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# Innovative Management and Implementation of Applied Research Project “Green Cost-Efficient Package Selection”

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Additional information is available at the end of the chapter

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## Abstract

Cost-effectiveness is one of main criterions of innovation. In the current research, the generic mechanisms of university-enterprise collaborative project realization are included, which can be used to introduce the fresh ideas to industry. Such projects are useful for both partners: enterprise and university. Professors receive applied research projects experience and can publish the results of research, the students, involved in the project, can use received knowledge in their master or bachelor theses, and enterprises can employ new and active engineers. The aim of the project was to develop the green cost-efficient package for electronics industry, which should replace the previously used package. The target of this chapter is to bring the project team experience to the broader audience, who can successfully apply it for similar research project management and practical implementation. Today, the companies frequently use expensive package, which exceeds required quality specifications. That means the quality standards used by the company have too high requirements for the product types that package should protect. Purpose of current research project was to reduce the total cost of the packaging process and to select the environmentally friendly materials. Research team has elaborated the methodology for assessment of possible package variants.

**Keywords:** green package, cost efficiency, sustainability

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## 1. Introduction

### 1.1. Innovative applied research projects for university-industry partners

The Ministry of Education and Research implements national research policy, organizes the financing and evaluation of the activities of R&D institutions, and coordinates international research cooperation at the national level [1].

The TUT's mission is to create and mediate values that ensure Estonia's development in the globalizing world. Committed to its mission, TUT fosters research, academic, and applied higher education and technical culture and creates synergy between the different sciences to promote societal development. TUT collaborates with research centers and universities from all over the world.

Modern Estonian Knowledge Transfer for You (MEKTORY) was initiated by the Tallinn University of Technology—Innovation and Business Centre and the current partner universities: Tallinn University of Technology, the Estonian Academy of Arts, University of Tartu, Estonian University of Life Sciences, Tallinn University, and Estonian Academy of Music and Theatre [2].

One of the forms of Contracted Research & Development is Mektory projects. Mektory is an interdisciplinary innovation platform—a joint platform between universities and companies, where students supervised by the teaching staff come together to put their knowledge into practice in order to create prototypes and launch start-ups. Mektory is focused mainly on practical science projects. It has the following goals [3]:

- to support the innovation and development of TUT (institutes of higher education) as practically as possible—to get round to prototypes;
- to support the emergence of start-ups;
- to keep talent at university—the students do not go to work but stay to get their academic degrees;
- to create frequent cooperation with international innovation platforms;
- to be an acknowledged R&D partner for enterprises all over the world.

One of the aims of TUT Mektory is to provide services to the companies in three directions:

- design and product development;
- mobile services and media;
- development of business models.

Mektory projects bring together scientists, students, and entrepreneurs to solve practical product development problems and to generate new ideas. The authors have developed the general scheme of applied research project initiation as introduced in **Figure 1**. The tasks to be performed by a company are given in the yellow rectangle; the tasks performed by a university are given in the gray rectangle.

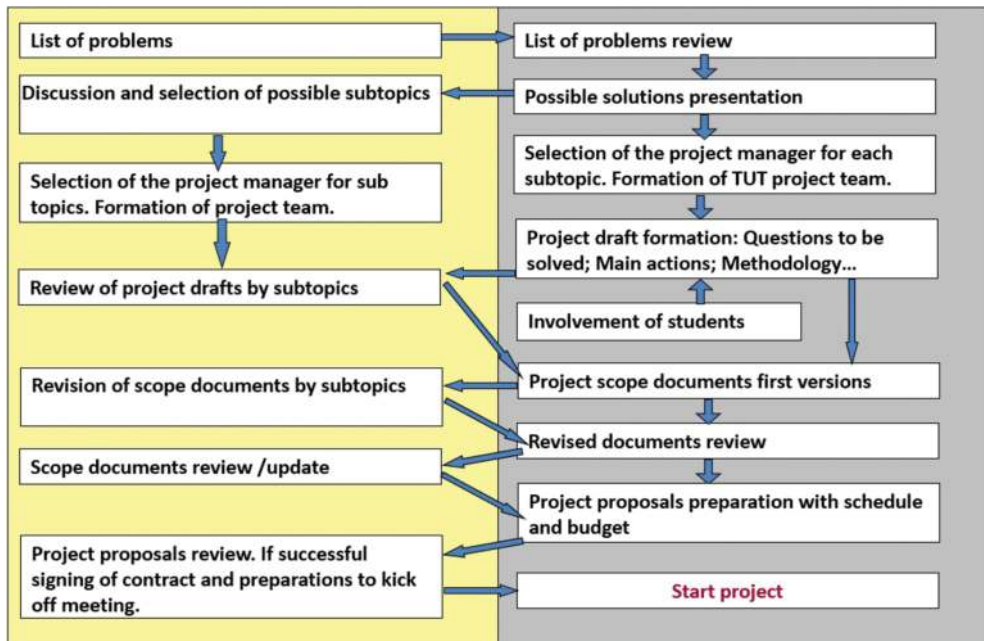


Figure 1. Applied research project initiation.

In order to validate the general scheme, authors have selected the Mektory project "Green-Cost Efficient Package Selection for Electronic Industry" that was targeted to develop the green cost-efficient package in order to replace the currently used package.

## 1.2. Project "Green Cost-Efficient Package Selection for Electronic Industry" background

Every product must be delivered to customer without defects. The common understanding is that package protects the product inside, but there are actually much more possibilities and opportunities for the companies connected with the package and its design. Each package has four important functions: product identification, product protection, convenience, and product promotion. Package is able to tell to the consumers that your product and brand are different from the same area competitor's one.

Companies have to remember that product's package also has a communication purpose: what your brand stands for and what it means for your customers. It is important to adjust packaging to the product and to consider the necessary protection for material selection. There are a few brands in the world that are different from the others. Apple is a good example. Everybody knows that Apple has a clean, high-quality design of the product and clean and minimalistic design of the package as well, which is well designed and customer friendly. Package can also advertise the company, and it even might have a bigger advertising role than the product itself. Packages are usually covered with the brand logo and other company information. A well-designed package might give the customer a high confidence about the

product and supports positive first impression, which enables to achieve a sustainable relationship with the customers.

Poor packaging has a significant impact on the product quality and company's reputation. It raises the cost of the products due to the defects caused by weak or badly designed package. In addition, poor or nonenvironmentally friendly package can cause the waste of the material, financial resources, and pollute the environment [4]. Packaging may also be harmful to the environment during the whole life cycle. Among the environmental criteria that the manufacturer might consider through life cycle analysis are the following: [5, 6].

- The reduction of packages weight or volume.
- Improvement of energy efficiency in the manufacturing process.
- Optimization of package production process.
- Improvement of product's life cycle.
- Selection of raw materials with a less environmental impact and compatible with recycling processes.

Often companies are using a package solution with too high a cost, and usually, it exceeds the package quality specifications. It means that the companies are using quality standards with too high impact limits for the type of the products that it should protect.

Product package engineering is a science that contains different aspects of the package setup. Product package engineering contains different science topics like material, chemical, and mechanical engineering. When designing a package we need to know what are the loads, in what conditions those packages are stored in, and how the package should protect the product.

The manufacturer should consider multiple aspects during the package design:

- Which material(s) the manufacturer can uses.
- How manufacturer can process them.
- Which company or national standards the manufacturer needs to follow.
- What is the productivity of packaging.
- How many products the manufacturer needs to fit into a single package.

The needs of packaging may be summarized in the following common definitions [7]:

1. Packaging is a coordinated system of preparing goods for transport, distribution, storage, retail sale, and end use.
2. Packaging is a means of achieving safe delivery in sound condition to the final user at a minimum overall cost.
3. Packaging is a technoeconomic function for optimizing the cost of delivering goods while maximizing sales and profits.

In terms of the different requirements to which packaging are subjected, García-Arca et al. [8] associate packaging with three large functions: marketing, logistics, and environmental. In its marketing function, the package presents customers with information about the product and promotes the product through the use of color and shape. The central purpose of the environmental function is to optimize packaging while minimizing packaging waste wherever appropriate and to reuse or recycle.

The purpose of this research is to reduce the cost of the package materials and to choose environmentally friendly materials. The current research is limited only to the fitments, which have the highest cost in the package set.

The authors have developed and applied the approach on a case study company. This company produces large electronic products, which are transported to different world regions. The selected packaging material should support the use of all means of transportation: train, truck, air, and boat. The limiting dimensions of all these transportation means must be considered during the package design.

The package selected for the case study consists of multiple components (see **Figure 2**), and its primary purpose is to protect the product. Fitments are packaging components, and their purpose is to absorb the impact and vibration loads. Fitments should be able to protect the products against most kinds of damages and electrostatic discharge (ESD) and at the same time suppress the impact. It is possible to produce the fitments from different materials. The commonly used materials are polymeric foams and cellulose-based structures. Protection bag protects the products from moisture and other environmental-caused damages such as mold or rust. Package box is keeping the entire package set together, takes some of the impact loads and pressure of boxes, placed on each other.

The right side of **Figure 2** shows the percentages of the full package set prices for selected products. As can be seen from the pie chart, the largest cost component is fitments with ~60% of total cost, then cardboard with ~20%, and then other smaller components. The fitment solution is the most expensive part of package set, and it has the largest effect on yearly packing cost.

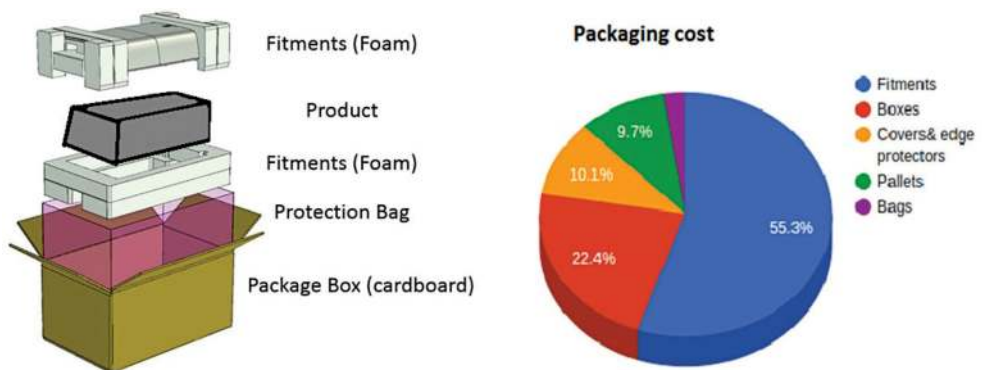


Figure 2. Package set and packaging cost.

The packed equipment must remain protected during a transport period of up to 3 months. The severity of the requirements is in conformity with ETSI EN 300 019-1-2 Class 2.3 “public transportation” [9]. Packed equipment must remain protected during a storage period of up to 12 months. The severity of the requirements are in conformity to ETSI EN 300 019-1-1 Class 1.2 “weather protected, not temperature controlled storage” [10]. When selecting packaging materials and components, tolerance to flora, fauna, chemically active substances, and mechanically active substances must be taken into consideration in accordance with the severities specified in ETSI EN 300 019-1-2 Class 2.3 “public transportation” [9].

## 2. Packaging alternatives

To design new fitments, a research group has discovered aspects that influence products safety and found the best feasible solutions that fulfill the research objectives (minimum package set price and usage of green materials). In **Figure 3**, the authors introduce the main steps of packaging selection and research methods.

### 2.1. Evaluation of possible alternatives

In order to develop a new packaged design, research group has generated the list of twenty-two possible new design versions. The sketches of ideas for selected solutions are shown in **Figure 4**. Then added them into evaluation matrix, added suitable materials, evaluated package design

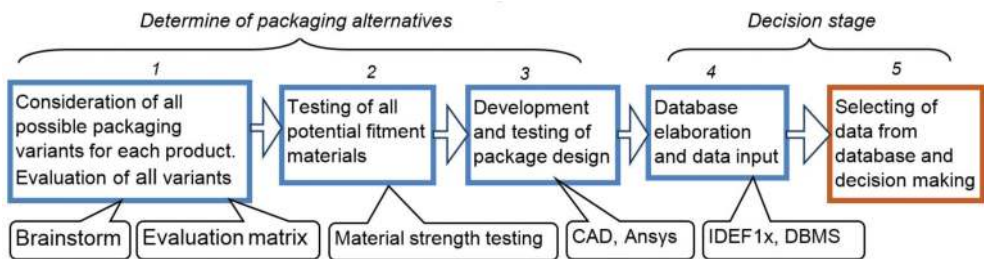


Figure 3. The general scheme of the research.

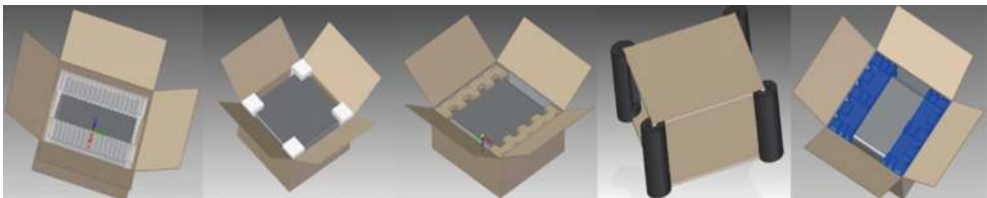


Figure 4. The proposed design versions sketches.

properties based on green and price categories, calculated the total grade for each alternative solution, and selected possible new design alternatives with highest grades.

In order to compare the different design versions, the researchers assessed the alternative solution in the evaluation matrix by green and price categories (see **Figure 5**). Each category consists of several criteria evaluated on 1–5 scale. The authors have defined each criteria weight in percentage based on enterprise expert's opinions.

The green category consists of following criteria:

- Effectiveness—is the ability of the package to satisfy functional requirements for the particular product. The designer should try to avoid using many different materials.
- Efficiency—is the reasonable usage of materials, energy, and water throughout the package life cycle. The designer should replace heavy materials with lighter ones.
- Recyclable/cyclicality—is the usage of renewable materials, such as wooden particles, paper mold, and bioplastic.
- Safety—for people and the natural environmental, whether it is compostable, biodegradable, etc.

The criteria for the price:

- Additional tools requirement—it is a cost of new complex machines or tools for manufacturing.
- Properties—whether the selected material is suitable for a particular solution, e.g. too rigid materials will not absorb shocks.
- Weight—the ratio of density and material volume; package should use as less a material as possible. For example, overpacking with extra or higher density foams is not required to protect the product from damage.

Nr	Version	Material	GREEN					PRICE					Total
			40%	20%	15%	25%	100%	30%	15%	30%	25%	100%	
1	Soft pillows in corner	Foam, small particles, wooden	3,5	3	3	4	13,5	4	3,5	4	3,5	15	28,5
2	Extruded Clamp	(Bio)plastic, paper board	3	3,5	3	4	13,5	2,5	2,5	3	3	11	24,5
3	Eco pulp	Pulp, recycled paper	3,5	3,5	4,5	4,5	16	4,5	4	4,5	4	17	33
4	Loose foam particles	Foam	2	2,5	3	3,5	11	3,5	3	4	2,5	13	24
5	Bubble film	Biodegradable film	2,5	3,5	3,5	4,5	14	3	3	4,5	2	12,5	26,5
6	Loose thick paper	Paper	2	3,5	3,5	4	13	4	2	4	2,5	12,5	25,5
7	Tension springs	Plastics, rubber	1,5	2,5	2,5	3	9,5	2,5	2,5	3,5	2	10,5	20
8	Fiber mesh	Plastics, natural fiber	3,5	2,5	3	3,5	12,5	3	3,5	3,5	3	13	25,5
9	Inflatable balloons	Rubber, plastic film	3	2	2	2,5	9,5	3,5	3,5	4	3	14	23,5
10	Brush like fibers	Bio plastics	1,5	3	3	3	10,5	3	3	3	2	11	21,5
11	Standard foam plates	Foam	4	3	3,5	3,5	14	3,5	3,5	3,5	3,5	14	28
12	Air tubes	Rubber, plastic film	1,5	2,5	3	3,5	10,5	3	3,5	4	3	13,5	24
13	Small foam lever+imp reaction mat	Foam capsules	3	2	2	3	10	2,5	2,5	4	4	13	23
14	Thick cardboard honeycomb	Card board	2	3	3,5	4	12,5	4,5	3,5	4	2,5	14,5	27
15	Magnetic levitation	Permanent magnets	2	3,5	3	3	11,5	1,5	2	2,5	3	9	20,5
17	Porolon, contact	Porolon	3	3	3	3	12	4	3	4	4	15	27
18	Pressure Balls	Tennis ball, foam ball	2	3,5	3,5	3	12	4	3	4	2,5	13,5	25,5
19	Foam sticks	Foam	2,5	3,5	3,5	3	12,5	4	3	3	2,5	12,5	25
20	4 products packages	Cardboard and foam	3,5	3,5	3	3,5	13,5	3,5	2,5	4	3	13	26,5
21	Minimize the material usage	Foam or other material	4	4	3,5	3,5	15	4	4	4	4,5	16,5	31,5
22	Foam fittings top and bottom	Foam	4,5	4	3,5	3,5	15,5	4,5	5	4,5	4,5	18,5	34

Figure 5. Evaluation matrix.

- Assembling—the amount of labor required to pack the product, e.g., too many package pieces used to protect the product.

The results of brainstorming are introduced in evaluation matrix in **Figure 5**.

The evaluation matrix shows that highest ranking have solutions number: 3—eco pulp (pulp recycled paper), 21—minimize the material usage and cover with double film, and 22—foam fitments top and bottom (foam or other material, e.g., mushroom material).

After the authors have selected the best possible design solutions, it is necessary to choose the best possible materials as well (see **Figure 6**). Consideration of the factors in green category is still the same and in price category, authors considered only current market price, the cheaper it is, the better price grade received. There were two materials available in the market that customers can get for less than 1 €/kg, and they got a max price grade 5, others have a higher price and a lower price grade. In the same way, authors have assessed the properties of other materials: effectiveness, efficiency, cyclicity, and safety. Since the company is interested in reducing the cost and making the packaging greener, the price category has a weight 40% and green area in total has the other 60%.

Corrugated board (single or double) is used for protecting a package. The cardboard box element of product packaging is taking most of the pressure loads. The box must be able to

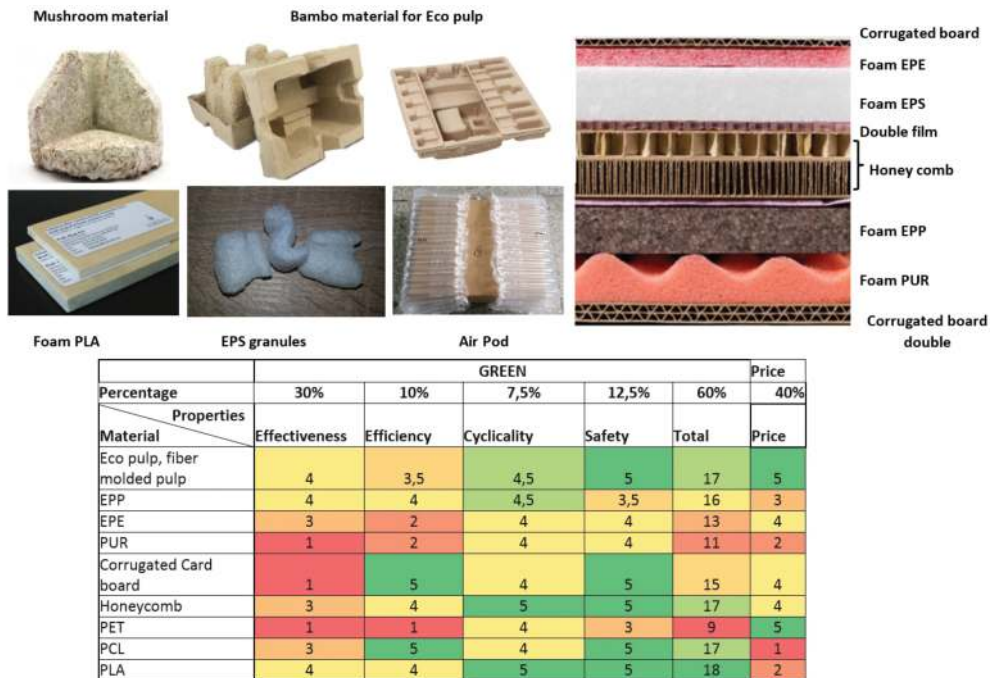


Figure 6. Materials considered for packaging.



protect against pressure and moisture conditions. After the cardboard box has held heavy products during the transportation, it loses its strength and rigidity, and it is not recommended to reuse it again. The recycled cardboard cannot be reused for the next round of dispatch because it is also not as strong as it was before the transportation. Therefore, products inside of recycling boxes are less protected, even if the cardboard has the same thickness and dimensions [11].

Bubble film or EPE (expandable polyethylene) is usually used for low volume products (<10,000 pcs/year). This material does not require many tools, and the required ones are very cheap tools. Those materials are used for inner protection, but they are flexible and deform fast.

Expanded polystyrene (EPS) or expanded polypropylene (EPP) is usually used for high volume products. Their inner protection can be cost-efficient to use; EPS and EPP materials require more complicated and expensive manufacturing tools.

Honeycomb is the lightweight, rugged, and environmentally friendly solution suitable for protective packaging needs. The restriction is that the honeycomb cannot be used as a fitment of the packaging. Honeycombs have high mechanical strength at low densities. Honeycombs have good cushioning properties, but not as good, as do foams. Honeycombs can protect products from shock or vibration damages during transportation, and it is used together with EPE foams due its softness property.

The manufacturer can minimize the environmental impact by using as minimum material as possible either by weight or by volume. Furthermore, it can be achieved by replacing the current heavy materials with lighter ones, by analyzing the changes in transport logistics, product dimensions, product fragility level, and by adapting design quickly to these changes.

#### *2.1.1. Green packaging solutions*

The Landaal Packaging System has invented green cell foam. This corrugated-like panel is a sustainable alternative to polyethylene, polystyrene, and polypropylene foams. This foam fully biodegrades in 4 weeks in moist environments and dissolves in water. Foam product has also no-ESD properties, which is perfect for electronic packaging. Green cell foam is also compostable, and it will vanish in every compost facility. After usage, the customers can easily recycle the material together with corrugated or paper materials [12]. Green cell foam easily absorbs the vibration and dropping loads. Accordingly, to the green cell foam official homepage performance, it can even absorb the baseball bat hit [13]. Average person can move the baseball bat up to 80 km/h [14].

***Polylactic acid (PLA)*** is a corn, starch, or sugar-based biopolymer, which is also biodegradable. This very lightweight polymer is used a lot in the food industries. The foams have good properties in heat insulation and impact resistance. PLA foam can be processed with the same tools and same technology as in EPS processing [12]. Since EPSs have a big carbon footprint, then some companies have substituted EPS with PLA materials. PLA unbounded beads can be used also as cavity fillers and also in the toys or in the furniture manufacturing that are using bean fills. PLA can be composted under the industrial composting conditions. PLA foam is

also chemically recyclable to new PLA polymers. The foam density can go between 20 and 100 kg/m<sup>3</sup> using carbon dioxide blowing [15].

**Molded pulp** is made from natural cellulose fibers and recycled paper. Recycled paper fibers and water will be mixed together as a pulp. Some of the companies add additives or bleaches into the pulp to improve the pulp properties or functions. However, this is not that environmental friendly so that is why most of the manufacturers are not using additives at all or just adding the natural additives (additional fibers). Pulp breaks down comparatively fast in normal landfills and compost piles, and it is fully biodegradable. Materials have been used for decades so molded pulp has a lot of experience and its technology and supply base are very well developed. Molded fibers due to its long-lasting experience base is being quite widely used in consumer packaging applications with really high expectations [16]. One of the main disadvantages of molded pulp is the heavy weight, which raise the emissions during the transportation. It may not be that cost-effective or environmentally friendly if shipping for a long distance.

**Bamboo packaging.** Sustainably sourced bamboo packaging certified by the Forest Stewardship Council. Benefits: Strong, renewable, promotes healthy soil, local to manufacturing sites, biodegradable, and certified compostable.

**Air pod** (air bubble) replaces traditional packaging material, such as foam, EPS, cardboard, and bubble wrap, providing customers with a simple and effective solution to protect products from shock and vibration during the transportation process.

**Mushrooms (Myco foam 4).** Packaging materials are grown from mushrooms. Already used by Dell [17] and HP group. Planning to start using, IKEA group [18], company PUMA [19], and Ford group [18] are also planning to start using it. Transportation cost of materials from USA was higher than the cost of materials. The latest developments are that students of Academy of Arts (Estonia) have studied the material and the test pieces were already grown in EU [20].

## 2.2. Material testing

The existing package solution was produced from EPP material. The density of the material during testing varied 25–35 kg/m<sup>3</sup>. It has Young's modulus 1300 MPa, and Poisson's ratio is 0.001. Material tensile strength can go up to 0.16 MPa depending on the density, which is the same as that of polystyrene. If comparing Young's modulus and tensile strength, the material has the same properties as do silicone and polystyrene, which are also packaging cushioning materials. The material is highly lightweight, has a good structural strength, and is recyclable [21].

### 2.2.1. Material impact testing

For material impact measurement, authors have used drop hammer test (adjustable heightwise) 23.3 kg, diameter of 20 cm, and surface larger than the test piece (**Figure 7**).

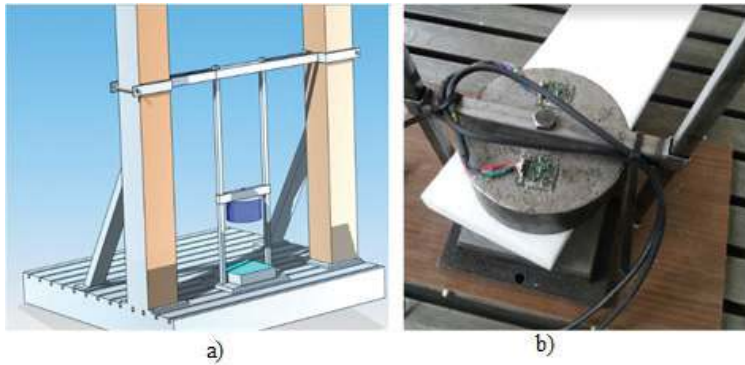


Figure 7. Impact tester (a) and drop hammer with two sensors (b).

Drop height is 250 mm, which corresponds to free fall impact velocity of 2.21 m/s under free fall in vacuum conditions of under standard gravitational acceleration. The equivalent free fall velocity is calculated using the Eq. (1) [22].

$$V = \sqrt{2gn * h} \tag{1}$$

where  $V$  is the final free fall velocity in meters per second;  $g$  is the standard acceleration of free fall, i.e.,  $9.80666 \text{ m/s}^2$ ;  $h$  is the measured height, in meters, of the hammer above the test piece. Referred standard is ISO 4651:2000 [23].

Figure 8 shows highest acceleration ( $g$ ) for different materials.

Material specimen parameters and tests results are introduced in Table 1, where one can also see the highest acceleration and deformation. EPE, EPP, and EPS share the similar characteristics of

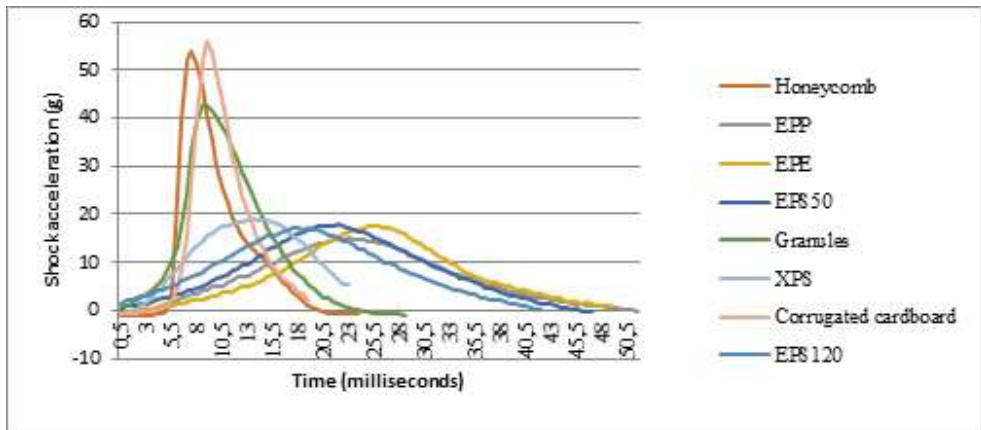


Figure 8. Highest shock for different materials.

Material	Length (mm)	Width (mm)	Thickness (mm)	Density (kg/m <sup>3</sup> )	Quantity (pc)	Highest acceleration g	Deformation (%)
EPE	100	100	45	30	4	18	5
Corrugated cardboard	100	100	45	N/A	4	53	30
EPP	100	100	45	35	5	15	6
XPS (polystyrene)	90	90	50	30	5	18	20
EPS50 (expanded polystyrene)	100	100	45	50	5	18	7
EPS120	90	90	45	120	5	17	12
Honeycomb	100	100	20	N/A	5	55	75
Granules of EPS standard	150	150	110	N/A	3 bags	42	

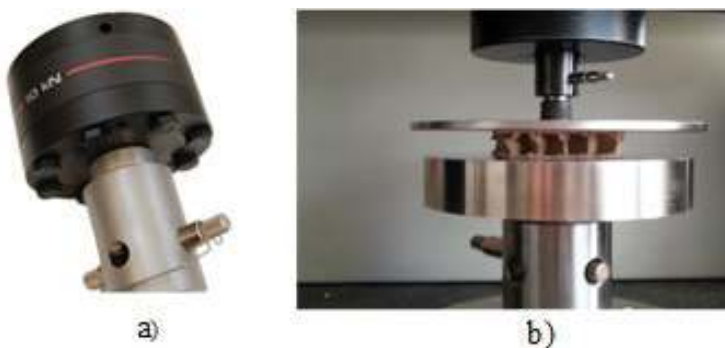
**Table 1.** Tested materials description and its properties.

shock absorbing and are the best choice impactwise (drops, sudden collapses against other objects, etc.) to avoid product damage during transportation. Honeycomb is the stiffest and absorbs shock badly 55 g, 75% deformed. Corrugated linear board is the second place accordingly to bad shock behavior, also 53 g but 30% deformation. In addition, EPS granules are in the third place.

### 2.2.2. Material compression test

For material compression, the Instron 5866 electromechanical testing system was used, which has two flat plates that have larger dimensions than the test pieces (see **Figure 9**). The static load cell 10 kN was used as a precision force transducer (the load cell is shown in **Figure 9a**) [24].

The load and displacement (strain) graphs were recorded for all tests. The test ending parameter compressive load 500 N was applied for EPP, EPE, and bubble film (with both big and small bubbles). The test ending time 3 min was used for honeycomb, and the maximum



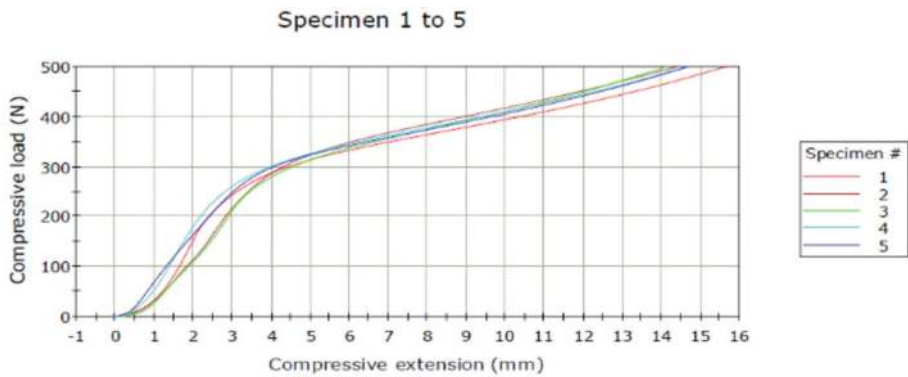
**Figure 9.** Instron load cell (a) and honeycomb under compression (b).

achieved compression load during that time was 10 kN (the loading speed was 1 mm/min). The example of material compressive test results is shown in **Figure 10** for EPP (expandable polypropylene).

As the behavior of both materials is very elastic (EPP and EPE), the compressive strength cannot be seen in terms of where the yield point is (above which plastic deformation starts), then we can only compare the extension interval and see from the vertical axis, the corresponding force. The deformation of EPE is 5 mm, and the force is 50 N; whereas for EPP, the force corresponds to ca. 350 N and one more, e.g., from 10 mm, for EPE, the force resulting is as 100 N compared with 400 N for EPP. Meaning the EPP needs more force to deflect to the same level as EPE, meaning the latter is a softer material. Also when doing this testing, the material needs to be even on size as any residue over the edge that touches the platens, although lightly may alter the result.

From the all studied materials the best material would be one with the smallest deformation of EPE by having the biggest elastic modulus 0.77 on an average. On comparison of EPE and EPP with honeycomb at the same load of 500 N, they had only deformed ca. 2 mm, whereas the EPP and EPE had already 15 and 20 mm, respectively, so at least in static stacking, the honeycomb has an advantage.

Material recycling coefficients *embodied carbon (EC)* and *embodied energy (EE)* are taken from inventory of carbon & energy (ICE) standards [25]. Comparison with existing package (based on current standard) is given in **Table 2**.



	Maximum Compressive load (N)	Compressive extension at Maximum Compressive load (mm)	Compressive stress at Maximum Compressive load (MPa)	Maximum Compressive strain (mm/mm)
1	499.63	15.63	0.20	0.52
2	499.24	14.38	0.20	0.48
3	499.49	14.11	0.20	0.47
4	499.29	14.62	0.20	0.49
5	499.50	14.66	0.20	0.49

**Figure 10.** EPP compressive test results.

Material type	Density (kg/m <sup>3</sup> )	Best impact performance (acceleration g)	Worst impact performance (acceleration g)	Deformation (%)	Elastic modulus	Embodied energy EE = MJ/kg	Embodied carbon EC = kgCO <sub>2</sub> /kg
EPP	25	12	15	6	0.158	93.1	1.32
EPS50	50		18	7		88.6	2.04
EPS120	120		17	12		88.6	4.896
XPS	25		18	20		88.6	1.02
EPE	60	15	18	5	0.13	80	1.02
Eco pulp	325					25	1.74
Mycfoam 4		35	50	47		25	0.26
Air bags (PE)	18	25	34			77.2	1.69

**Table 2.** Testing results.

### 2.3. Fitment design

The manufacturer can perform the testing of packaging also virtually. One possibility is to do a virtualized testing in a simulation software. It enables the users to predict the product performance in case of impact, vibration, etc. Simulation software can create complete virtualized impacts or other scenarios considering mechanical or other perspectives [26].

To design a new cheaper and greener fitment, we need to define the current package solution's pros and cons, and to do that, it is important to see how fitment reacts when it could get accidentally dropped. The manufacturer can minimize the environmental impact by using a lesser and lighter material either by weight or by volume respectively. Furthermore, it can be done by replacing the current heavy materials with lighter ones, by analyzing the changes in transport logistics, product dimensions, product fragility level, and by adapting designs quickly to those changes.

#### 2.3.1. Current package testing

When packages are transported or handled from one location to another, a lot can happen. People and machine can make mistakes, and therefore, some mechanical or manual handling can make a lot of damage to the product. Products may fall down from the pallets, from the machines, or from the warehouse shelf. That is why a lot of package design solution companies are doing the drop test. This is the main indicator to say that package can protect the product.

Dropping type of events can happen usually during mechanical or manual handling of the product. Product falling can happen also during vehicle cornering or braking, automated warehousing or forklift wrong package placement. Drop test (free fall test) is usually performed according to ASTM 5276 standards. Where all the tested products will be dropped down from the same height, but in three different angles—in the corner, on the edge, and the flat side [27].

Compression can cause problems for the products in the packages during pallet stacking in warehouse or during long transportation. Compression tests are performed according to ASTM D4169 and ASTM D4577 standards where packages will get preloads, and those loads will be increased up to maximum 20%. Compression test can be done empty or with the full packages.

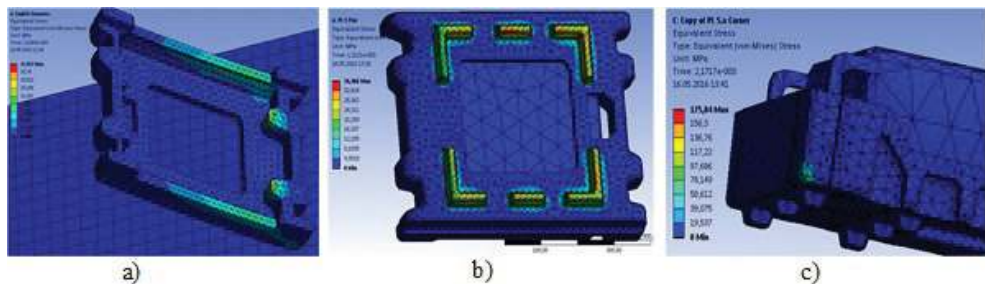
In **Figure 11**, we can see that packaging fitments are designed according to the need of protecting the product in different directions. Each of the bulges has important tasks. In **Figure 11(a)**, we can see when the product falls down onto the edge, then the main impact loads will go to the pads where the falling is directed—in this case, the direction is on edge. Also, we can see that when the product is falling to the edge, the bending will happen and fitment is going to break if the product mass will be higher. Also, we can see that in edge angle, the products have the highest values of Von-Mises stress, and this level of stress remains in the same value for some time. This means that the fitment is bending and suppressing the loads.

In **Figure 11(b)**, we can see the stresses in the flat falling situation, where the impact occurs directly on the whole product's lower case. For this, the situation designers have added falling protection pads. Those pads will protect the product and cushion the falling better than without the pads. Without pads, the shock will affect whole product inside and may break the assembled product, and also it has less weight than the whole fitment bottom covered with thickness of the pads. In the original products, fitments are covered with the cardboard package so that the cover will also take some of the loads and cushion the landing. Since the loads are scattered into a huge area, then stress value is low, even in the highest peak (**Figure 12**).

### 2.3.2. Alternative solution for modeling and simulation

In the current paper, we could not show all results of tested designs with various materials. Tests and simulation calculations will be done for molded pulp material according [28].

Material properties will be set according to the Hunan University of Technology scientific research whose experiments were done with the molded pulp packaging, and it was supported by Huilin Packing [29, 30, 31].



**Figure 11.** Fitment (a) edge drop, (b) flat drop, (c) corner drop.

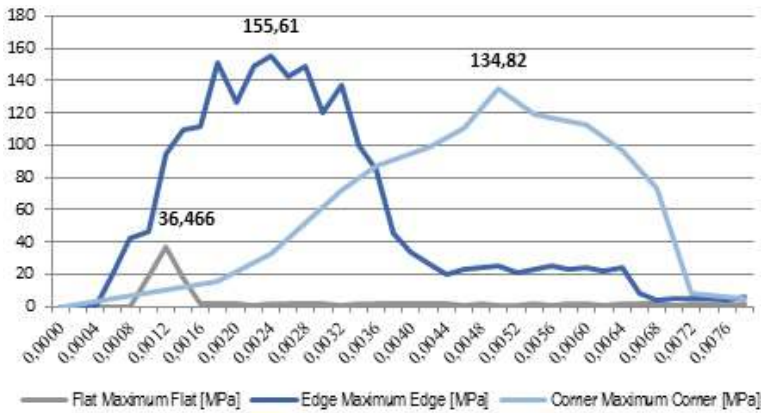


Figure 12. Equivalent stress results.

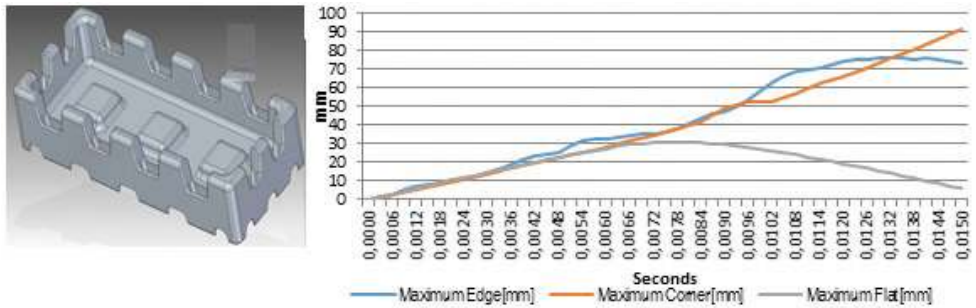


Figure 13. Molded pulp design and its total deformation.

According to the simulation, which can be seen in **Figure 13**, the total deformation is affecting the bulges that are red in the picture. That area will get the maximum level of the deformation in flat angle drop test. So we can say that this area is well designed and covers all of the cushioning needs for the product. Also, flat angle deformation is only 6.22 mm in that area. In edge and corner angles, the deformation will last longer and might break the product protection, if the loads will go higher. In corner dropping, the product cushioning material will have total deformation more than 90 mm that means that in this angle-molded pulp design needs more angled edges and some additional bulges.

In **Figure 14**, we can see that the product will need some additional shape optimization and rounding in the CAD (Computer Aided Design) modeling because the sharp edges are getting more loads, and these are not scattered around to the larger areas. So this means that product might break and then the fitments cannot be reused again and needs to be recycled again. More yellow and red colors are marked as stress areas, areas where fitment design needs more attention or different solution. We could expect that edge and corner Von-mises (see **Figure 15**)



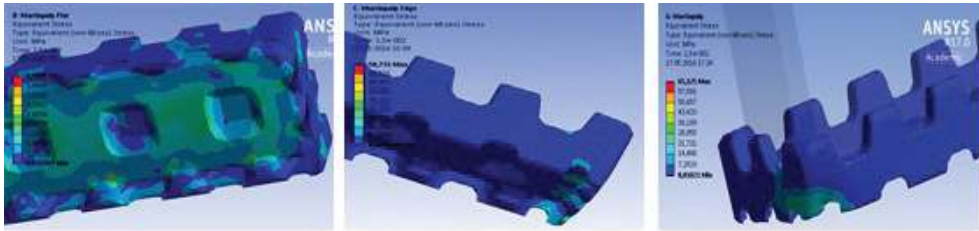


Figure 14. Molded pulp design (flat, edge, and corner).

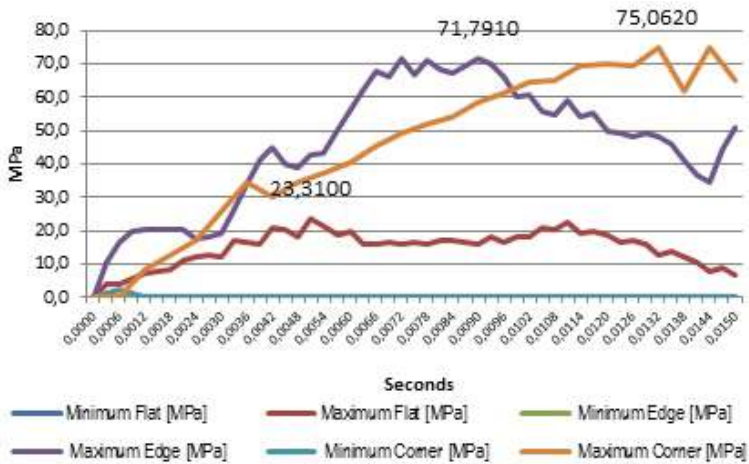


Figure 15. Molded pulp Von-Mises stress during test simulation.

stress is higher than flat dropping, but the difference is really big. It means that a little more inclination will lower the edge and the corner stress level and higher a little bit flat stress and that will dispel the risk of breaking the product on those angles.

Figure 16 shows the molded pulp acceleration behavior in the given conditions. In this graph, we can see that flat and edge angled product works quite the same—acceleration will go up in the middle of the measurement time and then the accelerations will slow down and then bump a little in the end. But for the corner, we can see that acceleration will go up slowly until the measurement time is ending. According to the acceleration probe, we can see that the acceleration will not go over  $1600 \text{ m/s}^2$ , and this is more than two times lower than the current solution. So this kind of solution will have a really great potential to substitute the current solution. Biggest minus for this solution will be that if the product will be fall down, then the fitment is broken, and this cannot be used again, and it will not suppress the loads after that. This fitment needs to be recycled again to be able to be used again.

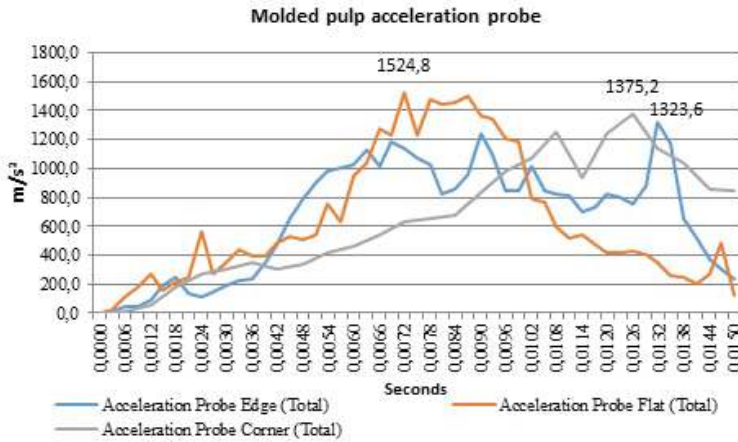


Figure 16. Molded pulp acceleration during test simulation.

Acceleration probe	Edge (m/s <sup>2</sup> )	Corner (m/s <sup>2</sup> )	Flat (m/s <sup>2</sup> )
Current product	3845.1	2272.7	22206.0
Molded pulp	1323.6	1375.2	1524.8

Table 3. Acceleration probe maximum value.

The most important characteristic of the cushioning solution is to reduce the peak of the acceleration for the protected product. Therefore, acceleration probe was selected onto the product that was inside of the cushioning material. Compared with the current solution's acceleration to new solutions (see Table 3), we can see that the acceleration is really low for molded pulp fitment, which means that this type of fitment can absorb well the impact loads and protect the product. We can say that in this kind of solution, product is protected.

#### 2.4. Database for packaging data

Authors have elaborated the database structure for data collection by using Computer-Aided Software Engineering (CASE) methods IDEF1X (Integration DEFINition for information modeling) and ERwin Data Modeler (all fusion) software. All objects (tables) are connected by the key attributes. This structure may be used directly by several database management systems (DBMS) for data collection, analyzing, and selection.

All objects (tables) are connected by using key attributes: primary keys are shown in the top part of every object and can be moved to other objects as a foreign key (FK) (see Figure 17).

Structure consists of the next main parts:

**Packaging structure** data that consist of the description of fitments (*fitment drawing number, type, weight, size, and cost*), boxes (*drawing number, type, weight, size, and cost*), and secondary boxes (*SecBoxType, weight, sizes, cost, and number of included boxes*).

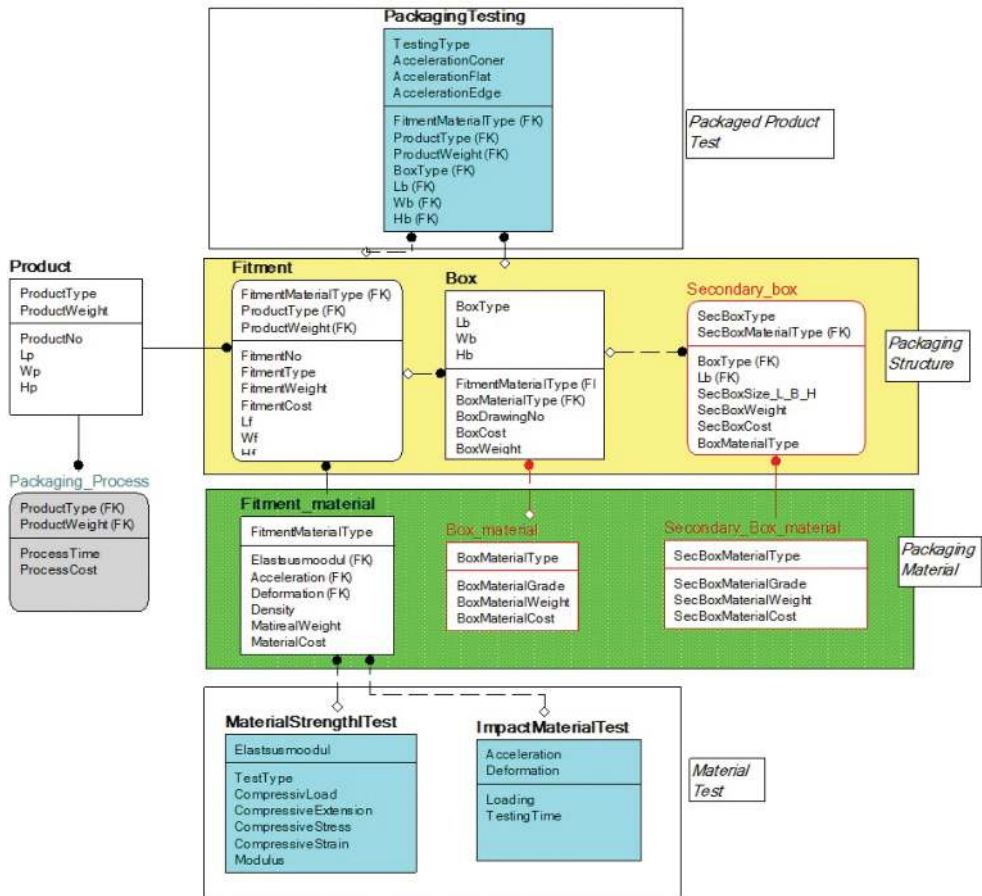


Figure 17. Database structure for packaging.

**Packaging process** data consist of process *time* and *cost*.

**Material tests** data by test parameters.

**Packaged product test** data consist of *testing type*, *acceleration probe by corner*, *edge*, and *flat*.

Packaging data must be included according to the DB structure for several types of products. Theoretically, new fitment with decreased volume can be made from different materials, and it gives an overview of the possible solutions in the tables they are marked as “Theoretical.” Furthermore, a few new package solutions were tested using alternative material including ecomolded pulp, Myco foam 4, and air bubble bags. **Table 4** is presented in several fitments data for two product types.

Selection algorithm for fitment design and material selection for decision-making is introduced in **Figure 18**.

Product type	Fitment										Material										Price	
	Lp (mm)	Wp (mm)	Hp (mm)	Weight (kg)	Weight (g)	Fitment no.	Fitment no.	Lf (mm)	Wf (mm)	Hf (mm)	Material type	Density (kg/m <sup>3</sup> )	Acceleration (g)	Deformation (%)	Elast modulus	Embodied energy EE = MJ/kg	Energy (MJ)	Embodied carbon EC = kgCO <sub>2</sub> /kg	CO <sub>2</sub> (kg/per filiment)	Price (€/kg)	Fitment mat cost (€)	
Product A	705	310	180	22.2	489	RLX12345	RLX12345	777	376	270	EPP	25	15	6	0.158	93.1	46	2.7	1.32	12	5.87	
Product A	705	310	180	22.2	400	EPP04.00	EPP04.00	2 × 180	2 × 395	2 × 260	EPP	25	15	6	0.158	93.1	37	2.7	1.08	12	4.80	
Product A	705	310	180	22.2	800			2 × 180	2 × 395	2 × 260	EPS50	50	18	7		88.6	71	2.55	2.04	0.87	0.70	
Product A	705	310	180	22.2	1.920			2 × 180	2 × 395	2 × 260	EPS120	120	17	12		88.6	170	2.55	4.90	0.61	1.17	
Product A	705	310	180	22.2	400			2 × 180	2 × 395	2 × 260	XPS	25	18	20		88.6	35	2.55	1.02	3.8	1.52	
Product A	705	310	180	22.2	600			2 × 180	2 × 395	2 × 260	EPE	60	18	5	0.13	80	48	1.7	1.02	5.4	3.24	
Product A	705	310	180	22.2	1350	ECC04.00	ECC04.00	2 × 160	2 × 360	2 × 220	Pulp	325				25	34	1.29	1.74	2.74	0.58	
Product A	705	310	180	22.2	200	MUS04.00	MUS04.00	765	370	240	Mycfoam 4	50	47			25	5	1.29	0.26		5.50	
Product A	705	310	180	22.2	205	BUB04.00	BUB04.00	2 × 200	2 × 365	2 × 260	Air bags	18	34			77.2	16	1.69	0.35	0.7	2.00	
Product B	518	470	186	26.3	580	RLX67890	RLX67890	690	535	286	EPS	35	15	6		88.6	51	2.55	1.48	1	0.29	
Product B	518	470	186	26.3	580			2 × 160	2 × 570	2 × 260	EPS	35	15		0.158	88.6	51	2.55	1.48	1	0.58	
Product B	518	470	186	26.3	800			2 × 160	2 × 570	2 × 260	EPS50	50	18	7		88.6	71	2.55	2.04	0.87	0.70	
Product B	518	470	186	26.3	1.920			2 × 160	2 × 570	2 × 260	EPS120	120	17	12		88.6	170	2.55	4.90	0.61	1.17	
Product B	518	470	186	26.3	400			2 × 160	2 × 570	2 × 260	XPS	25	18	20		88.6	35	2.55	1.02	3.8	1.52	
Product B	518	470	186	26.3	600			2 × 160	2 × 570	2 × 260	EPE	60	18	5	0.13	80	48	1.7	1.02	5.4	3.24	
Product B	518	470	186	26.3	1450	ECC04.00	ECC04.00	2 × 110	2 × 526	2 × 220	Pulp	325				25	36	1.29	1.87	2.74	3.98	
Product B	518	470	186	26.3	200	MUS04.00	MUS04.00	578	530	246	Mycfoam 4	50	47			25	5	1.29	0.26		5.50	
Product B	518	470	186	26.3	200	BUB04.00	BUB04.00	2 × 160	2 × 530	2 × 260	Air bags	18				77.2	15	1.69	0.34	0.7	1.80	

Table 4. Product/fitment data for 2 products.

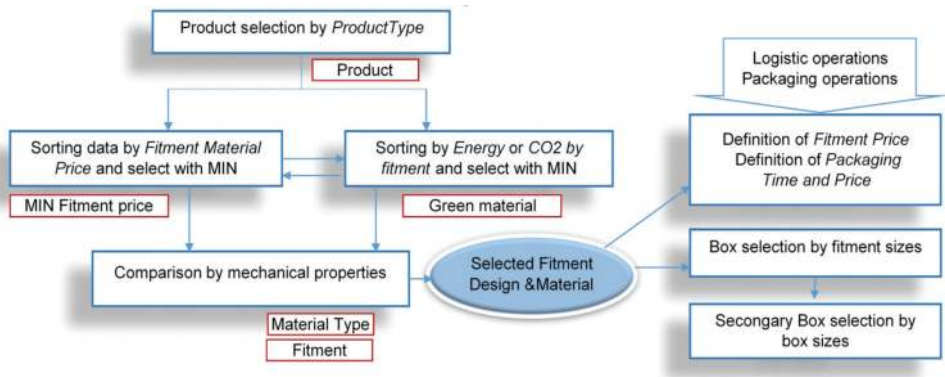


Figure 18. The algorithm for green and cheap packaging selection.

## 2.5. Suggested alternative solutions

The following alternative solutions are based on the current data, and the comparison is based on the current fitments of expanded polypropylene (EPP) material:

*A green solution of mushroom fitments is made from Myco foam material:* This packaging solution can be used for all the products. It has lower emissions, but the cost of material is comparable with current EPP fitment (material cost reduction 5%). The outbound logistics costs are the same because it is possible to fit approximately the same amount of boxes to the pallet.

*Green and eco pulp are made from bamboo and bagasse blend:* The bamboo-based material enables to apply the packaging solution for all products. Compared to the current solution, the inbound logistics costs are smaller because more units can be stacked into a container, and it has lower emissions. Moreover, the cost of material is (20–35%) less when compared with current fitment, the outbound logistics costs are minimized by 25%, since it is possible to fit more boxes on the pallet.

*Bubble solution (or air Pod):* Inbound logistics costs are very cheap, which depend on the product. It has lower emissions due to 2% of film and 98% of air, and the cost of material is much lower (65%) when compared with the current fitment. The outbound logistics costs are lower because it is possible to fit more boxes on the pallet (up to 25–30%), but it is more risky in a way that extra protection corners should be added to secure the product from damage.

Hence, the eco pulp fitment solution is the suitable feasible packaging solution as compared to current using packaging material.

## 2.6. Outbound logistics volume comparison

With the new developed packaging solutions, we also made the calculations of how they impact the outbound logistics and whether the new solutions contribute to cost reduction. During the analysis, we used the standard 40-foot container and EUR-pallet, trying to fit the maximum amount of products onto the pallet and then the pallets into the container in double-stacks. The summary table fragment of the calculation is shown in **Table 5**.

Version	Product	BOX size			Per pallet			Total	Total products per container	Change (%)
		Lb (mm)	Wb (mm)	Hb (mm)	L prod	W prod	H prod			
Current	Product A	787	385	278	1	3	3	9	378	0
New decreased	Product A	775	400	260	1	3	3	9	378	0
Molded pulp	Product A	750	370	220	1	3	4	12	504	25
Muco foam4	Product A	775	380	250	1	3	3	9	378	0
Air bags	Product A	270	550	380	3	2	2	12	516	27
	Product A	380	550	270	2	2	3	12	504	25

**Table 5.** Logistic volume comparison.

## 2.7. Package financial forecast comparison

Package price will depend on the package material and the material processing. Material price for ARPRO EPP (expandable polypropylene for automotive dunnage, the reusable shipping containers) is approximately 5 €/kg [32]. This price takes into account raw material price, and as we know that processing EPP is very hard and it takes money and time to produce, it means that processing cost can be double amount of the raw material price so altogether this will be 15 €/kg, and if we also consider that one product uses 0.4 kg of EPP material, which is almost same weight as current material's lighter version (25 kg/m<sup>3</sup>). Then this means that from the economical perspective, this solution will need more development and shape optimization to lower the material usage. Material weight should be maximum 0.35 kg and processing should be easier or almost at the same level as current solution. So then the initial goal will be successful.

Pulp raw material and processing proportion are divided into 23 and 77%. Molded pulp raw material is 0.35 €/kg and adding 1.15 € for processing cost, then all together it is 1.5 €/kg. Since the fitment design for upper and lower part will be same, the processing cost for package set will be lower when compared with the EPP design.

When adding this calculation to the manufacturing forecast for the coming year for seven several types of products, then we will get the picture as shown in **Figure 19**.

In **Figure 19**, we can see that monthly average product groups package cost is close to 6% and end of this figure, we can see that monthly cost is close to 4%. This is compared with the initial fitment solution's yearly cost for package sets. Old fitment line shows that on an average, the new solution will reduce the packaging cost by 2% per month. This means that by the end of the forecast, the company will have reduced 24% of the fitment cost. According to this information, the initial goal has been reached and project is successful.

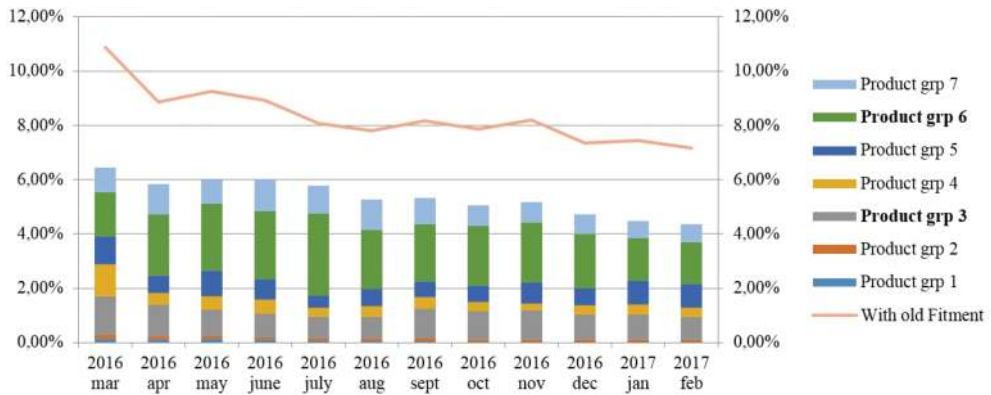


Figure 19. Monthly forecast with new materials.

### 3. Conclusion

The goal of current innovative research project was to reduce the package cost and choose an environmentally friendly material that is easy to process. Material and design selection were done using several methodology steps, which were shown in the general scheme of this research. All of the results were applied to the most expensive product groups. Current material values were compared with the new material values, and the final selection was done based on those values. This research study is giving an idea about packaging design and corresponding aspects needed to be taken into account in material strength testing, line capability wise, and packaging cost. Proposed framework enables decreasing the inbound logistics costs and leads to more fitments that can be loaded on to one pallet. It has lower emissions and material costs. The outbound logistics costs decreased only based on fitment material weight.

Such applied research projects are useful for both the enterprise and the university. The professors get applied research projects experience and publish the results of the research, and the students involved in the project can use received knowledge in their master or bachelor theses, and enterprises can employ new and active engineers.

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