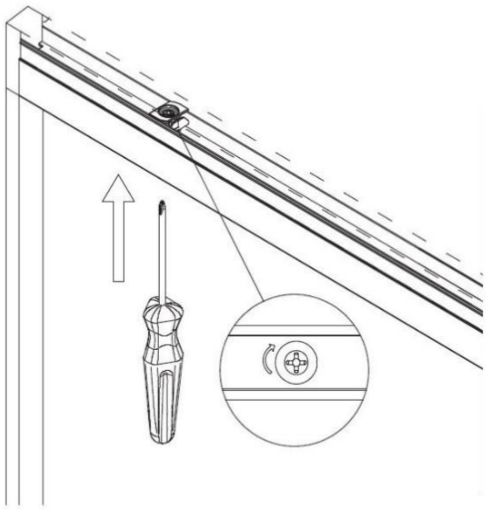
Nano Sintesi installation instructions	
	
1. Assemble the upper fastening guide, inserting the caps from the sides of abutment profile (long fin) and head-box (short fin)	2. Position the upper fastening guide, making sure to align the abutment profile cap with the wall. Mark the holes and secure with screws and plugs.
	
3. Position the side profile with the clips on the head-box side and secure it with screws and plugs.	4. Position the abutment profile with the metal plate on the opposite side of the head-box and secure it with screws and plugs.



5. Remove the double-sided tape cover from the bottom guide and position it in a centered manner relative to the frame.

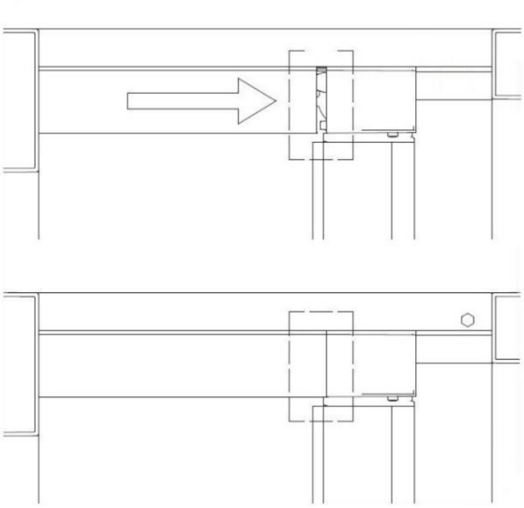


6. Position the upper telescopic guide in place, fitting it into the fastening guide closer the abutment side, with the rectangular recess on the profile facing towards the head-box side.

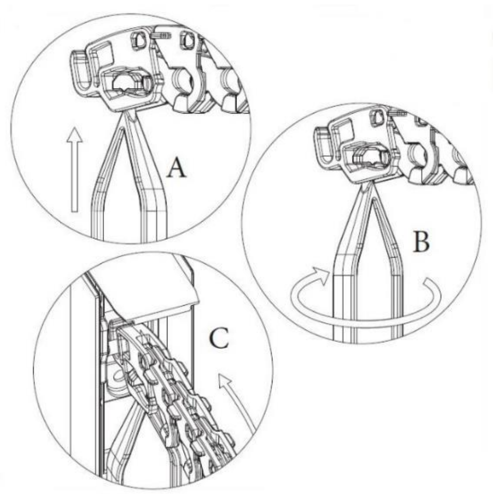


7. Push the screw of the telescopic insert upwards until it reaches the stop and turn it until a 'click' sound is perceived. This means that the telescopic guide has been properly attached to the fastening guide and cannot fall down.

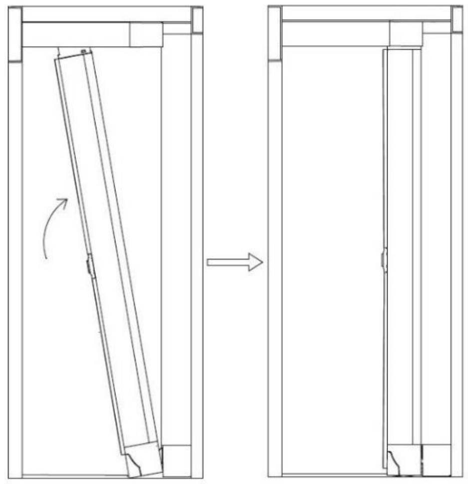
8. Place the lower part of the head-box on the lower guide and the upper part inside the side profile with the clips. Slide it into position vertically and then fix the head-box on the clips.



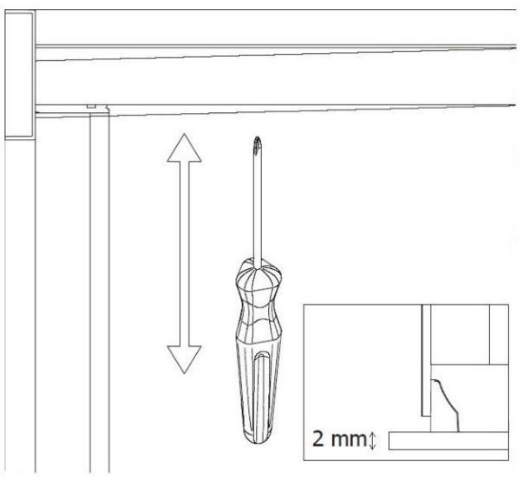
9. Move the upper telescopic guide closer to the head-box unit, allowing the fins on the telescopic head to fit into the grooves of the profile.



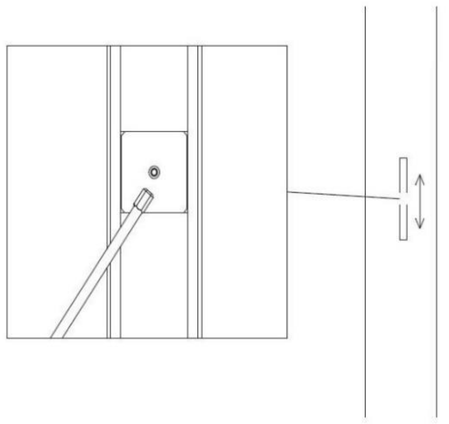
10. Insert the dedicated key into the groove on the first chain of the upper carriage and hook it to the abutment profile cap.



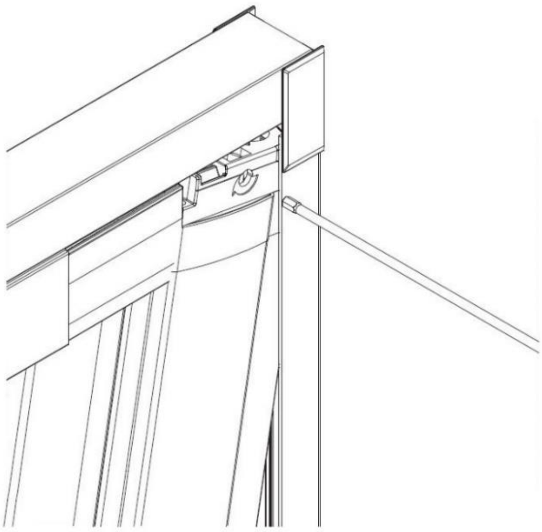
11. Check the alignment between the handlebar and the head-box. In case of misalignment, strike the handlebar against the head-box with gradually increasing force.



12. Bring the handlebar close to the abutment profile. Then, rotate the telescopic insert from the below to adjust the handlebar's height. Continue with the adjustment until there is approximately 2 mm of clearance between the bottom of the handlebar head and the floor.



13. Position the metal plate inside the abutment profile profile at the correct height using an Allen wrench, in order to achieve the desired magnetic retention force.



14. If necessary, to adjust the spring tension, detach the head-box from the side profile to make the adjustment screw on the upper head accessible.

Right head-box: turn clockwise to tension the spring, counterclockwise to release it.

Left head-box: turn counterclockwise to tension the spring, clockwise to release it.

Appendix B

The complete list of CPC titles encountered in the text and figures is reported in Table 7.3.

Table 7.3 – CPC titles and descriptions.

CPC code	Title and Description
B01D	Separation
H01L	Semiconductor devices; electric solid state devices not otherwise provided for
G02F	Optical devices or arrangements for the control of light by modification of the optical properties of the media of the elements involved therein; non-linear optics; frequency-changing of light; optical logic elements; optical analogue/digital converters
G02B	Optical elements, systems or apparatus
Y10T	Technical subjects covered by former us classification
G06F	Electric digital data processing
Y10S	Technical subjects covered by former uspc cross-reference art collections [xracs] and digests
B32B	Layered products, i.e. products built-up of strata of flat or non-flat, e.g. cellular or honeycomb, form
H04N	Pictorial communication, e.g. television
H05K	Printed circuits; casings or constructional details of electric apparatus; manufacture of assemblages of electrical components
G09F	Displaying; advertising; signs; labels or name-plates; seals
H01P	Waveguides; resonators, lines, or other devices of the waveguide type
H01J	Electric discharge tubes or discharge lamps
G03F	Photomechanical production of textured or patterned surfaces, e.g. for printing, for processing of semiconductor devices; materials therefor; originals therefor; apparatus specially adapted therefor
H04M	Telephonic communication
C02F	Treatment of water, waste water, sewage, or sludge
H03H	Impedance networks, e.g. resonant circuits; resonators
G03B	Apparatus or arrangements for taking photographs or for projecting or viewing them; apparatus or arrangements employing analogous techniques using waves other than optical waves; accessories therefor
G01N	Investigating or analysing materials by determining their chemical or physical properties
Y02A	Technologies for adaptation to climate change
E06B	Fixed or movable closures for openings in buildings, vehicles, fences or like enclosures in general, e.g. doors, windows, blinds, gates
D03D	Woven fabrics; methods of weaving; looms
B29C	Shaping or joining of plastics; shaping of material in a plastic state, not otherwise provided for; after-treatment of the shaped products, e.g. repairing
B07B	Separating solids from solids by sieving, screening, sifting or by using gas currents; separating by other dry methods applicable to bulk material, e.g. loose articles fit to be handled like bulk material
A47H	Furnishings or windows or doors

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Vorrei ringraziare tutti coloro che a vario titolo mi sono stati vicino durante questo tortuoso percorso di dottorato. Prima di tutto i miei professori Rocco Furferi e Federico Rotini che grazie alle loro indicazioni ed i loro consigli sono riusciti a sollevarmi anche nei momenti più difficili, incoraggiandomi sui risultati delle attività svolte, credendo a loro volta nel progetto e nella mia persona. Un immenso grazie anche al mio tutor aziendale Luca Barbieri, nonché collega e amico, che è stato per me una guida fondamentale nel mio percorso di crescita professionale e non solo. Grazie al mio amico Alberto, collega di dottorato in università, con il quale abbiamo condiviso gioie e dolori durante tutto il percorso. La tua presenza è stata fondamentale. Grazie anche ad Alessandro Monti ed Emanuele Turchini, che si sono sempre dimostrati disponibili nei miei confronti, aiutarmi a risolvere le situazioni nelle fasi più critiche che sono sorte durante il percorso. Grazie alla mia dolce metà, che mi ha sempre sostenuto moralmente in tutto questo percorso, aiutandomi a vedere sempre il lato positivo nelle cose, tu sai. Infine, grazie a tutti i miei amici e familiari che mi sono sempre stati vicino, fornendomi consigli e parole di incoraggiamento.