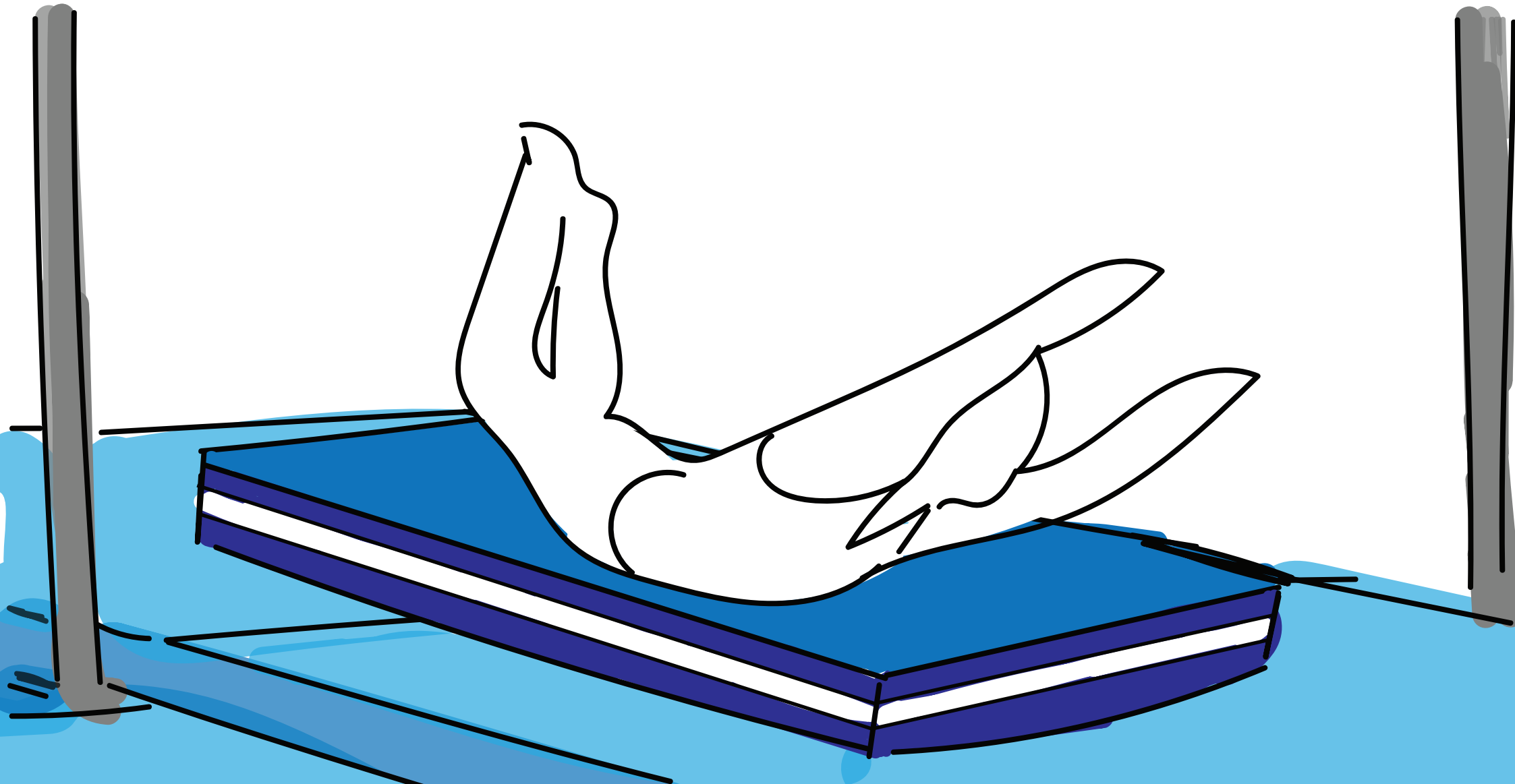
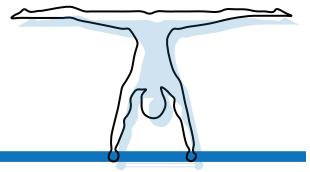
REDESIGN OF A GYMNASTIC CRASHMAT

Better be safe than sorry



Summary



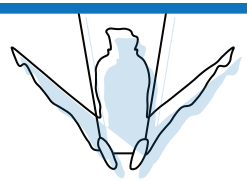
This report contains a full description of my graduation project for my Master degree in Design for Interaction at Delft University of Technology. I did this project in collaboration with the association called InnoSportLab s'Hertogenbosch. They were asked by the prior national men artistic gymnastic coach to create a transportable crashmat.

To figure out the exact problem, the current context was explored by doing literature- and user research. In the literature research all different kinds of gymnastic mats were analyzed and divided into landing mats, damping mats and crashmats. To make sure the new designed mat will be safe, current crashmats were analyzed by conducting a drop-hammer test to find out the mat's characteristics. Also the interaction between the mats and the gymnasts was analyzed by doing observations and conducting interviews. Based on these steps a list of requirements and wishes was created and a clear design assignment was made; Redesign the current crashmats to enable easier transportation without reducing its functionality.

With this redesign goal and the list of requirements and wishes the ideation phase was started. Lots of brainstorming was done, with an 365 brainstorm and co-design session to collect as many ideas as possible. Eventually this ideation phase resulted in five different concepts. These concepts were analyzed with a Harris profile based on the wishes and requirements set by the users. Based on this, two concepts were chosen and elaborated.

With a second drop hammer test and co-design session with actual users, more details about both concepts became concrete. With these details the two concepts were elaborated and low fidelity prototypes were made to test the concepts with gymnasts. Based on these tests, a final concept was created. To test this final concept in an user test, the most important showstoppers were made in three prototypes. These prototypes were tested with five professional gymnasts and evaluated as an successful product, especially in woman artistic gymnastics, according to its user's needs.

Foreword



Hallo there! Welcome to this report. In this report you will find an overview of my findings and the process of my development during my graduation thesis. During my graduation project, I've been busy delving into the world of gymnastics and gymnastic mats to design a product for the TeamNL athletes of the gymnastic association FlikFlak. The InnoSportLab s'Hertogenbosch was asked to develop a transportable crashmat for gymnastic events. Within their organization I was designing for and with the gymnasts and their coaches to come up with the best suitable solution to make their intense sport a bit safer. This research was set up to complete my Masters studies for Design for Interaction, at Delft University of Technology.

Before you can start enjoying my process, I would like to thank a few people which made it able for me to finish my project and supported me to get through it. So a few words of thanks to:

Arjen Janssen for his guidance, lots of feedback, enthusiasm and support as the chair of this project.

Renate de Bruin for her guidance, good, clear and personal feedback, her tips and support as the mentor of this project.

Maurice Aarts for his guidance and useful discussions as company mentor and lab manager of the InnoSportLab s'Hertogenbosch.

Stefan van Meurs for his contribution, feedback, tips and brainstorm sessions as the fixed strength of the InnoSportLab s'Hertogenbosch.

All the gymnasts and their coaches, in particular Tim Goedkoop and Shade van Oorschot, for sharing their expertise and knowledge for the project.

My friend Loes Quirijnen who helped me with my struggles in making the model and working with MatLab and accepting my swearing about all the error messages (and joining me sometimes).

My graduation friends for having my back, providing me with tips and joining me for brainstorm and co-design sessions.

My mother, brother and sister for always supporting me, providing feedback in their own enthusiastic way and helping me to get through the project.
Thank you all!

Fenne Hendriks
Tilburg, January 2023

Glossary

B-value	Damper constant
Crashmat	Gymnastic mats which are designed to absorb kinetic energy during a fall or crash.
C-value	Spring constant
Damping mats	Mat which is used upon a landing mat. A stable surface to land on, at the same time reduces peak impacts on the body.
Deflection	The measured distance (in mm) between a calibrated base plane and the maximum displacement of a mass below the base plane.
Gymnastic mats	All mats used in gymnastics
HB	High bar
Hight of rebound	The measured distance (in mm) between the base plane and the maximum displacement of a mass above the base plane.
ISLDB	InnoSportLab s'Hertogenbosch
JF	Janssen Fritsen
KNGU	Koninklijke Nederlandse Gymnastiek Unie
Landing mat	Gymnastic mats which are designed to absorb kinetic energy during landing in a controlled way on both feed.
MAG	Men Artistic Gymnastics
MAG HB	Men Artistic Gymnastics high bar
MAG13	Men's 0.10m supplementary mat
UB	Uneven bars
WAG	Woman Artistic Gymnastics
WAG UB	Woman Artistic Gymnastics uneven bars
WAG17	Woman's spotter mat

Table of content

1.Introduction

In this chapter an overview and explanation of the current gymnastic mats and their differences are given. Furthermore, the focus and set up of this research will be subscribed and explained.

1.1 Mats in gymnastics

Gymnastics has a long history as a competitive sport and became part of the Olympic Games in 1896. Today, gymnastics is a very popular sport internationally, especially among young people. The International Gymnastics Federation (FIG) has 148 associated federations, with an estimated 50 million people around the world participating in a gymnastics club (Piedade et al., 2021). The sport includes artistic or rhythmic gymnastics. In rhythmic gymnastics gymnasts make use of special apparatuses, like hoops, ribbons and clubs, to assist them while performing. On the floor they perform ballet and other routines accompanied by music. Artistic gymnastics is a discipline of gymnastics in which athletes perform short routines on different apparatuses (Brittney, 2021). In Men Artistic Gymnastics (MAG) there are a total of six apparatuses: floor, pommel horse, rings, vault, parallel bars and high bar. In Woman Artistic Gymnastics (WAG) there are four apparatuses, comprising: vault, uneven bars, balance beam and floor (Payne, 2019). For this research, the artistic gymnastics are studied since the impact loads are highest. To reduce the impact load on a gymnast during a fall or landing, gymnasts make use of landing-, damping- and crashmats during practices.

Gymnastic mats must absorb the kinetic energy in order to reduce the reaction transmitted to the body of the landing gymnast to a tolerable proportion. Landing mats are designed to absorb the biggest kinetic energy of a landing gymnast, but makes it still able to land in a controlled and stable way. These landings are seen as a conscious landing on both feed. Based on Janssen Fritsen (2022) most common measurements of landing mats are 200x200cm and a thickness of 20 cm. However, these measurements can change dependent on the apparatus it is used for. Figure 1 shows a landing mat.

Figure 1. Landing mat

According to Payne (2019) impact loads of landing reported values of up to 10 times body weight for gymnasts during landing from a height of 1.28m. To make sure gymnasts will experience a lower impact on their bodies, they make use of

damping mats. Just like landing mats they must absorb kinetic energy. However, these mats are used on landing areas, which means they are used on top of landing mats and on the gymnastic floor to absorb extra kinetic energy to make the impact on the body lower. These mats will have all kind of dimensions, but most common are damping mats which are as large as the landing mat they are placed on. They have a thickness of 5 or 10 cm. Figure 2 shows a damping mat.

Figure 2. Damping mat on landing mat

Crashmats are also used to absorb kinetic energy, but they are designed for crashes and falls. These mats are softer than landing mats, in that way they are able to absorb more motion energy. However, gymnast do not prefer using them by conscious landings, since these crashmats are more instable than landing mats which makes it harder to land in a controlled way. Crashmats will have different measurements and forms, based on the apparatuses they are used and the level and difficulty of the gymnast and their exercises. It starts with falling in the pit (Figure 3), followed by a very thick and soft crashmat (Figure 4) and eventually a small crashmat will be used on top of landing- and damping mats. Based on the gymnastic discipline, spotter mats can also be used. These mats are similar to crashmats, but have handles on the side to catch a gymnast from the air, especially used for trampoline exercises. Most crashmats have a dimension of 1x2m, but this again could differ per apparatus. They are lighter than landing- and damping mats and have a lower (foam) density. They are always used on top of other gymnastic mats. Figure 5 shows a crashmat.

Figure 3. The pit underneath a UB set

Large impact loads lead to a high risk of injuries. Surface contact is the most common injury mechanism. In gymnastics, landing has the highest rates of injury (49-76%), followed by falls and collisions (27.8%) which goes along with the risk of surface contact (Piedade et al., 2021). Surfaces like thinner mats, gaps between landing mats, and hard tumbling surfaces are predisposing factors to injury. Potential energy and risk of (more severe)

Figure 4. Thick crashmat

Figure 5. Crashmat

injury is directly related to height and is directly correlated to the amount of kinetic energy leading to injury during a fall (Piedade et al., 2021). Through these high impact loads, the so called crashmats are often used in apparatuses with a severe height. Such as vault, male high bar (HB), female uneven bar (UB) and the balance beam. Where the HB is 2.80 (to a maximum of 2.90m) above the ground and the athletes fly 0.60/1.00m above that and the upper of the UB is 2.50+0.10m off the ground (FIG, 2021b). The mandatory thickness of the landing mats for HB/UB is 0.20m (FIG, 2021b). Especially for the HB and UB there is a severe risk on missing the bar after doing a flight element, which could result in crashes (Zone, 2021). With the impact loads mentioned earlier, this could result in severe injuries. Therefore, this research is focused on the HB and UB (see Figure 6).

Figure 6. HB (left) and UB (right)

1.2 FIG regulations

This design project is done in cooperation with gymnastic association FlikFlak located in 'de Plek' in s'Hertogenbosch the Netherlands. De Plek is the national Topsport center for MAG and regional Topsport center for WAG. Within this association the InnoSportLab s'Hertogenbosch (ISLDB) is established. ISLDB is a nonprofit organization and the only organization focusing on the innovation for gymnastics in the Netherlands. They are measuring, monitoring and testing the gymnasts and their equipment. Since 2016 they are part of the SportInnovator and they are working closely together with the royal Dutch gymnastic union (KNGU) and other partners.

To make sure all mats are safe, they need to be approved by the FIG. This means that those mats need to have a specific deflection, height of rebound and a maximal force (FIG, 2021c). Where the deflection is set as the measured distance (in mm) between a calibrated base plane and the maximum displacement of a mass below the base plane. The height of rebound is the measured distance (in mm) between the base plane and the maximum displacement of a mass above the base plane. The maximal force (Fmax in Newton) is the maximum force estimated based on the deceleration measured during the impact (FIG, 2021c). It is important to test gymnastic mats over time, since the performance of these mats could change over time. With a drop hammer test the FIG regulations can be tested for each mat. The ISLDB has such a drop hammer, which makes it able to see if the gymnastic mats fulfil the FIG regulations. These requirements for different gymnastic mats are shown in Appendix A. Since crashmats are not obligated in events, the FIG did not set these requirements for crashmats, which makes it unclear when a crashmat is (still) safe to use. However, it is important to figure out the deflection, height of rebound and maximal force of the current crashmat to make sure the new designed crashmat will fulfill, this because the current crashmats are experienced as safe and nice to use.

1.3 Research set up

This design project can be described as a double diamond process (van Boeijen & Daalhuizen, 2020) as shown in Figure 7. First this research will diverge, which will focus on exploring the context to find out which aspects a good solution needs to fulfil. This phase will focus on the interaction of the gymnasts and coaches with the crashmats. How and when are they used now or why are they not used now? This will be achieved by doing observations, interviews and co-design sessions with the real users, the gymnasts and their coaches. Since landing mats have clear regulations regards their safety, it is important to find out when a crashmat is experienced as safe. This could have a quantitative as well as a qualitative side. Which regulations do crashmats have in comparison with landing mats, which will be measured with a drop hammer test and compared with literature research. At the same time this research would try to find out when and why a gymnast is experiencing a crashmat as safe. Observations and interviews will be done to figure this out. Than the research will converge again by making a list of wishes and requirements and a clear problem statement and (re)design goal. After this, the process will diverge again with the iteration phase. In this phase lots of solutions and ideas will be generated to achieve the (re)design goal. This iteration phase will be supported by learned methods like brainwriting, sketching, 365 brainstorming and co-design sessions. This phase will result in different concepts which will be compared with the list of wishes and requirements and which will be

discussed and tested with the gymnasts and their coaches to eventually converge again towards a final (re)design.

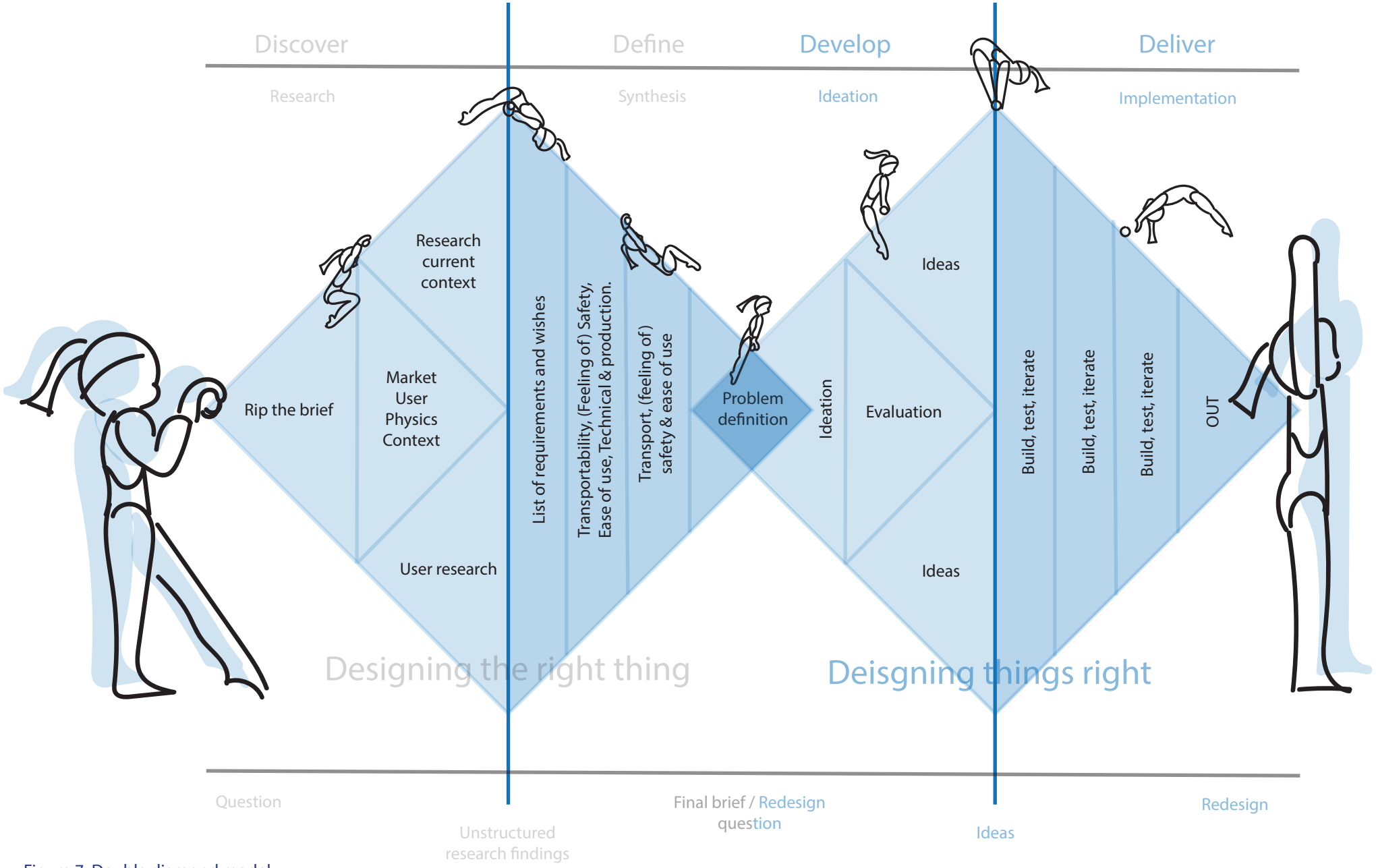
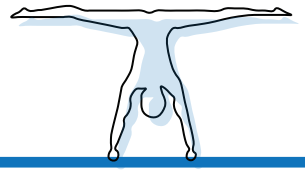


Figure 7. Double diamond model

2. Current context exploration



To explore the current context several components of the current crashmats were analyzed. First of all literature and an analysis of the catalogues of Janssen Fritsen is done to see what is already there, which characteristics these mats have and to see if there are any FIG regulations the crashmat could be compared with. Secondly, a drop hammer test of the current crash mats will be held to collect the FIG characteristics of the crashmats used in FlikFlak. Finally, the current context is explored by observations and interviews with gymnasts and their coaches.

2.1 Market research

To get a better understanding of these mats material, implementation, costs and measurements, the catalogues of a material producers for gymnastics is analysed; Janssen Fritsen (JF). JF has a collaboration agreement with the ISLDB, besides this 90% of the gymnastic material used in the training halls of FlikFlak is from JF. Therefore, this catalogues is analysed. According to JF's catalogues (2020) there are several mats, with different options for material, sizes and visual look. Appendix B shows the different type of mats JF has in their catalogues (2020), with some specifications/implementations and picture. Table 1 gives an overview of the mats which comes closest to crash mats used in practise.

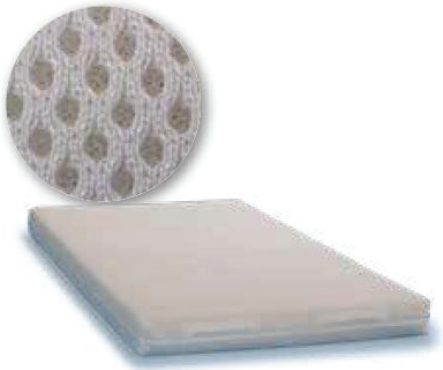
Mat	Implementation	Picture	Specification
Fall damping-flopmats	Used upon landing- and damping (hard landing situation) mats to reduce peak loads during a fall. Has a soft density foam filling.		**Prices:** €402,- **Sizes:** 200x100x15 cm
Spotter mat	Used to throw under a gymnast by a spotter to reduce peak loads during a fall. They are thinner and lighter and therefore easier to throw. Often used for trampoline exercises. Has a soft density foam filling.		**Prices:** €399,- **Sizes:** 200x100x12cm
Soft crash mat	Used when a gymnast is still unsure about their routine/exercise, but the next step after using the pit. It ensures a safe and comfortable falling surface and is made from three polyether foam layers.		**Prices:** €1453,- to €4499,- **Sizes:** 200x150x70 cm 350x200x70 cm 200x100x70 cm

Table 1. Different crash mats according to Janssen Fritsen (2020)

By comparing the mats in Table 1 similarities can be found and a clearer overview of the 'to be researched' crash mats is found. The so called fall damping flopmats and spotter mats are most likely to be used as crashmats upon landing- and damping mats before an event. The soft crash mats are more likely to be used during training. Furthermore there are some similarities between these crashmats. First of all, all mats are made from low density foam, they all have a minimum size of 200x100 cm and they all reduces the peak loads during a fall. When having a closer look at the material used for the mats in Table 1, again catalogues of JF was analysed. Especially for the landing mats, JF has four different material options, also shown in Appendix B. Table 2 shows the materials JF uses for their crashmats with their characteristics and implementations.

These materials are both used for crash landings. Where one is more stable than the other for landings on both feet. Both are made from polyurethane foam, but with another density. One is a combination of three foam materials, where the other is a solid block of the same foam, which is more appropriate for hard crashes (and thus very soft crash landings). Which could conclude that a lower foam density provides a softer crash.

2.2 FIG regulations for events

As mentioned in the introduction landing mats need to fulfil several FIG regulations. Next to the deflection, height of rebound and maximal force there are some more specific regulations per apparatus or mat. For example, landing mats have specific set dimensions during events. These differs per apparatus. To see if there crashmats also have specific dimensions for the HB and UB, a closer look on the set measurements for these apparatus was done. Figure 8 and Figure 9 shows

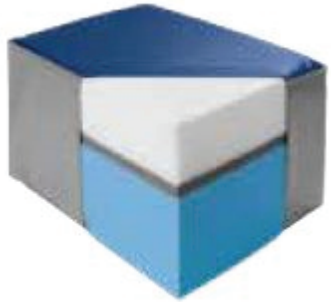
Material	Characteristics	Implementation	Picture
18 kg/m^3 polyurethane foam	Wide air channels for quick air evacuation.	Used **on** landing mats to create a very soft crash landing with less stability.	
JF sandwich padding. Polyurethane 30 and 35 kg/m^3 foam in combination with a polyethylene flat divider.	Fast soft top layer that signals the muscles to tense. Pressure distribution layer that converts the point load into an area-elastic impression.	This material is developed for soft crash landing compared with high stability.	

Table 2. Different materials used for crash mats according to Janssen Fritsen (2020)

the set mat dimensions for HB (Figure 8) and UB (Figure 9). According to the FIG (2021) the HB needs a 12x3m 0.20m thick landing mat (dark blue area) and the UB needs a 14x2m 0.20m thick landing mat (dark blue area). Both make use of a damping mat during events, represented by the light blue areas. If present, both apparatus use an extra damping or crashmat for training and warming up in the hall before an event. The figures shown that MAG13, corresponding to a 0.10m supplementary mat, and WAG17, corresponding to a spotter mat, are used for training and warming up in the hall (orange area). The FIG also stated specific rules for these mats, these specifications are shown in Table 3.

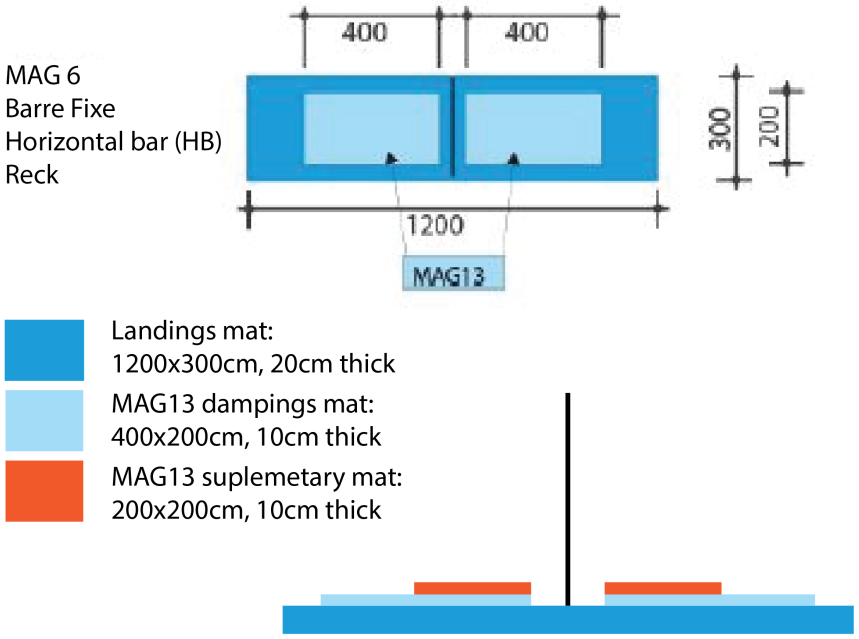


Figure 8. Landing mat specifications for HB (FIG, 2021)

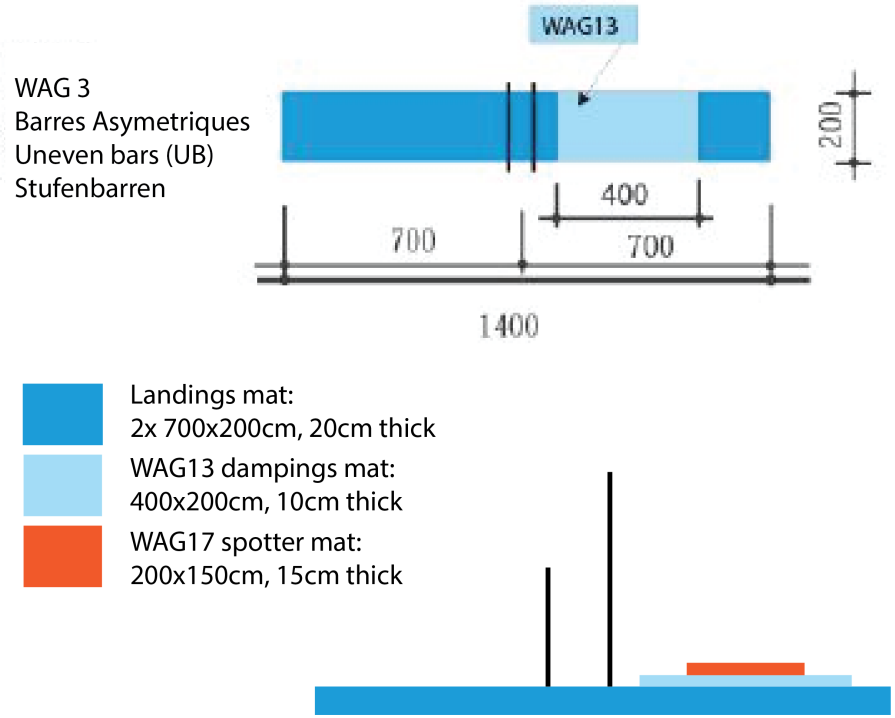


Figure 9. Landing mat specifications for UB (FIG, 2021a)

Based on this analysis, it can be concluded that there are lots of different mats used for gymnastics. By analysing JF's crash-mats it could be concluded that most crash mats have a minimum size of 200x100cm and are made of soft density foam. The lower the foam density, the softer the crash landing. By analysing the FIG's properties and regulations regards comparable products a clearer view on foam density, measurements, dimensions and covers are created.

	Supplementary mat (MAG13)	Spotter mat (WAG17)
Usage	The use of a supplementary mat is compulsory in competition for the athletes on the vault and on Horizontal Bar. For training and in the warming up hall an additionally supplementary mat shall be available at the Floor, Rings, Vault and HB.	The presence of a spotter mat is compulsory in competition for the athletes on the trampoline. It must have at least two handles or one long handle on the two long sides of the mat. This will make it able to catch someone from the air.
Density	25 kg/m^3 foam (+/- 2,5 kg/m^3)	20 kg/m^3 foam (+/- 2 kg/m^3)
Ultimate tensile strength	>= 115 kPa	>= 90 kPa
Compression stress value 40%	4,0 (+/- 1,0) kPa	2,5 (+/- 0.5) kPa
Outer material	By no means should mats be dislocated during performances. At the vault the supplementary mat shall be attached to the landing mat.	It must be covered with a material which will slide easily.
Dimensions	600x200cm by vault 400x200cm both sides by HB	Length: 200 cm (+/- 50 cm) Width: 150 cm (+/- 50 cm) Thickness: 15 cm (+/- 5 cm)

Table 3. Specific characteristics for supplementary and spotter mats according FIG (2021a)

2.3 Model

To get a better understanding of the crashmat and create a understanding about its damping. A model was created based on a mass-spring-damper system. This model was validated based on the results of a drop hammer test (see chapter 2.4) which can be seen in Appendix C. The model was created to be able to predict the deflection of the mat based on its material characteristics. Material characteristics like its spring- and damper constant, respectively c- and b-value. Nevertheless, the c- and b-value of materials is hard to find or measure. Because the deflection of the mat depends on the material and thus the c- and b-value of a material, the model was not further used in this research. This because without knowing these values, the model could not be used to predict the mats deflection.

2.4 Drop hammer test

A drop hammer test is conducted based on the standardized test by the FIG (2022b). This test is standardized for 20cm landing mats and therefore some variables are changed for testing crashmats. This because a crashmat is not used for landing and therefore not for point impact but area impact. If the crashmat is used for landing, the gymnast would go 'through' the mat to have a more stable landing on the landing mat placed underneath. Therefore, the test is modified in four variables. First of all, the point impact as well as area impact is tested by adding an extra area on the impactor to see how much this would differ. This extra area is created by adding a 0.10x0.20m cardboard area. Also the impactor weight is changed to 10 kg instead of 20 kg, since crashmats are made from low density foam which makes the crashmats less 'strong' as landing mats. Also the mat is not tested on 9 points but only in the

middle. However, it was made sure that every mat was tested in the middle of the mat. Finally, the underground of the test was supported by a small foam area, which was also tested without a mat on it and was used as the 'ground' mat. This to make sure the ground would not be damaged by the test. Figure 10 shows the set up of the test with the changed variables.

Since all tests are conducted to compare different mats, it is no problem that those variables are changed. It only needs to make sure that every mat is tested with the same variables shown above. Three different mats were collected from the training hall of FlikFlak and were tested: 1) old matrass used in WAG as a crashmat during training, 2) the specific mat used in WAG UB trainings and 3) the specific mat used in MAG HB trainings. All mats are used in training halls as crash mats, they all consists of low density foam. However, other characteristics are not known. This because crashmats are not used in event halls and do therefore not have any FIG regulations. However, these mats are still used in training halls and experienced as safe by gymnastics and their coaches. Therefore, the drop hammer test is performed to figure out the characteristics of these mats.

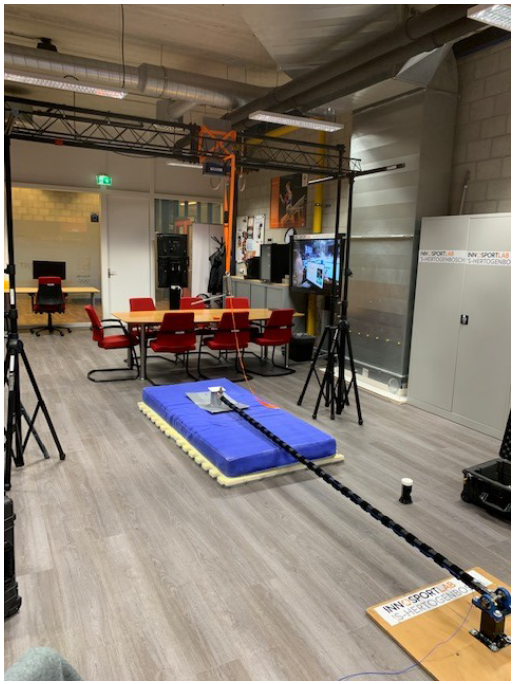
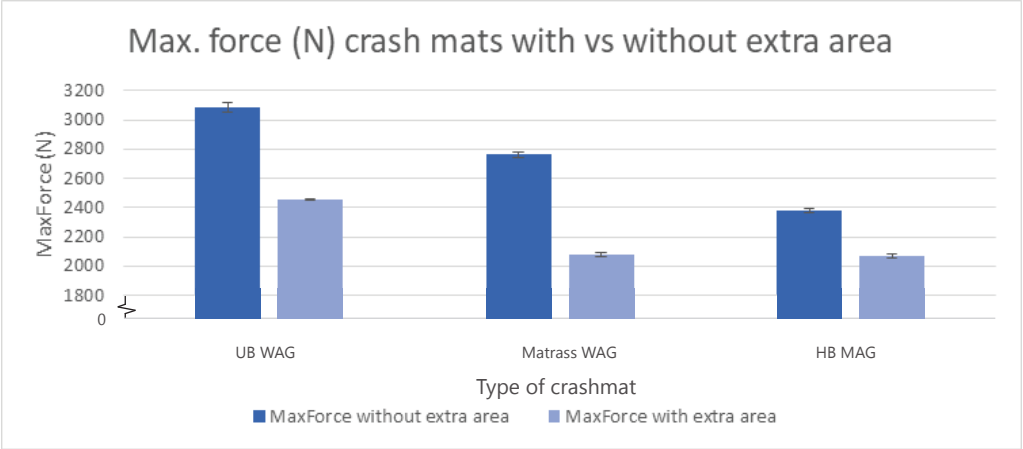


Figure 10. Drop hammer test set up

2.4.1 Outcome drop hammer test

First of all the test was performed with and without an extra area, the averages of all tests were compared with each other. Graph 1 shows the comparison between both. The vertical axis starts at 1800N to be able to better compare the Standard Deviation (St. Dev). As can be seen, the maximal force without an extra area is higher in every test. Which means that landing in a crashmats absorbs less kinetic energy than falling in a crashmat. However, since the extra area was a cardboard plate, this area would transform after every drop and could therefore be less reliable for a consistent result for every test. Also the point impact has the highest maximal force, this means that the mat will damp more if the athlete will fall flat. Therefore, the point impact will be used to further analyze the results, to make sure all tests are comparable and to make sure the mat is safe with the maximal impact. As can be seen in Graph 1 tests with extra area do not have any bigger St. Dev as the tests done without extra area. All analyzed data can be found in Appendix D.

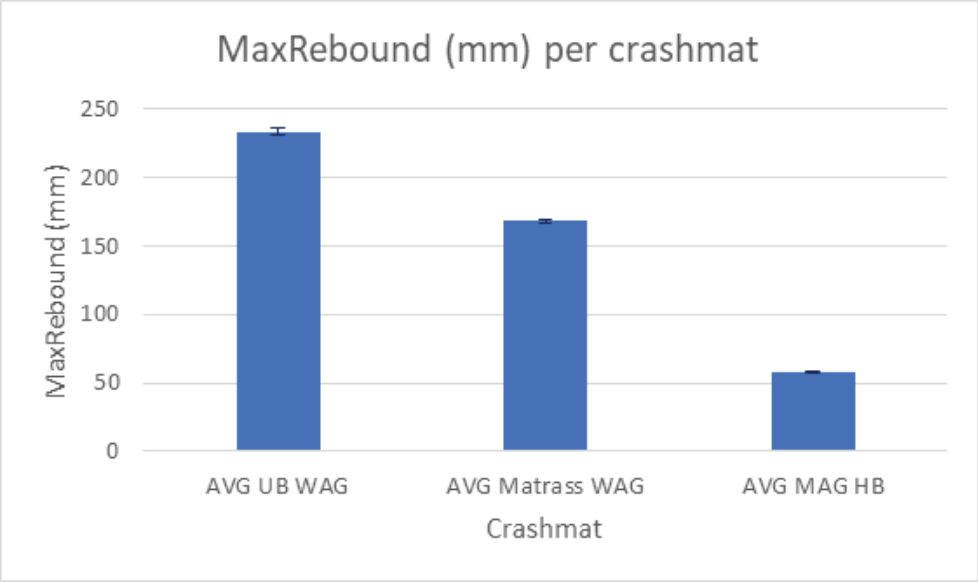


Graph 1. Comparison of average with and without the test with an extra area.

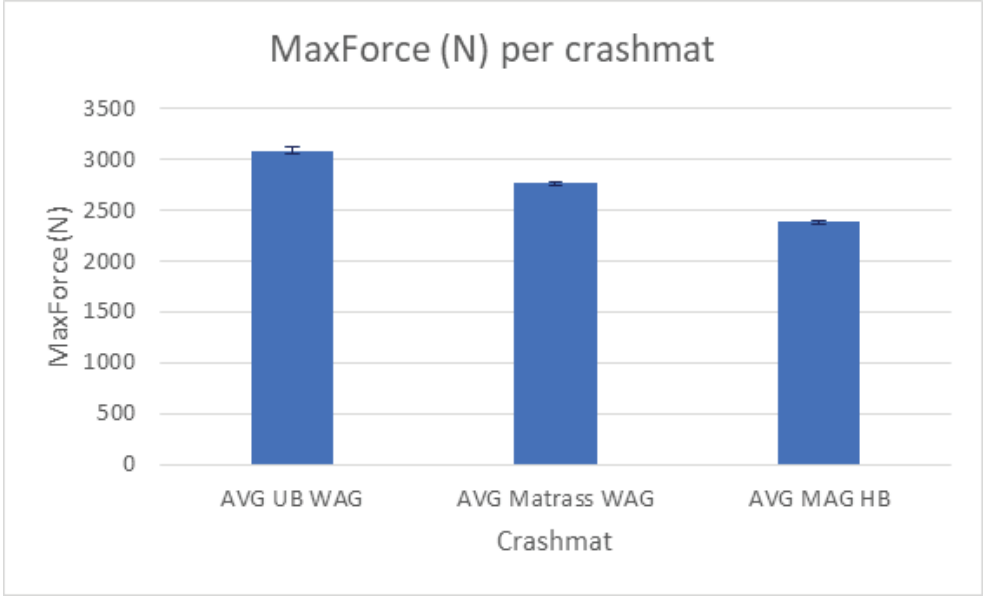
Table 4 shows the average of each test per mat. This data corresponds to the Graph 2, 3 and 4, in which the data is shown to compare the different mats. In the table also the St. Dev is shown to see the variety in the tests. As can be seen in Table 4, the St. Dev in each test is very low. Therefore could be concluded that the test outcomes are consistent and average outcomes could be used for further research.

	MaxDeflection (mm)	MaxRebound (mm)	MaxForce (N)
AVG UB WAG	153,083	233,297	3085,795
St. Dev	0,358	2,385	31,392
AVG Matrass WAG	136,023	168,191	2763,631
St. Dev	0,274	1,040	19,792
AVG MAG HB	99,927	58,489	2381,408
St. Dev	0,097	0,444	12,695

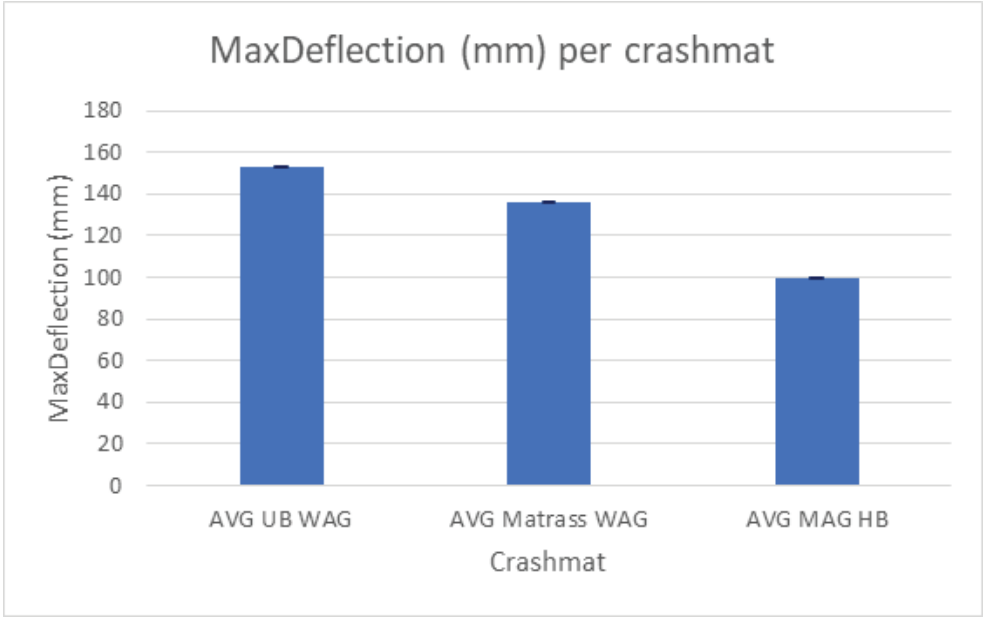
Table 4. Average of three drop hammer tests per mat.



Graph 2. Overview of the maximal rebound per mat.



Graph 3. Overview of the maximal force per mat.



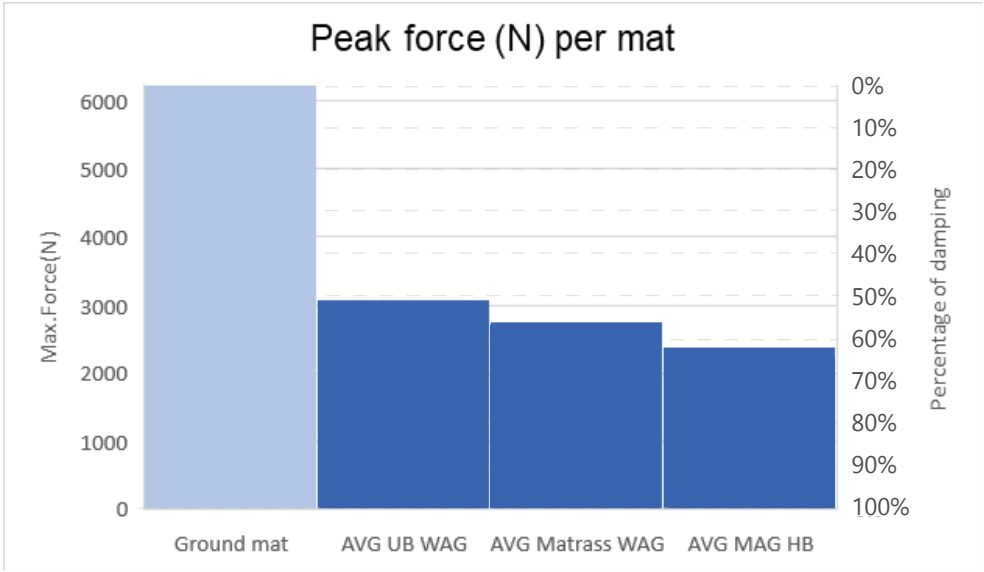
Graph 4. Overview of the maximal deflection per mat.

As can be seen from Graph 2, 3 and 4, the maximal rebound, force and deflection all correlate with each other. The higher the maximal force, the greater the maximal rebound and deflection. For a gymnast it is most important that the maximal impact force will be as low as possible. This means that the crashmat will absorb the most kinetic energy, which makes the force on the gymnasts body as low as possible. Regarding the maximal deflection, it is important that the crashmat is not too bouncy, which means that the athlete should not fly too high in the rebound. In that way the second impact force will be lower and this will give a safer feeling for the gymnast. Finally, the maximal deflection must not be greater than the thickness of the crashmat when falling flat. When it is greater, the gymnast will fall 'through' the crashmat, which means it will fall on the 'hard' landing mat underneath. This means the crashmat should absorb the first peak impact. However, it is important that the peak force when landing on two feet (point impact) will fall through the crashmat. This makes it able for the gymnast to land on the crashmat.

In graph 2, 3 and 4 can also be seen that there is a difference in crashmats. Crashmats have lots of different characteristics, which not only differs in MAG and WAG, but also in the individual mats. However, in general all mats damp around 50% to 60% of the peak forces, see Graph 5. Which means in practice that the (re)designed crashmat should damp at least 60% of the peak forces, which means it will damp even more when falling flat onto the mat.

2.5 Users

Finally, the interaction between the user and the crashmats was



Graph 5. Overall damping percentage per mat

explored. By providing interviews with gymnasts and doing observations, questions were answered; 1) what is the current user context of the crashmats and how are users currently interacting with the mats, 2) what is the problem regards the transportation of crashmats and finally 3) when is a crashmat experienced as safe. All gathered information will be used to generate a list of wishes and requirements and make a clear redesign goal for this research.

This exploration started with some observations. Immediately, it stood out that they struggled with the dimensions and the weight of the crashmats. Especially in the WAG training hall. Some crashmats are too big and too heavy to transport with only one person. In WAG these mats were often transported with at least four athletes, which is inconvenient but especially not doable during events. The small crash mats most of the time were thrown instead of carried to transport.

Especially for UB and HB the crashmats are already in place most of the time and are not transported during training sessions. An training hall off course has a different set up than an event hall, which makes it easier to leave the crashmats in place. Also they train UB and HB on 'soft' landing in training halls, which means they will use the pit, or a big soft landing mat. They only have one (uneven)bar in which you could land on landing mats and even there are lots of crashmats placed upon the landing mats, see Figure 11.

Figure 11. Training hall FlikFlak UB situation.

Observations of the WAG World Cup qualifiers in Rotterdam training hall gave a better understanding of the problem. However, since this is a training hall, the mats were represented. It stood out that almost all gymnasts used the mat during warm up, especially the youth athletes. Most of the time mats were transported by coaches. In some cases the crashmat was also used during the actual routine, in which it was placed underneath the UB by the coaches if a flight element had a severe risk of going wrong. It happened several times that the gymnast crashed in the mat, which made clear the importance of these mats being present in event halls.

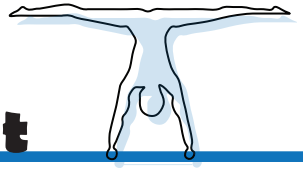
The prior national MAG coach was the first one who questioned the fact that there were no mats available on some events during warm up and training. Therefore a first interview was held with this coach to gain a better understanding from the wishes and requirements of the mat. This interview was held by Maurice Aarts from the InnoSportLab s'Hertogenbosch on 19-05-2021 and can be found in Appendix E. Also some small unstructured interviews were held with the current trainers and coaches. At last, structured interviews (Appendix F) were held with two professional gymnasts; an 18 year old female gymnast practicing gymnastics 26 hours a week at Topturnen Zuyd and TeamNL and a 23 year old male gymnast who is currently phasing out of the TeamNL gymnasts but always competed on the highest level. The interview was mainly focused on getting a better understanding of the current context, focusing on (the preparations of) events.

From these interviews the current context became more clear, also several important wishes and requirements were found for the new design of the mat. The problem which was mentioned by both participants is the presence of the crash mats in event halls, especially when going abroad. Despite of the FIG's obligations for MAG13 and WAG17 for HB and UB (the orange area in Figures 8 & 9), it is unsure if the mats will be present or

usable in event halls. “It changes a lot, sometimes those mats are present in those halls, sometimes they are not, you do not know that in advance.” (S. van Oorschot, personal communication, 2022). Also there is a need, especially in MAG, to have a freedom of movement in a crashmat. Which means they should be able to land in every way they want on the crashmat, without injuring or hurting their selves. For them this is important for their feeling of safety (T. Goedkoop, personal communication, 2022). Also bringing your own mat with you is hard and inconvenient since mats are big and clumsy to take with you; ‘there is a reason we only took a mat with us once.’ (T. Goedkoop, personal communication, 2022). Therefore, the mat should be made transportable. For trainer and coaches it is important that the mat is easy to handle, to make sure they are able to slide it under the UB or HB to catch the athlete if necessary (B. van Bokhoven, personal communication, 2021).

2.6 Requirements and wishes

Based on these interviews, the earlier literature and market research and a product life cycle (Appendix G), a list of requirements and wishes was made based on; production, ease of use, transport, technical, safety and feeling of safety. Most important requirements are based on the categories safety, transportation, and the ease of use of the product. Safety can be divided in qualitative and quantitative safety. Quantitative implies that the mat should be safe in terms of damping percentage, point and area impact forces, border zones, etc., while qualitative means measurements, material feeling, etc. For transportation the requirements are mainly focused on weight and measurements. Ease of use is very important for gymnasts, especially before an event. This means they want to focus on their event as much as possible. Therefore (un)packing the mat should take less than one minute and no additional actions are needed to use the mat during warming up or practice. The full list of requirements and wishes is elaborated during the design phase of this research and can be found in Appendix H.



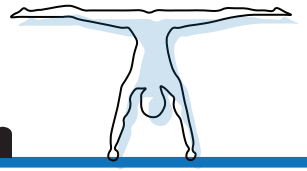
3. Design assignment

Ending the first research phase could state that the current context has several problems regarding the transportation and usage of crashmats in competition halls. The most important problem is the insecurity about the presence of a crashmat in competition halls. Therefore, the InnoSportLab s’Hertogenbosch was asked to create a transportable crashmat. To make sure a crashmat could be used in event halls, to reduce the risk on injuries during practice and warming up before an event. Thereby, it is important that the mat is safe, which means that the functionality of the crashmat should not reduce in the design process. Which means in practice that the mat should absorb at least 60% of the peak forces. The mats are always used on landing mats, so the first peak force is most important to be absorbed. To make sure gymnasts could make use of a crashmats in competition halls, the following design goal could be stated:

Redesign the current crashmats to enable easier transportation without reducing its functionality.

Based on the user research there are eleven hard requirements. These requirements are set based on the users' needs and wishes, and are therefore seen as hard requirements. These hard requirements are mainly focussed on the (feeling) of safety and the ease of use of the product. This was seen as most important by the gymnasts, to persuade them to user the product. The hard requirements are as followed:

- Mat needs to catch every gymnast despite their weight, length, gender, etc.
- Using the mat must not lead to extra actions while being used during warming up or exercise.
- (Un)Packing the mat must take less than 1 minute.
- The mat should have a minimum length from elbow to knee.
- Needs to withstand high forces without breaking.
- Absorbency: Must absorb at least 60% of the peak forces from the first contact.
- Impacts on the border zones should not cause different indentations than on the remaining surface, which means that landing on the borders should not have a damping factor lower than 50%.
- The cover of the mat should be safe material for the skin.
- No chance on the athletes hurting their selves from the mat.
- The athlete should have the possibility to land in the way that they want. This will mean in practice that the mat should damp point as well as area force with at least 60% and used material should give the opportunity to land on your feet without injuring something.
- The products working must not relay on human actions.



4. Ideation

While the first phase of the double diamond model was ended by having a clear view on the current context and its users. The second phase started with the ideation phase. The goal of this phase is to gather as many ideas as possible in all kinds of directions on how to answer the redesign question. To gather these ideas, several ways of brainstorming were used; individual brainwriting, sketching, 635 brainstorming and co-creation with fellow students.

4.1 Brainwriting, sketching and 635 brainstorm

This phase started with some individual brainwriting and sketching, which gave some first ideas. To gather more ideas a 635 brainstorm was held. Nevertheless, it could better be described as a 335 brainstorm due to late cancelations of some of the participants. However, the session was still held with three participants in an online setting. All participants were Design for Interaction master students, to get creative ideas. A Miro board was used to gather the ideas online. The session had three participants, each writing 3 ideas in 5 minutes. After 5 minutes the participants go to the other 'paper' and contributes to ideas from others on that 'paper'. This is done for six rounds which results in 54 ideas regards the redesign goal (see Appendix I). What stood out; most ideas were focused on the material or filling of the mat. They came up with for example air, foam, water, old bathrobes, fiberfill filling, stress balls and styrofoam. Also some transportation methods repeatedly came by, mostly focused on rolling, clicking and stacking. All ideas were analyzed and used to come up with more ideas and later

on some first concepts.

4.2 co-creation session 1

After the first rounds of brainstorming, lots of ideas were generated. Nevertheless, those ideas were not always realistic or feasible. To make these ideas more feasible and to gather even more ideas a co-creation session was held with three participants. Therefore, the co-creation focused on low fidelity physical prototyping. All participants where again master students Design for Interaction at Delft Technical University, aged 22, 25 and 26. Two of them participated in gymnastic events in their youth so they had some affinity with crashmats. To make sure every participants understood the context a small introduction 'presentation' was given, with some in context pictures and shared experiences by interviews and observations. session had two main goals; 1) how would they transport their mat and 2) how will they make their mat transportable. For the first goal of this session the participants will be provided with a scaled mat in the form of a paper. The participants are asked to prototype a system to transport these scaled mats towards the event. They get twenty minutes to prototype these mats and they were allowed to ask for new 'mats'. In the upcoming ten minutes the prototypes they made were discussed in the group. For the second goal the table was filled with all sorts of materials, from foam to rope see Figure 12. They were asked to create a way to transport a mat with these materials. They got twenty minutes to make as many prototypes as they wanted and again the next ten minutes were used to discuss the prototypes.

Figure 12. Co creation session overview

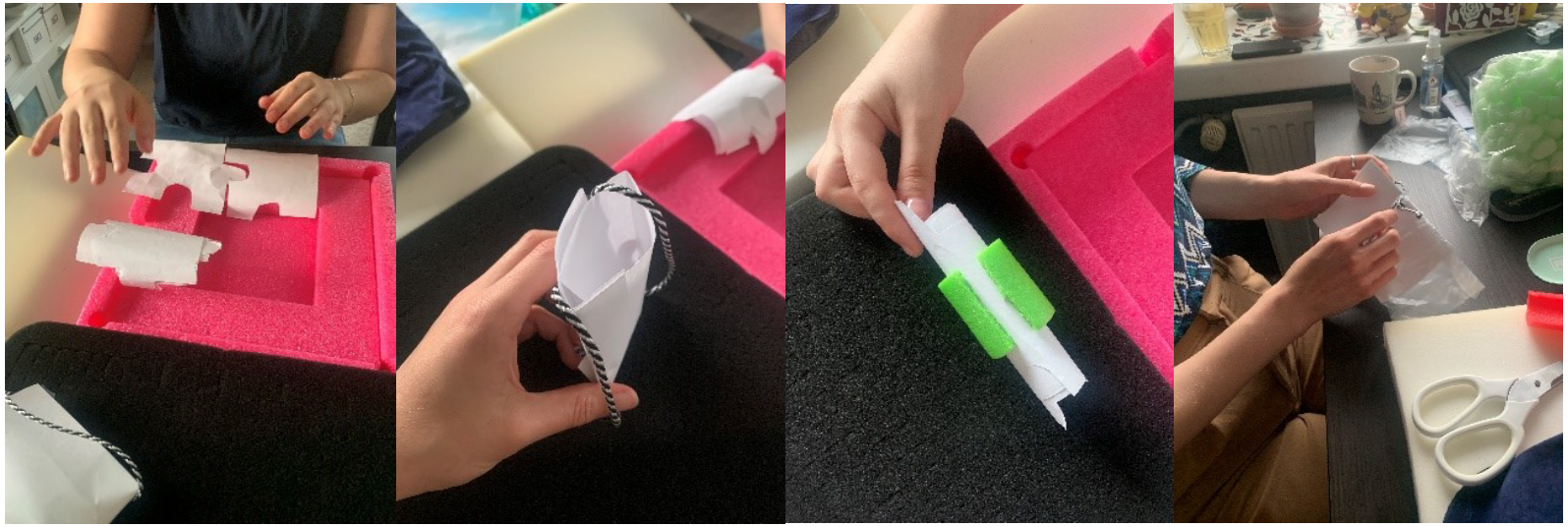


Figure 13. Most interesting ideas of co-creation session regards transportation.

Figure 13 shows the most interesting and realistic ideas of the first question: how should you transport the scaled mat? Most ideas consists of rolling the mat, fold it in a way that it transforms in a bag (backpack or suitcase) or transport it in different pieces (like the child floor puzzle foam).

Regards the second goal, the prototyping was harder and therefore less prototypes were made. Nevertheless, two potential prototypes were generated. One of them was based on rolling the mat and secure it with a double sided layer on the back of the mat (Figure 14 left). In this way there is no need for separated materials. Also by rolling the mat the air is going out of the foam and the foam is getting smaller. The second idea was based on a rope mechanism that secures the mat while rolled (Figure 14 right).

Figure 14. Most interesting ideas of co-creation session regards the design goal.

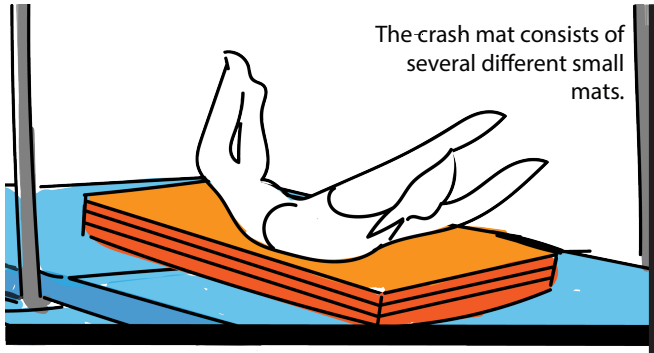
5. Conceptualization

After the ideation phase, the conceptualization phase started. In this phase the ideas become more concrete which eventually will end in one final concept. Five first concepts were generated from the ideation phase and were evaluated during the conceptualization phase to come up with the best possible ideas. To evaluate these ideas and specify concrete details of the mat several methods were used; 1) an interview with gymnasts to get their opinion about the first concepts, 2) a second drop hammer test for material selection and 3) a co-design session to find out specific details like size and color.

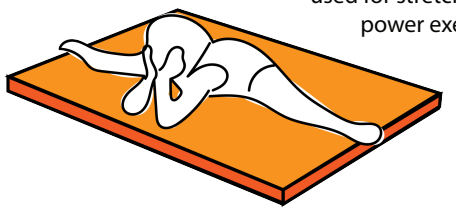
5.1 first concepts

A selection of ideas was made based on the feasibility and how they scored in comparison with the list of requirements and wishes. These ideas were sketched out and further analyzed based on their feasibility. From this first selection, a vALUe analysis (van Boeijen & Daalhuizen, 2020) was made to select the best ideas from the selection. This full analysis can be found in Appendix J.

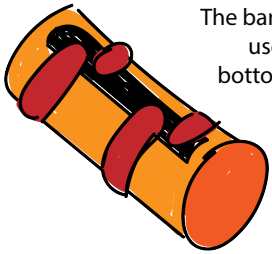
Based on the vALUe analysis five ideas were selected and elaborated to some first concepts. These five concepts were sketched, see Figure 15-19, and taken to the next phase; conceptualization.



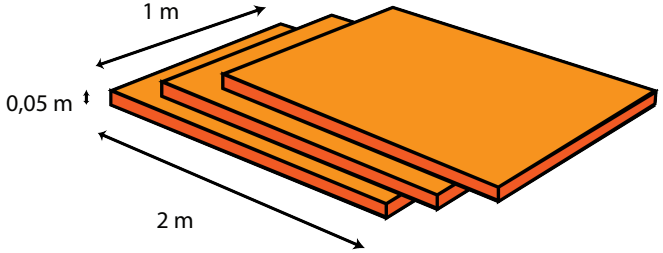
The crash mat consists of several different small mats.



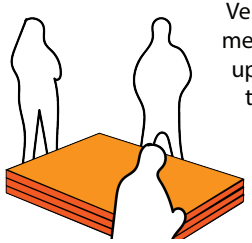
The single mat can be used for stretching or power exercises.



Band with velcro ends can be attachted to hold the mat in place. The bands can also be used to cover the bottom 'hard' velcro.

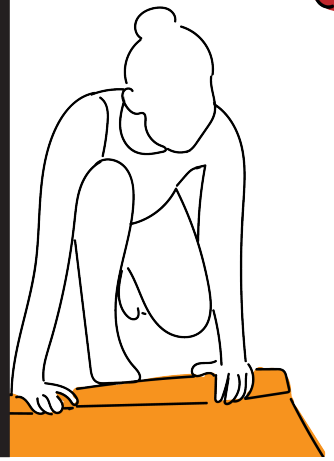


Measurements



Attach mats with your team to form the crash mat.

Velcro attatche-ment soft on the upper, hard on the bottom.



Roll your own mat to transport your mat.

Transport the mat with your team and staff to the event. No extra luggage area, just attach it to your backpack and go!

Custimizable: The mat is customizalbe for each athlete individual, but it can also be customizable for one team.

TeamNL

Concept 1: sharing is caring

In this concept the mat will consist of multiple mats, which individually can be rolled and transported. The mats will be connected and secured with velcro and can be custimizable per athlete.

Figure 15. Concept 1

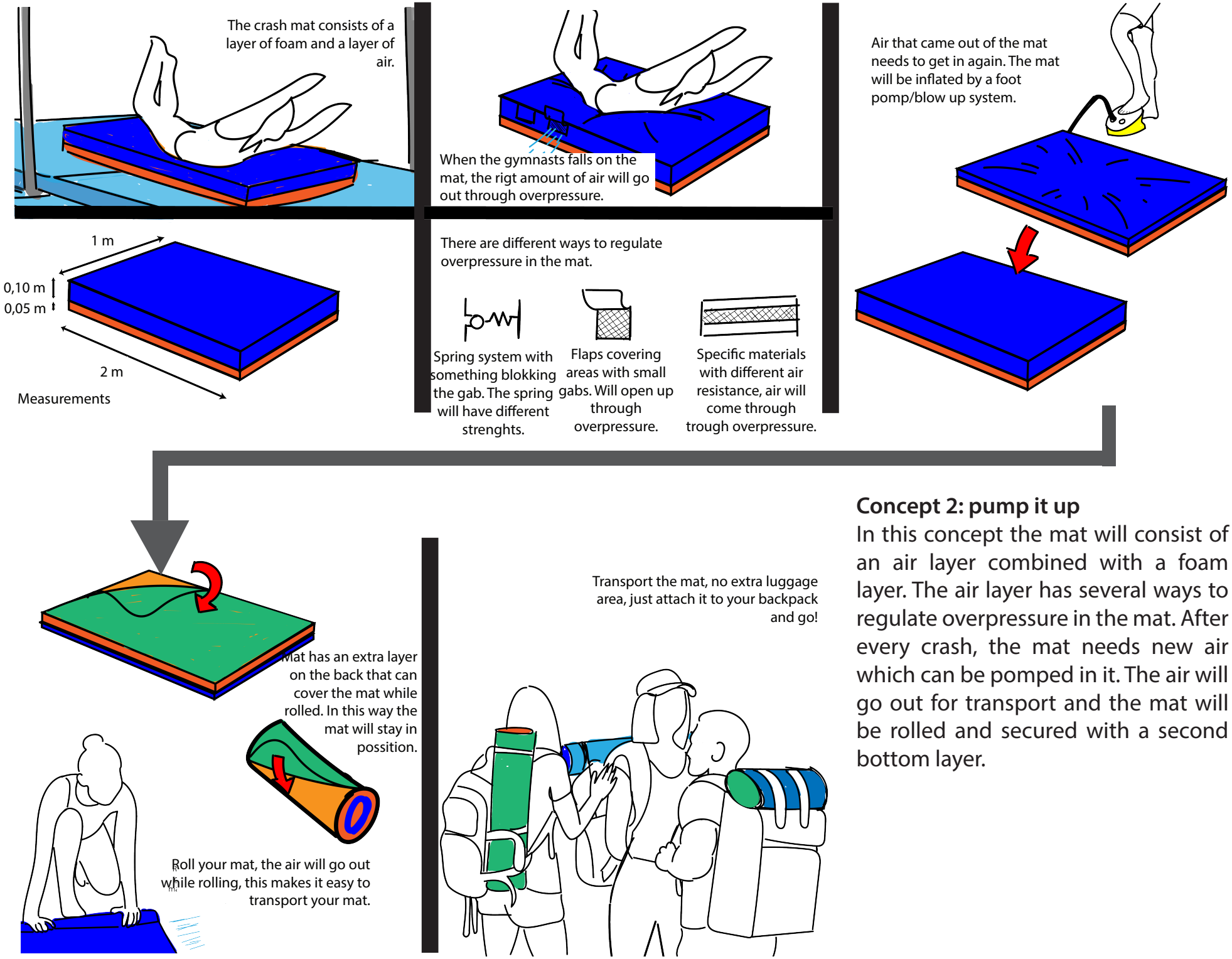
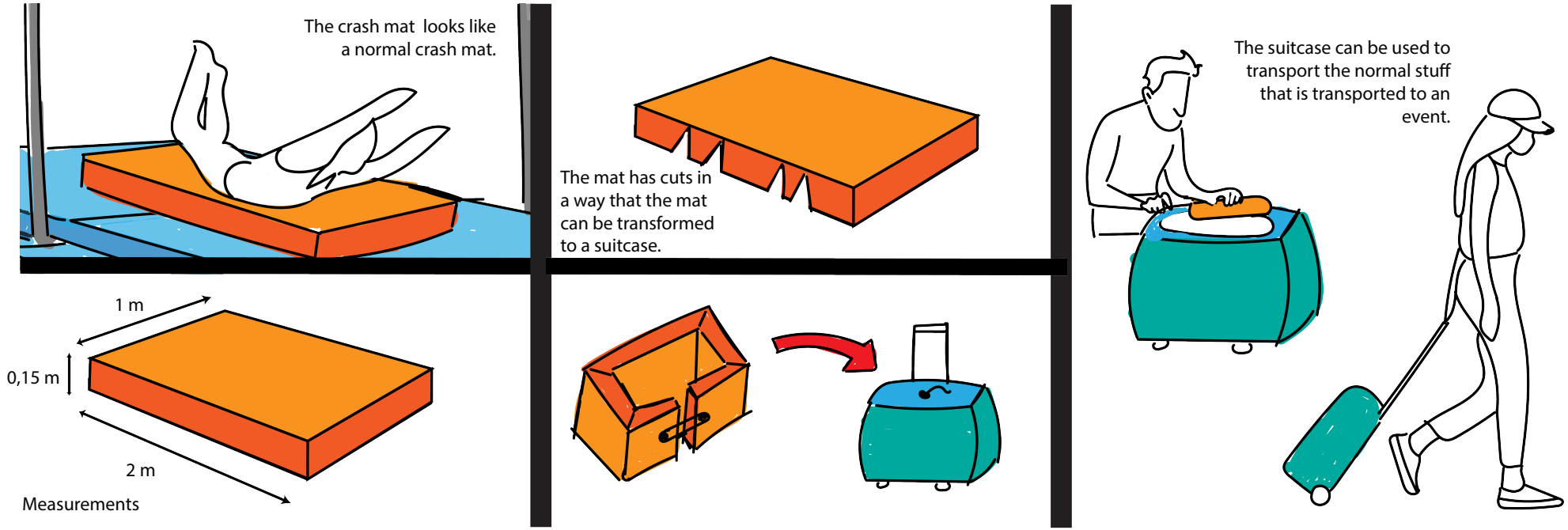


Figure 16. Concept 2

Concept 2: pump it up

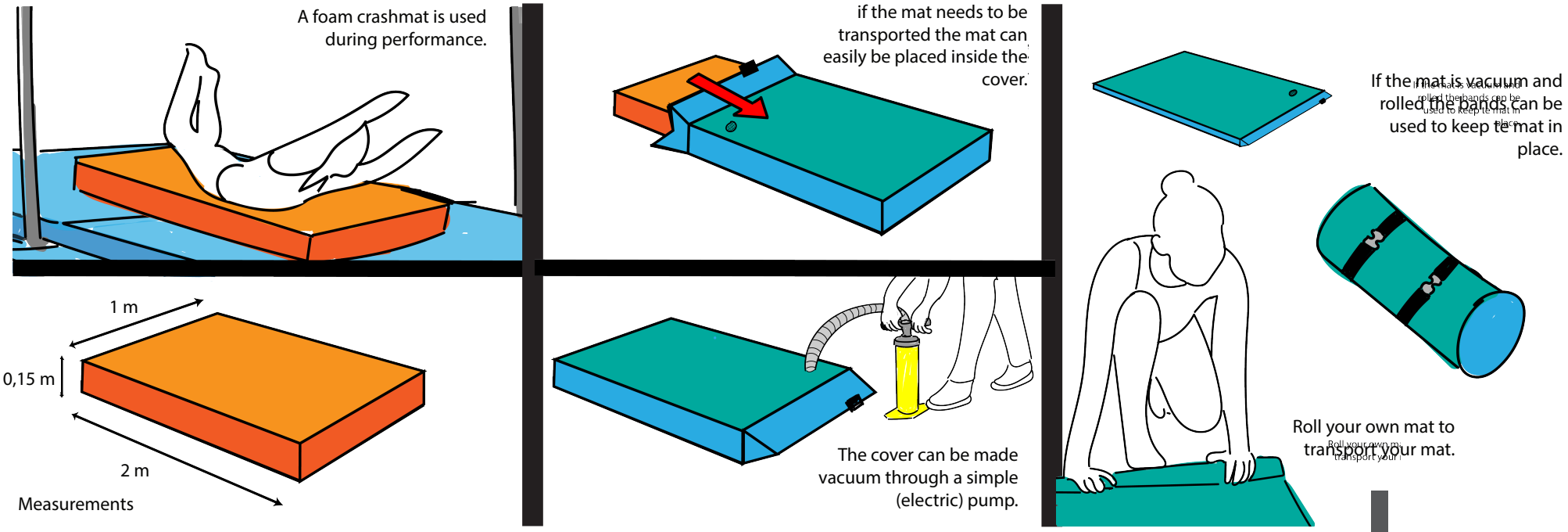
In this concept the mat will consist of an air layer combined with a foam layer. The air layer has several ways to regulate overpressure in the mat. After every crash, the mat needs new air which can be pomped in it. The air will go out for transport and the mat will be rolled and secured with a second bottom layer.



Concept 3: roll away

In this concept the mat will have several cuts. Folding the mat with this cuts transforms the mat into the outer of a suitcase. By adding a outer bag on it, the mat can be used as a suitcase to transport some other materials.

Figure 17. Concept 3

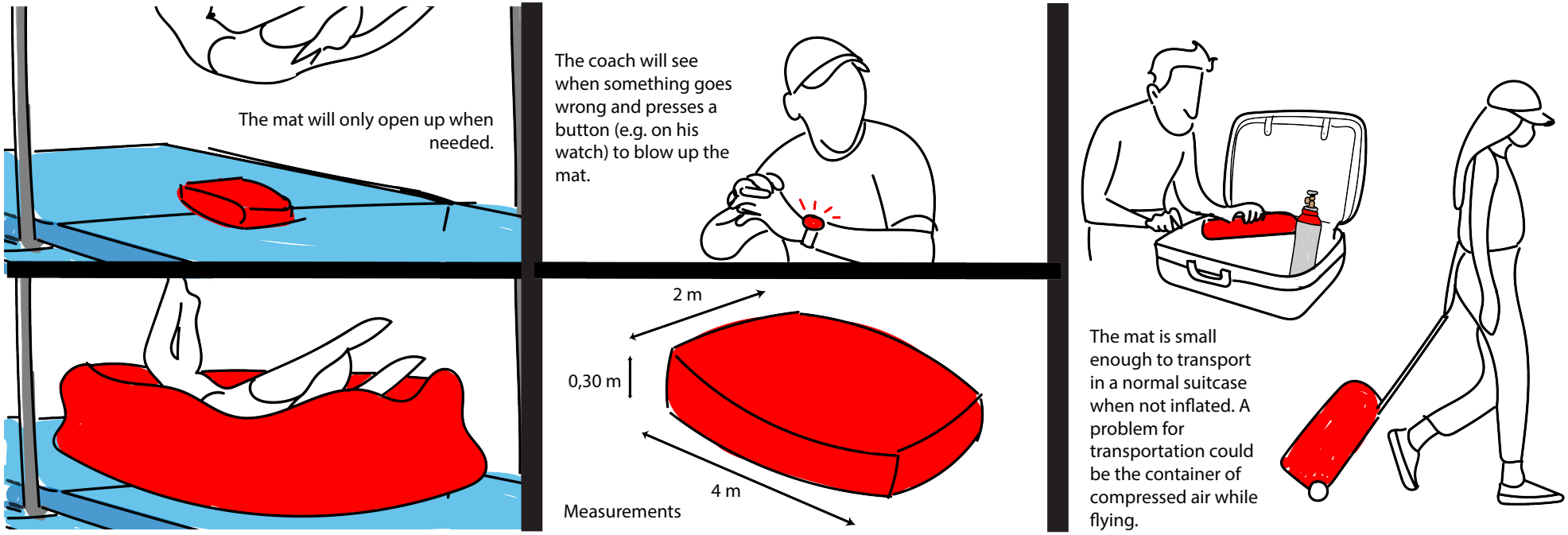


Transport the mat, no extra luggage area, just attach it to your backpack and go!

Figure 18. Concept 4

Concept 4: no air

In this concept the mat will be a normal foam mat. This mat wil be placed in a cover/bag and rolled and secured with bands. By pumping out the air, the foam will become much thinner.



Concept 5: airbag

In this concept the mat only consists out of air. The mat will be transformed as a small 'package'. This package consists of an seal and a container with compressed air. If the athlete makes a fall, the coach/trainer will press a button which will activite the compressed air, which will fill the bag with air fast. The athlete will fall in the bag filled with air and the bag will slowely deflate.

Figure 19. Concept 5

5.2 Concept evaluation

To start this phase, the five concepts created at the end of the ideation phase were analyzed based on structured interviews with two gymnasts (Appendix F). The interviews were analyzed with a thematic content analysis (van Boeijen & Daalhuizen, 2020), which is shown in Appendix K and give some clear insights and created or changed/ specified some requirements and wishes. Based on these interviews a Harris profile (van Boeijen & Daalhuizen, 2020) was made to have a clear overview of the concepts and their strengths and weaknesses. The list of requirements and wishes consist of six categories; production, ease of use, transport, technical, ease of use, safety and feeling of safety. These categories were used to analyze the concepts. Additionally, the absorbance of peak forces (the only hard requirement in safety) is not added to the profile as well, since it is a hard requirement which all concepts need to meet. For production the feasibility is added to the Harris profile, to make sure the concept could be created in the given time. The final five concepts were analyzed in the Harris profile in Figure 20. Four blocks are shown, from left to right the block corresponds to; --, -, + and ++. Based on the interviews, the requirements are listed from most important (above) to least important (below). The full reasoning behind the interpretation of the Harris profile can be found in Appendix L.

5.3 material analysis

From this Harris profile could be concluded that concepts 1 and 4 scores best and will therefore be further developed. One clear resemblance within these concepts is the material used: foam. To further analyze which foam is best to be used, a second drop hammer test was done. Once again the test was performed as the standardized test by the FIG (2022b), with the same changes as mentioned in chapter 2.4. Four different types of foam were analyzed, as well as combinations between them and the influence of layers or solid used foam blocks. Since this test was used to compare different types of foam, it was decided to again measure the point peak forces of the impactor. This because the point peak force will be higher than

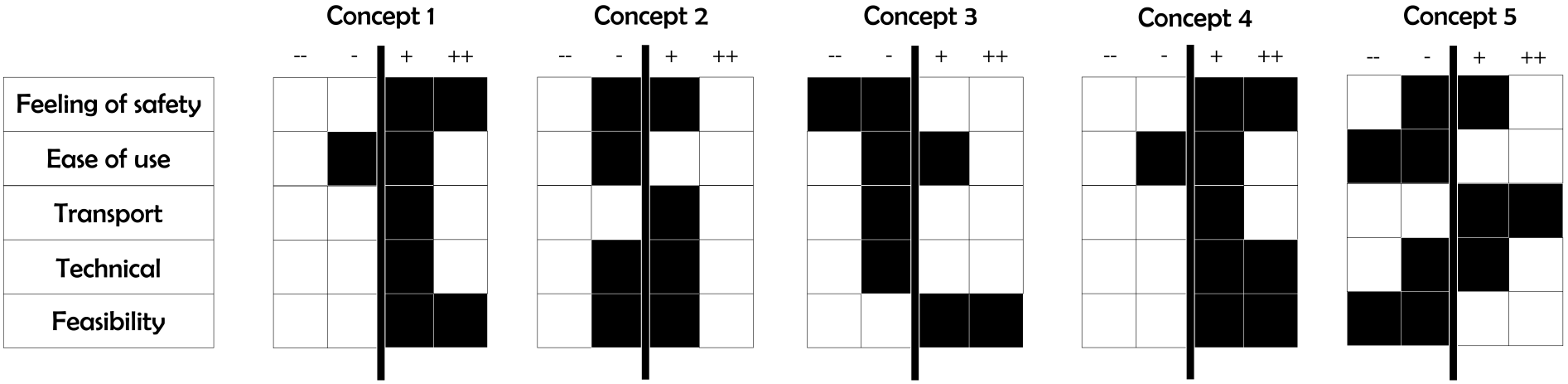
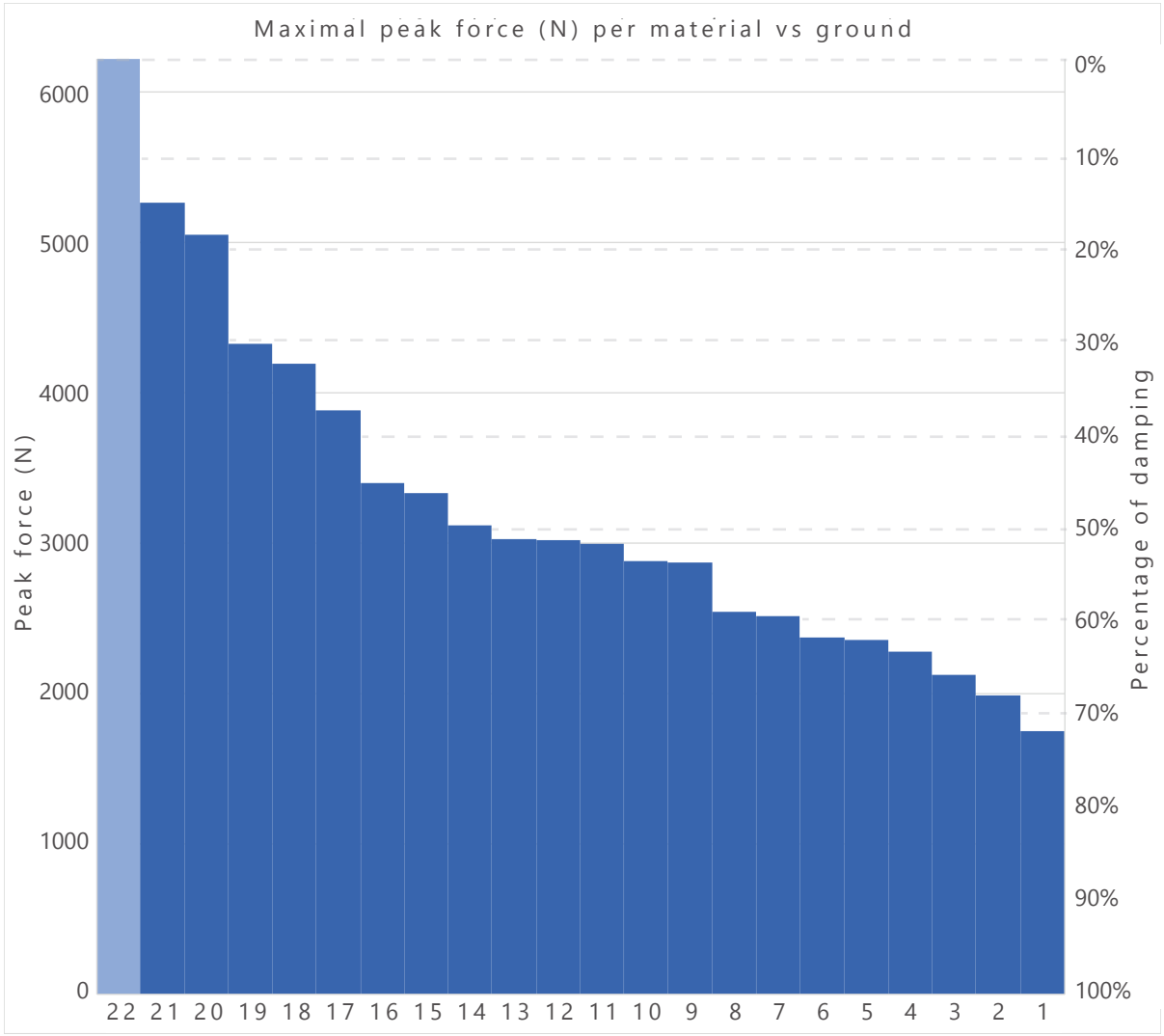


Figure 20. Harris profiles for the 5 concepts

the area peak force, in that way the maximal damping factor will be tested per material. All samples have the same size (20x20cm) and are tested in the middle. In this way, the foams are also tested on what happens if the gymnast will land close to the border. All tests are done to compare specific materials. If all variables are constant, it is able to compare the results and thus the materials. Graph 6 shows the damping percentage per tested material. From this graph can be seen that polypress foam has the highest damping factor of over 70%. All materials shown in the table under the orange line are corresponding to a material that is damping at least 60%, which is a hard requirement set for the redesign. All data and the further analysis can be found in Appendix M.

Numbers corresponding to the following materials, in which 22 scored worse on damping(ground) and 1 scores best on damping:

22 – Ground (mat)
21 – koudschuim 1x5cm
20 – traagschuim 1x5cm
19 – koudschuim 2x5cm
18 – traagschuim + koudschuim 2x5cm
17 – traagschuim 2x5cm
16 – polypress 1x5cm
15 – koudschuim 3x5cm
14 – koudschuim 1x15cm
13 – traagschuim 3x5cm
12 – koudschuim + polypress 2x5cm
11 – koudschuim + plastic bag with gabs 1x15cm
10 – traagschuim + polypress 2x5cm
9 – koudschuim + plastic bag without gabs 1x15cm
8 – polyether 3x5cm
7 – polyether 1x15cm
6 – traagschuim 2x5cm + polypress 1x5cm
5 – polypress 2x5cm
4 – traagschuim 1x5cm + polypress 1x5cm + traagschuim 1x5cm
3 – polypress 1x5cm + traagschuim 2x5cm
2 – traagschuim 1x5cm + polypress 2x5cm
1 – polypress 3x5cm



Graph 6. Damping percentage of the peak force (N) per material test.

5.4 Co-design session 2

However, polypress is a stiff foam and does therefore feel very hard to land on. To compare the test results with the user perception a co-design session was held. In this session some more physical characteristics of the concepts were tested; 1) measurements, 2) cover and 3) transportation. The session had six participants. Two of them are TeamNL gymnastics. Two of them are the lab leaders, who have a high affinity with gymnastics because they did and are doing many researches within this field, from which several drop hammer tests for damping materials. At last, two human movement scientists, which also work for the lab which gives them some experience with gymnastics, collaborated in the session. The entire set up of the session and the full outcome can be found in Appendix N.

After selecting two concepts based on the Harris Profile, the co-design session created a clearer view on the final concept by combining the remaining concepts. With the co-design session, several components were made clear; material, dimensions, cover, transportation and the connection of the different mats. All are elaborated and explained below.

5.4.1 Material

First of all, the material was ranked by all six participants during the co-design session, from worst to best; 1) Polyether, 2) Koudschuim 1x15cm, 3) Koudschuim 3x5cm, 4) Traagschuim and 5) Polypress. Also the materials were ranked based on the amount of damping they gave during the drop hammer test, this resulted in the following material ranking; 1) Polypress, 2) Polyether, 3) Traagschuim, 4) Koudschuim 1x15cm and 5) Koudschuim 3x5cm. By comparing these rankings there can be concluded that Polypress had the highest damping percentage, but had the lowest scores corresponding to the results of the co-design session. Polyether scored second best in the drop hammer test and also best during the co-design session, since this material was experienced as soft but strong by every participant. Therefore, polyether will be used as material for the redesigned crash mat.

5.4.2 Dimensions

According to the co-design session, the dimensions of the mat can be set. The participants were asked to lay down on a cardboard plate and draw their minimum and maximum size of the mat. According to these given measurements, an average of the minimal measurements can be made. These measurements will be 160 by 80 centimeters, this is corresponding to the distance from elbow to knee of a relatively big gymnast shown in Figure 21. The total thickness of the mat will be 15 centimeters, since this scored best in the drop hammer test for the chosen material. To transport the mat, the mat will be divided in three equal pieces of five

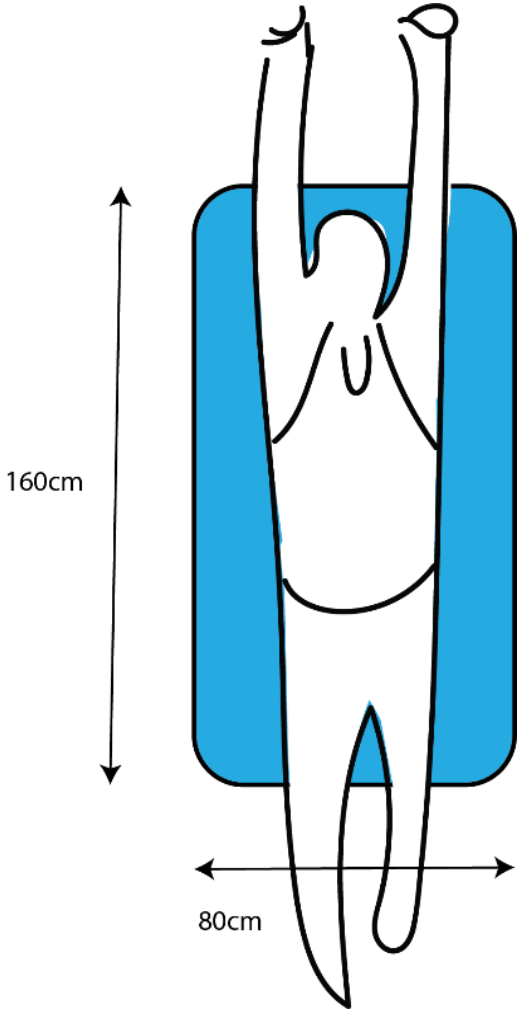


Figure 21. Crashmat measurements + gymnast

centimeters. This because from tests was given that five centimeters is the maximal thickness to roll a foam mat by one person. If the mat becomes thicker, it becomes harder to roll it by yourself. At the same time, the mat will not be thinner since than there will be more mats to transport and connect, which will lead to more actions required for set up and transport.

5.4.3 Cover

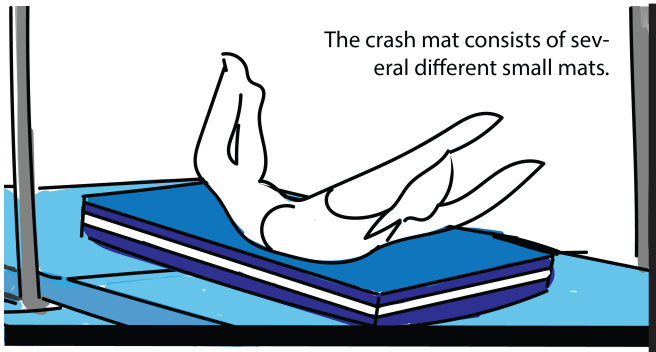
According to the cover, the co-design session resulted in a favor for soft material. Nevertheless, they all agreed with the fact that the material must be hygienic, since it could be hard to wash the cover and they will simply not do it (T. Goedkoop, personal communication, 2022). Therefore, experts of the Textielstad shop in Tilburg were asked for advice. They advised to use strong cotton or tricot, since these materials are strong, elastic and safe to fall on. Since tricot feels softer than cotton, tricot will be used for the cover of the mat. The outer two mats will have a blue cover, since this will not distract the gymnast while being in the air (S. van Oorschot & T. Goedkoop, personal communication, 2022). Additionally the middle mat will have a white color, since this will distract the gymnast the most (T. Goedkoop, personal communication, 2022). In that way it is intuitively clear that the gymnast need to use at least three mats to have a safe crash mat, since a crash mat will not have a set top or bottom. This to make sure it can be used as quick as possible when needed, so that there is no discussion of which is the top and bottom (B. van Bokhoven, personal communication, 2021).

5.4.4 Transportation and connecting the mats

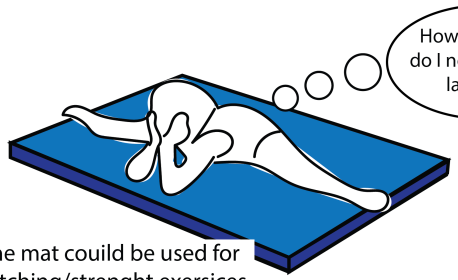
To answer the last question regarding transportation, two transport methods are most popular from the co-design session; rolling and vacuum. Mats are big and inconvenient to transport. Even if the mat will be vacuum, it is still very big. To transport the mat, a combination of both transport methods could be used.

First of all, the mats will be disconnected to three individual mats. An individual mat will be rolled and secured so that it will stay in place. Rolling the first part of the mat could be inconvenient, and therefore is supported by some small cuts at the end of the mat which will have a minimum influence on the damping in that place. If the mat is rolled, it wants to roll back in place immediately. Therefore a small brainstorm was done on how to make sure the matt will stay in place. Several ideas where generated like a zipper, velcro, clicking, bands, covers etc. Eventually two options were selected: 1) keep the mat in place with elastic bands (see Figure 22) and 2) keep the mat in place by immediately putting a bag over it that is connected to the other end of the mat (see Figure 23). Those were selected since it were the most safe and fast options from the brainstorm, since other ideas consists of hard materials like zippers or the 'hard' side of velcro.

Two transportation methods were further analyzed. This was mainly focused on transport with and without vacuum, to see if the transportation measurements are a requirement or a wish for the gymnast. With the concrete ideas resulted from the co-design session, two concepts were created. Concept 1: Vacuum bag (Figure 22) and concept 2: pack your bag (Figure 23).

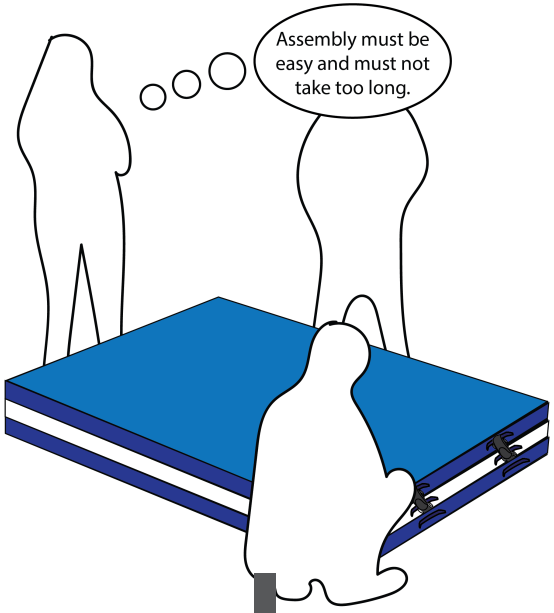


The crash mat consists of several different small mats.

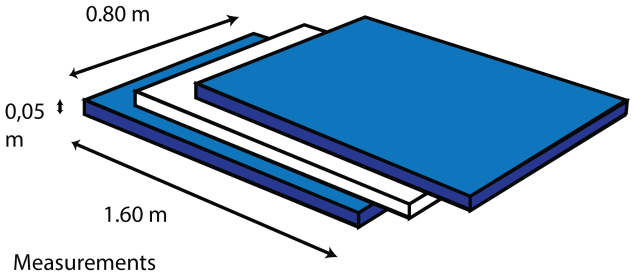


How many mats do I need to use to land safe?

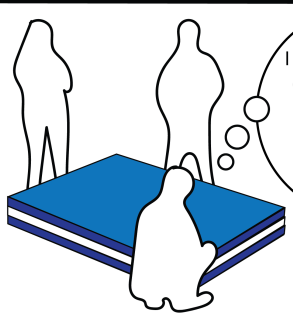
One mat couild be used for stretching/strenght exersices.



Assembly must be easy and must not take too long.

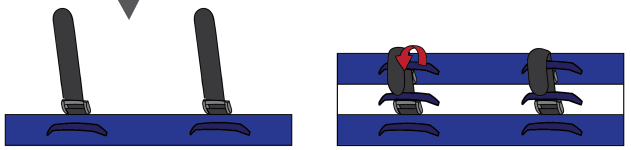


Measurements

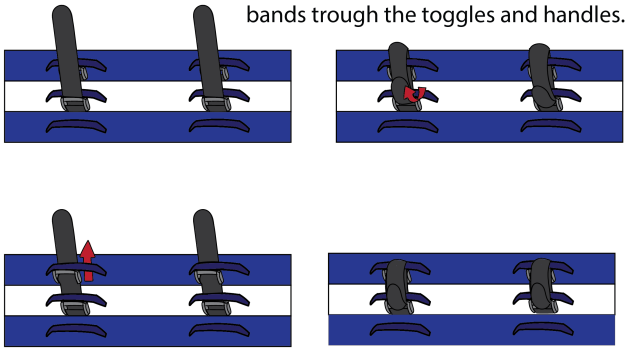


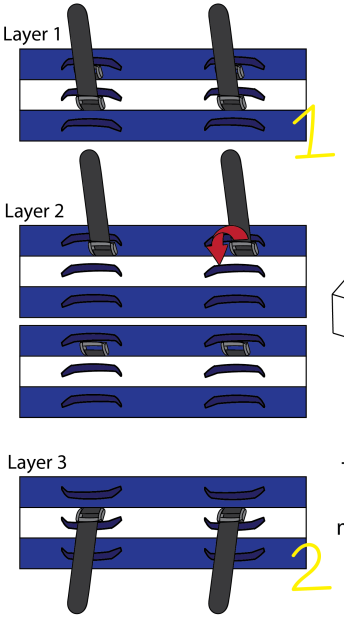
I don't want to land on the white mat, because this is distracting, so I would use that in the middle.

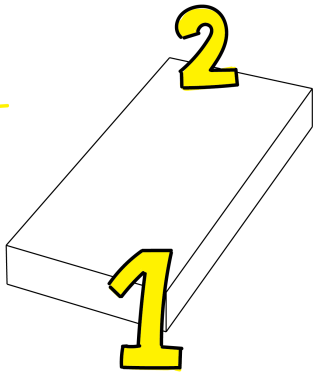
Attach mats with your team to form the crash mat.



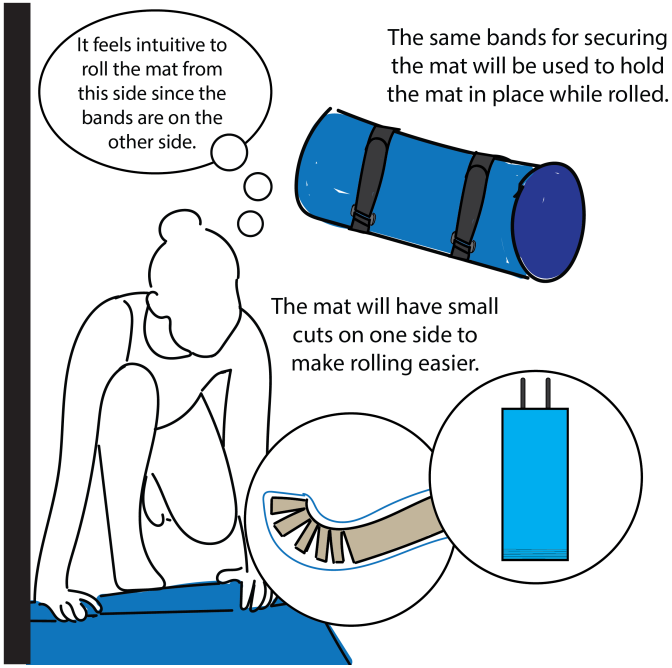
Each mat will have elastic bands with velcro on the end and a small plastic toggle. To secure the mats put the bands trough the toggles and handles.







The bands of the middle mat can be placed in between mats. The plastic toggle of the middle mat will be used to secure the mats.



It feels intuitive to roll the mat from this side since the bands are on the other side.

The same bands for securing the mat will be used to hold the mat in place while rolled.

The mat will have small cuts on one side to make rolling easier.

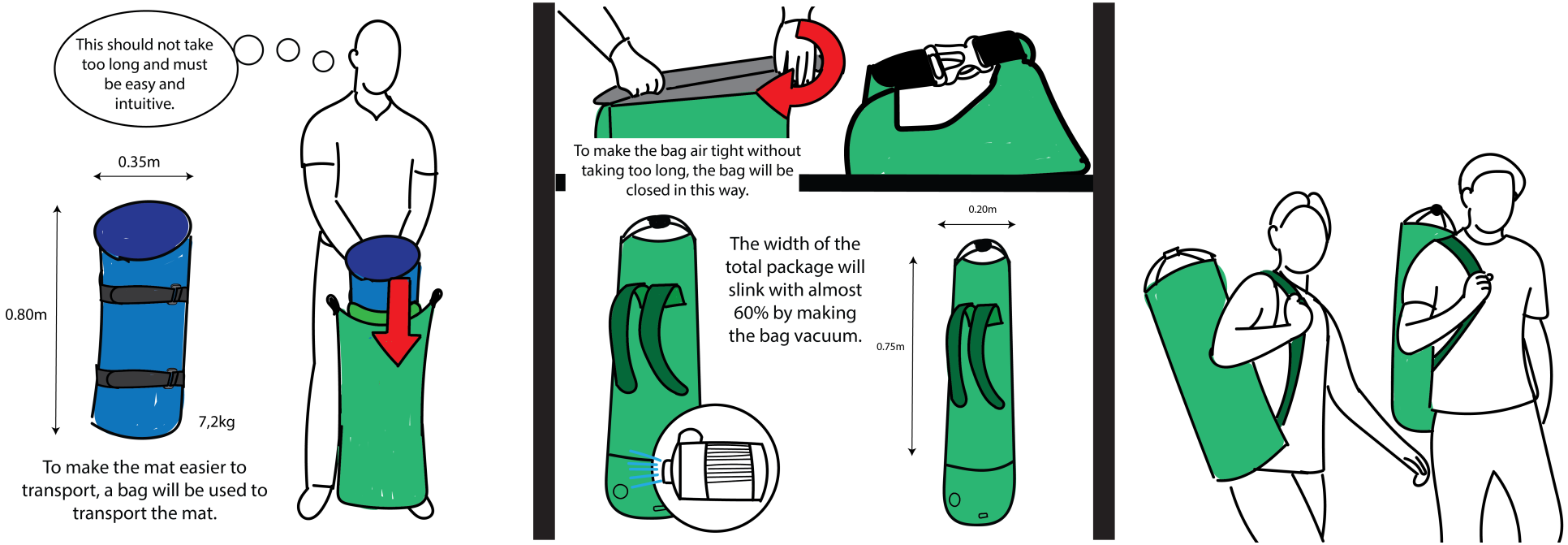
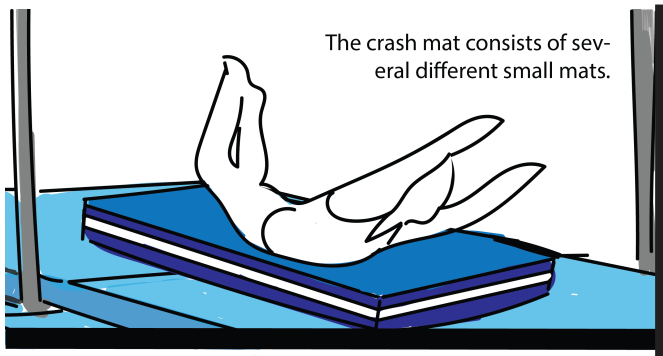


Figure 22. Overview of the set up (transportation) from Concept 1.

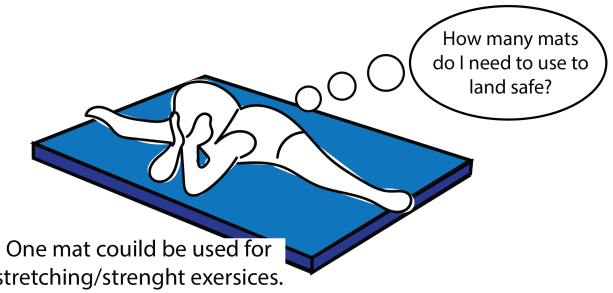
Concept 1 is mostly focused on transporting the crashmat with a vacuum bag. The mat will still consist of three parts. One side of the mat will have the cuts to simply roll the mat, the other side will have the elastic bands to 1) hold the mat in place while being rolled and 2) connect the three mats against each other. This connection is made by putting the elastic bands through the handles and plastic toggles of the other mats and secure it with velcro against each other. For transportation the mat will be rolled and placed in a bag. This bag will be made vacuum through a 24V electric pump in the bottom of the bag. This pump will make the bag almost 60% flatter. However, this does only make the mat flatter and not smaller in length. At the end, the mat could be transported as a backpack by three athletes/coaches. Creating this concept will cost around 520 euros, Table 5 will show the total price build up.

Necessities	Costs per product	Total costs
3x 160x80cm 5cm thick Polyether foam mat	€ 41,60	€ 124,80
3x 170x90cm tricot cover	€ 35,00	€ 105,00
6x 1m 35mm thick elastic bands	€ 3,90	€ 23,40
6x plastic toggles	€ 0,15	€ 0,90
2m 25mm thick strong velcro	-	€ 2,00
1x1.5m water-resistant polyester black	€ 9,50	-
Plastic vacuum seal	€ 22,99	-
Closing mechanism	€ 4,34	-
Shoulder bands	€ 24,59	-
Micro vacuum pump 80Kpa	€ 25,00	-
Total costs mat	€ 86,70	€ 256,10
Total costs bag	€ 86,42	€ 259,26
Total cost 1 product	€ 173,12	
Total costs full product		€ 515,36

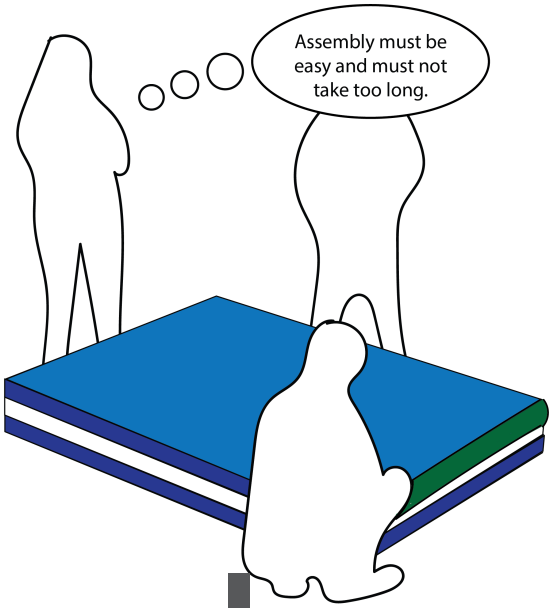
Table 5. Overview of costs for prototyping Concept 1

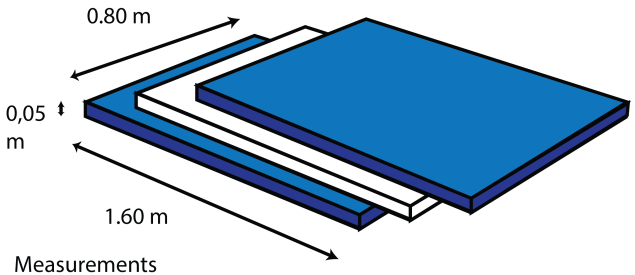


The crash mat consists of several different small mats.

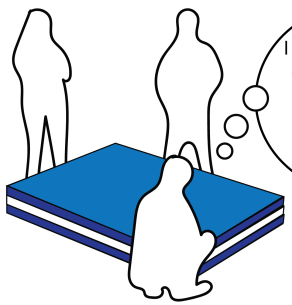


One mat could be used for stretching/strenght exersices.

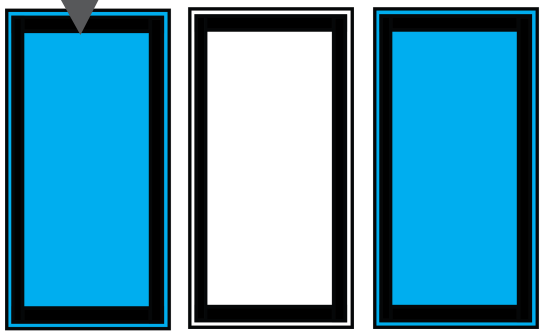




Measurements

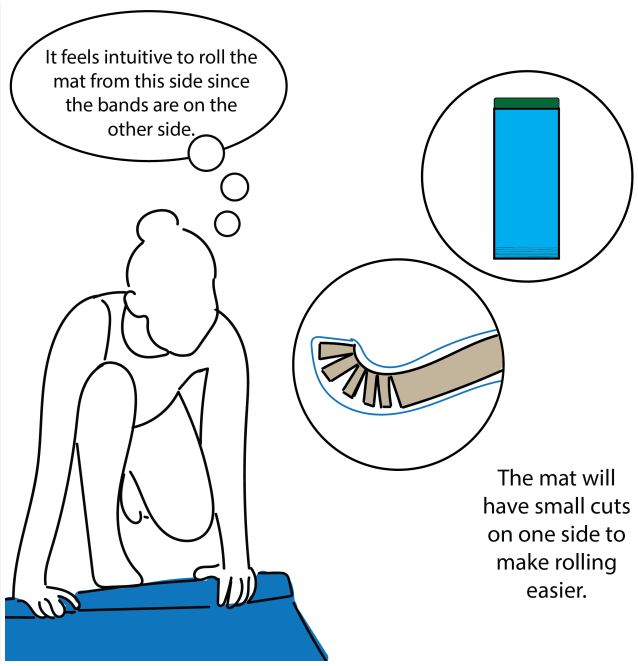


Attach mats with your team to form the crash mat.



Middle mat (white) has two sided velcro upper and bottom one only on one side.

Velcro attatchement soft on the upper, hard on the bottom.



The mat will have small cuts on one side to make rolling easier.

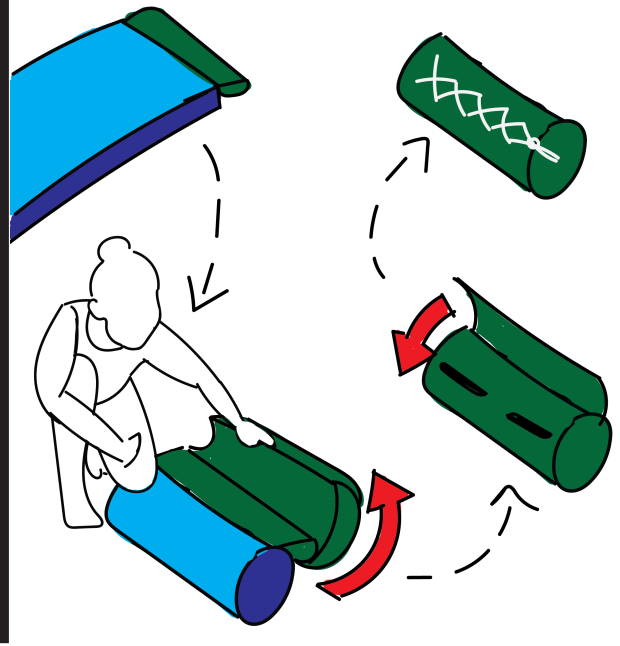


Figure 23. Overview of the set up (transportation) from Concept 2.

Concept 2 is focused on the ease of use of the transportation. The mat will also consist of three parts. One side of the mat will also have the cuts to simply roll the mat, the other side will have a small bag maintaining the entire 'bag' for transporting the mat in it. The three mats will simply be connected with each other by using velcro. To make sure the athletes will use three mats, the middle mat is made white since this color will distract them while performing (T. Goedkoop & S. van Oorschot, personal communication, 2022). Since this mat will always be the middle one, this mat will have velcro on both sides, in which the other will only have it on the bottom or top. In this way the athletes will never be in contact with this velcro. Each mat will have their own bag connected to the mat, the mat will be rolled from the other side and the bag can be simply be unfolded from the small bag and placed over the mat. At the end, the bag will be connected with velcro strips to make sure it will not open during transportation. The bag will have some laces which can be tightened to make the bag a bit smaller. Eventually the mat can be transported as a backpack by three athletes/coaches. Creating this concept will cost around 310 euros, Table 6 will show the total price build up.

Necessities	Costs per product	Total costs
3x 160x80cm 5cm thick Polyether foam mat	€ 41,60	€ 124,80
3x 170x90cm tricot cover	€ 35,00	€ 105,00
15m 100mm thick strong velcro	€ 3,30	€ 49,50
Texture polyester 1x1.5m	€ 3,95	€ 11,85
Sail eyelets		€ 16,95
Shoulder bands	€ 24,59	€ 73,77
Total costs per mat	€ 108,44	
Total costs full product		€ 381,87

Table 6. Overview of costs for prototyping Concept 2

5.5 Concept selection

To make sure the concept which fits best for the target group is chosen. A prototype of both concepts was made. Figure 24 showing the prototype of concept 1 on the left and the prototype of concept 2 on the right. Both prototypes were created for testing the most important showstoppers of the concepts; 1) rolling the mat, 2) securing the mat in place and 3) transportation. These prototypes are used to test the concepts with two TeamNL gymnasts. They tested the product separately. First the steps in Figures 22 & 23 were shown and a bit explained to them. After this, they were asked to make the mat ready for transportation. First in the way of concept 1 (in which a vacuumcleaner was used for making the mat vacuum) and secondly for concept 2. The whole session was recorded. When the product is ready for transport, the athletes were asked about their experiences.

Figure 24. Prototype of concept 1 (left) and concept 2 (right)

5.6 Final concept

Observations during testing the showstopper made some things clear. First of all there is a difference between MAG and WAG. Woman gymnasts are willing to 'take care' about the product, which allows them to take a bit more time to make the product ready for transportation compared to male gymnasts. Where the male gymnasts wants to do it as fast as possible, by only using the straps to secure and transport the mat. The female gymnasts wanted to take more time to make sure the mat was fully packed. However, they both agreed on the fact that making the mat vacuum, costs too much time in comparison with the result. The mat became way smaller, but they both agreed that it still was not small enough to transport by plane and they did not care about transporting it by car in the unvacuumed way. This in combination with other disadvantages of the vacuum pump, like; the needed power, the costs (see Table 5) and the high risk on damaging the bag (which reduces/breaks the product), makes the decision to not work with vacuum for the final concept.

To make sure the mat will work for both male and female athletes, the product needs to change their behaviors a bit, by finding a combination between fast and taking care of the product. For this, the bag in the second concept will work best. If the bag is strong and easy to put over the mat, it is able to put the bag over the mat fast. Were the female athletes can still cover the whole mat, to make sure it will not become dirty or break during transport.

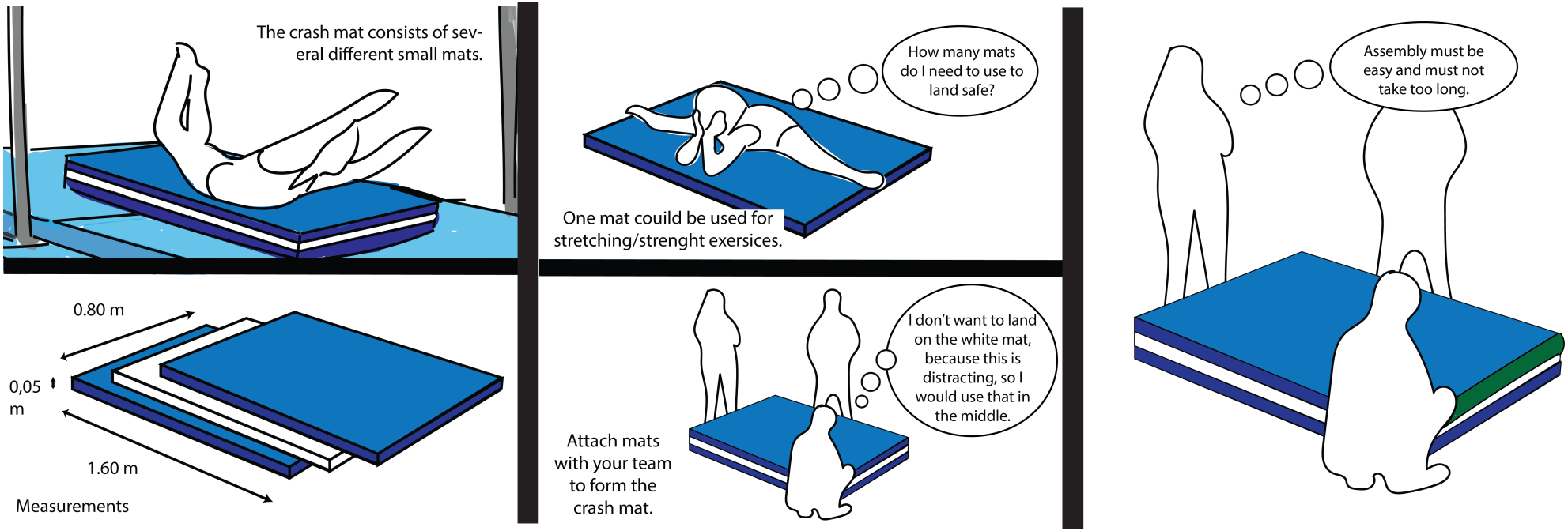
Also, they both questioned the presence of velcro in both concepts. From their experiences they know that foam and magnesium in the gymnastic halls will get stuck in the velcro, which reduces the working. Therefore, the connection of the three mats with velcro will significantly reduce the lifespan of the product. Therefore, they both preferred the way to connect the mats in concept 1 (with the bands and toggles), if it will not take too long and the toggles will not be too hard. However, the second problem could be easily fixed by placing the plastic toggles underneath the bag. In this way the toggles are covered by a soft material. At the same time the trainers and coaches needs to be able to thrown the mat underneath their athletes if necessary. They prefer to have handles on the side to easily grab the mat like they are present in concept 1. However, they only need these handles on the long side of the mat, since they will always stand on the long side of the HB or UB. The handles to connect the mats could therefore be a bit different. Also the coaches would prefer the bag to fit in a suitcase while traveling by plane. That is why the product will be delivered with an 'airplane mode'. The airplane mode will be a small bag, consisting a vacuum bag, bands and a description. With a vacuum bag the mat will fit in the big TeamNL suitcases which have a measurement of 76x50x31cm (Princess Traveller, n.d.).

The coaches, however, are not the end user and therefore these were no hard requirement.

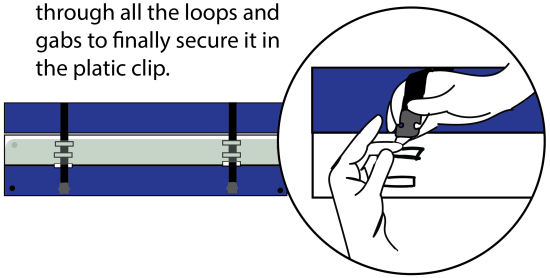
Eventually, they both liked the cuts in the beginning, since 'it makes it way more easier to role the mat' (S. van Oorschot, personal communication, 2022). They also liked the chosen foam material and the cover felt very good. Also the measurements were perfectly chosen for both of them, where S. van Oorschot is a tall gymnast, in comparison with others.

Since the mat should be used for MAG and WAG, it is important to find out if the mat would make changes in behavior of the athletes. For example, male gymnasts are not always willing to use the crashmats during warming up before an event. 'It makes it looks like you are not ready to do that specific exercise if you lay a crashmat underneath it. Let alone if you bring one your own.' (T. Goedkoop, personal communication, 2022). This would be an important behavioral change that the mat needs to fulfil while being used for MAG. While for WAG the mat needs to look and feel safe. They rely on the products they used now, and question new products and their working often. For them it needs to make sure the mat looks and feel safe so they are willing to use it.

So eventually, the final concept will be a combination of concept 1 and concept 2, based on the needs and experiences of the gymnasts, the final concept sketch can be seen in Figure 25 and Figure 26 shows the coach wishes.



Grab the cord and take it through all the loops and gabs to finally secure it in the platic clip.

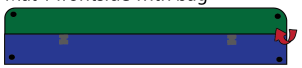


Mats connected side 1

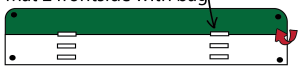
Mats connected side 2

Gab in stitches of bag and mat. Easily visable by border with another color.

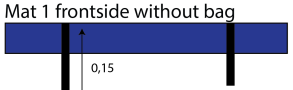
Mat 1 frontside with bag



Mat 2 frontside with bag



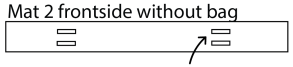
Mat 1 frontside without bag



0,15

The band is the total lenght of three mats, it could only connect 3 mats.

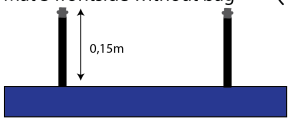
Mat 2 frontside without bag



Loops to secure the mats against each other.

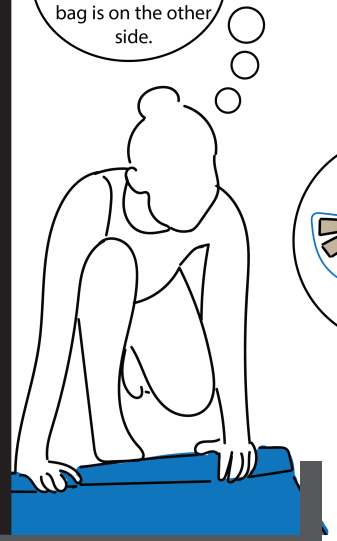
Mat 3 frontside with bag

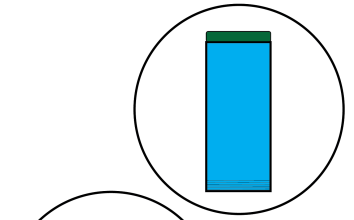
Mat 3 frontside without bag

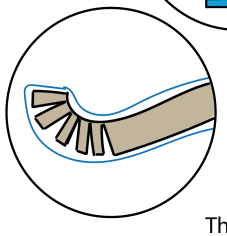


0,15m

It feels intuitive to roll the mat from this side since the bag is on the other side.



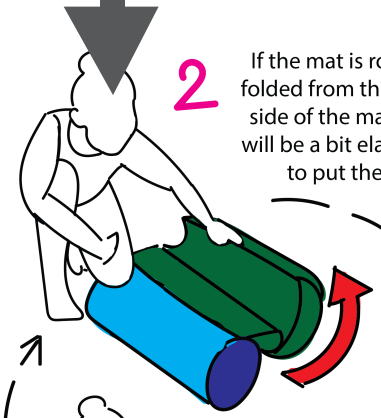




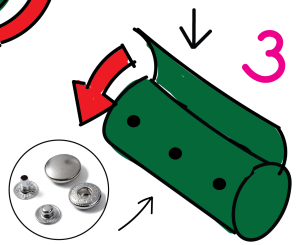
The mat will have small cuts on one side to make rolling easier.

2

If the mat is rolled, a cover can be unfolded from the little green back on the side of the mat. The sides of the cover will be a bit elastic, which makes it easy to put the cover over the mat.



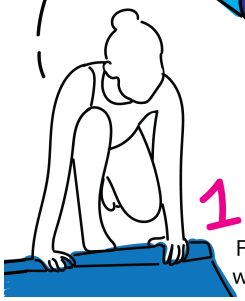
3



If the cover is over the mat, the cover can be simply secured with push buttons.

1

First the mat will be rolled.



If the mat is rolled and secured, the cover will have handles which the athletes could use to easily tranport the mat. Each team will have 3 seperate mats which can be tranported per individual.

Figure 25. Final concept sketch

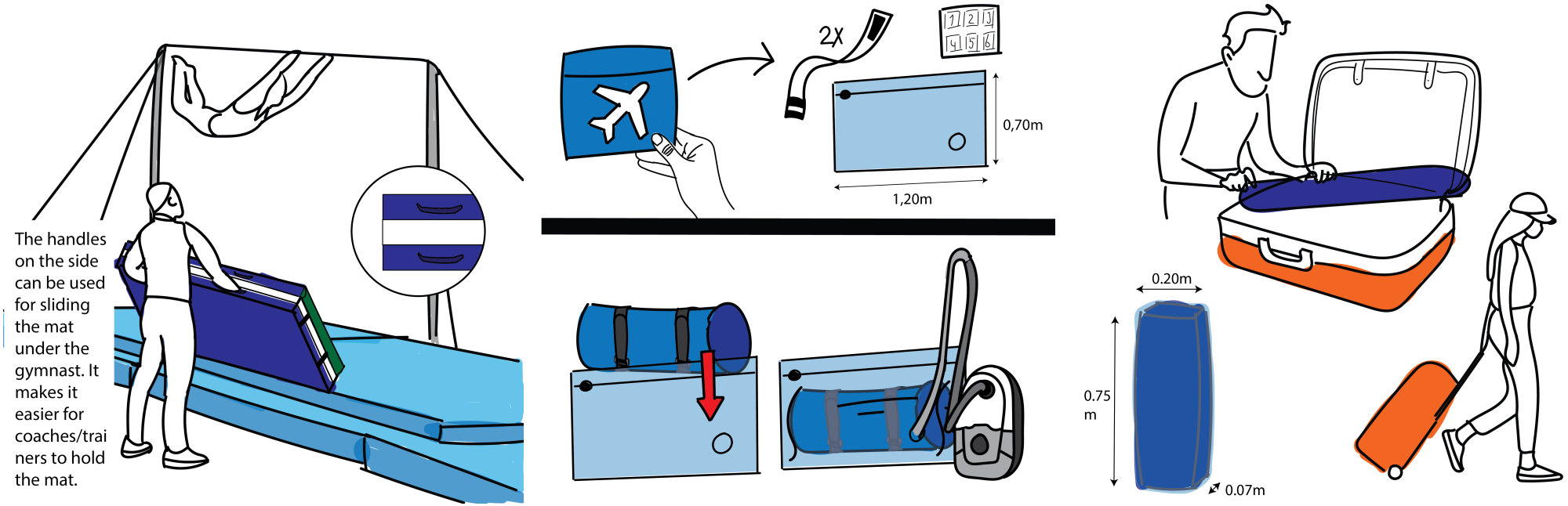


Figure 26. Coach wishes

5.6.1 Viability

Table 7 shows the costs for prototyping the final concept. The product will be bulk production, since the product will first be used for TeamNL gymnasts. In the future other national teams can also make use of the mat. For amateur gymnasts the mat will not be interesting, since they will only have events in the Netherlands in training halls, in which all training materials are included. Therefore, the overall production will never become mass production.

The product could be created in collaboration with the partner of the lab; Janssen Fritsen. In this way the sales price will depend on their fixed costs, like personnel, rent, machine- and material costs. They also use foam for current mats, so they can buy these in masses, which lowers the price of the foam purchases. Eventually the final selling price of the product is estimated around 500 to 600 euros.

Necessities	Costs per product	Total costs
3x 160x80cm 5cm thick Polyether foam mat	€ 41,60	€ 124,80
3x 170x90cm tricot cover	€ 35,00	€ 105,00
Snap fastener	€ 3,50	€ 3,50
Texture polyester 1x1.5m	€ 3,95	€ 11,85
Click buckles strong plastic 50mm	€ 5,60	€ 22,40
Belt for backpacks 50mm	€ 27,50	€ 27,50
Shoulder bands	€ 24,59	€ 73,77
Total costs per mat	€ 141,74	
Total costs full product		€ 368,82

Table 7. Overview of costs for prototyping the final concept

6. Testing

To evaluate the concept in practice, a user test was set up. To do this, first some prototypes were created. Later the test was performed with potential users and the results were analyzed.

6.1 Prototype

Throughout the project some low fidelity prototypes were made and tested with one male and one female gymnast. These prototypes were created to iterate on concepts and ideas to generate the final concept. Now the final prototype is created, some 1:1 scale prototypes were made.

The concept was separated within different showstoppers, due to time and cost limitations. This resulted in three prototypes. The first prototype was created to test the transportation of the mat. One of the three mats was created with the actual cover and the bag on the side which has the sheet to make transportation of the mat possible (Figure 27, image 1). The bag on the side consists of the same material as the sheet in it and is more elastic and soft as the first prototype in Figure 24, this makes it easier to pull the sheet over the mat (Figure 27, image 2).

The second prototype was created to test the connection of the mat (Figure 27, image 3). Three pieces of foam were ordered with the same width as the actual mat (80cm) but much shorter (20cm). In this way, the process of connecting the three mats could be tested by its users. Two ways of connecting the mats were prototyped, to see which connection favors: 1) a click buckle and 2) wooden string closure. Also the small bags on the side of the mat and the loops on the side were created to get the optimal test experience.

At last the airplane bag was created with content (Figure 27, image 4). This was created to show the participants of the user test the option and gain feedback about it. Also a sketch of the explanation of the steps to make the mat vacuum was created, printed and inside the bag (Figure 28).

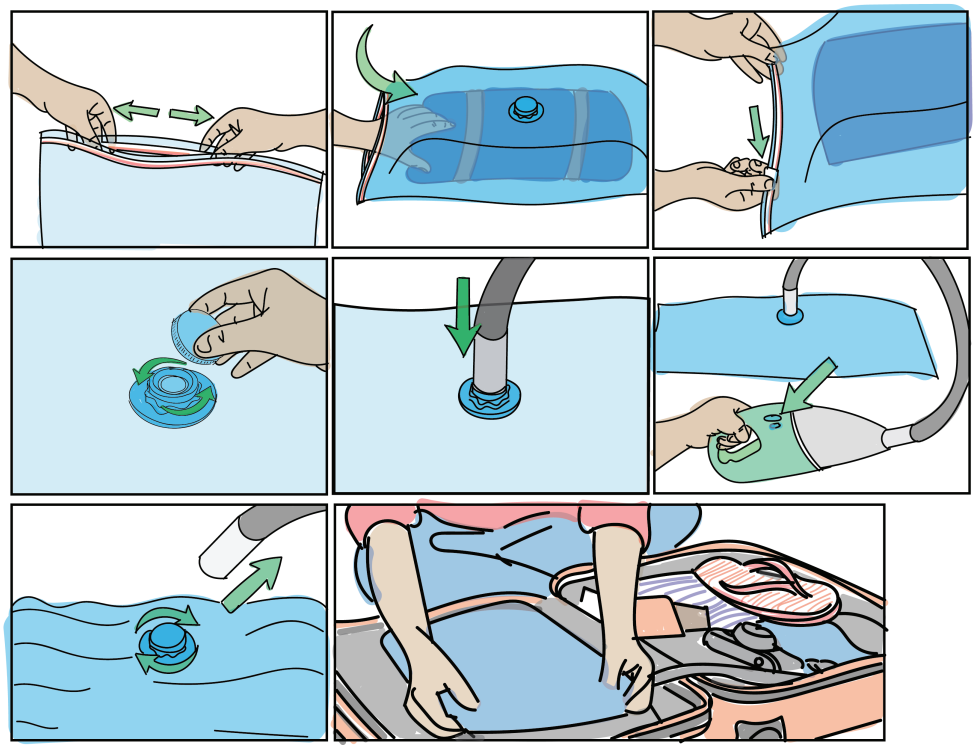


Figure 28. Airplane bag description

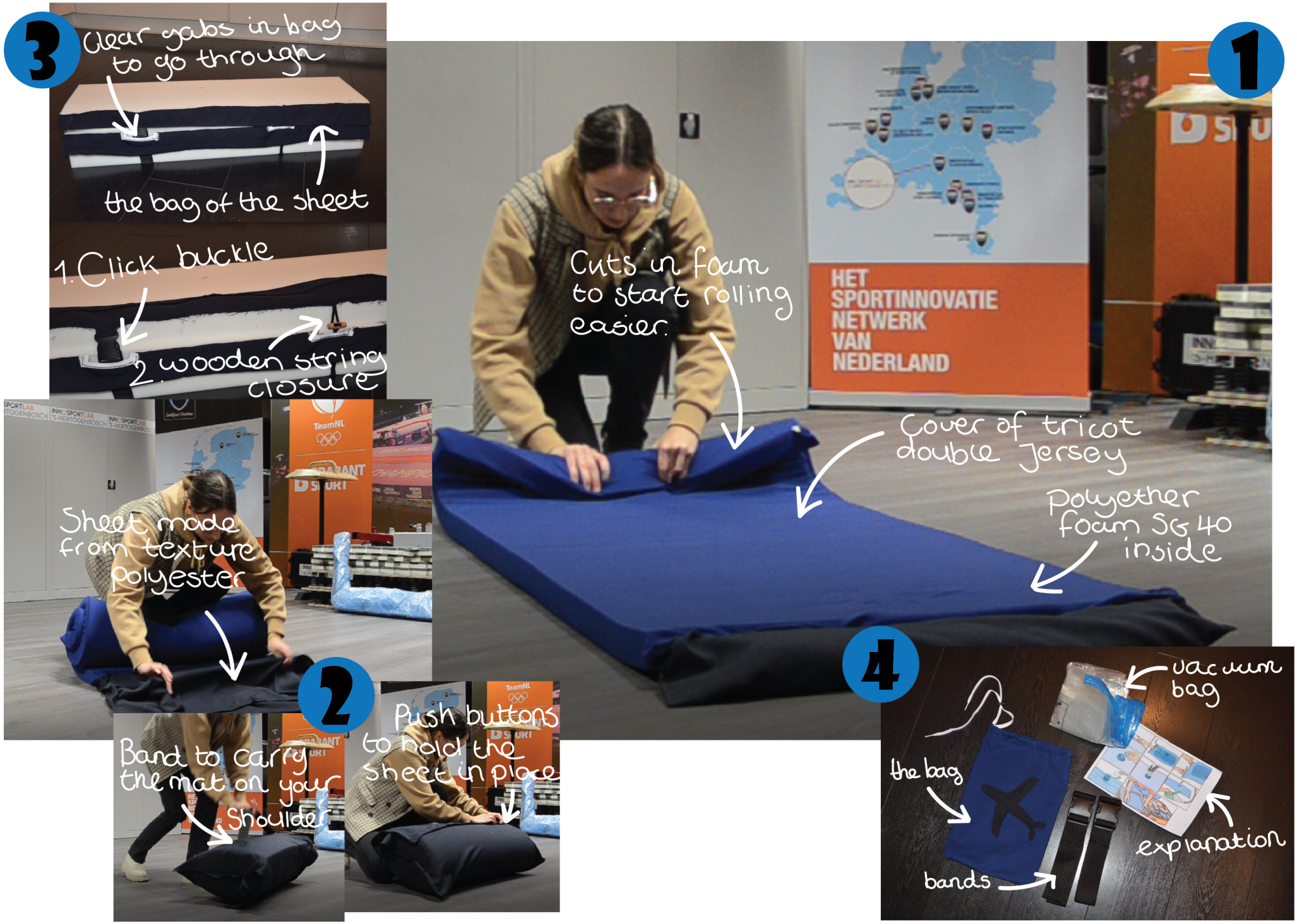


Figure 27. Final prototypes explained

6.2 User test

To evaluate the concept, a user test was performed. First the user test set up was explained, followed by details about the test itself and its outcome.

6.2.1 Set up user test

The user test had two goals; 1) which connection between the mats do they prefer and 2) how do the users interact with the product, how do they experience this and are they willing to use the product in real life or do they have some areas of improvement. To answers these questions three actions were required from the participants; 1) use both connection methods, 2) make the mat ready for transportation and 3) open the airplane bag and take out the content. For all three actions, the participants are asked to think out loud about their experiences.

After these three actions, the participants were asked to fill in a questionnaire about their experiences with the product. In this questionnaire they were first asked a bit about their gymnastic- and HB/UB experiences. Followed by their normal usage of crashmats during training and events. Ending with some questions about the concept and their experiences with it. The full questionnaire can be found in Appendix O.

Afterwards, the feedback of the participants will be used to evaluate the desirability of the concept, and to see if this concept meet all hard requirements and the most important wishes. The test is also done to make some last design decisions and to find out whether the concept had problems not found earlier, which should be addressed in further development.

6.2.2 User test outcome

When the prototypes were done and the test set up was created, it was time to test the concept in practice. All participants performed the three actions and were later asked to fill in the questionnaire, the filled in questionnaires can be found in Appendix P.

Eventually the test was performed with five gymnasts. Two male gymnasts both performing at Turncentrum Zuid and (prior)TeamNL, aged 23. Three female gymnasts all performing at Turncentrum Zuid and one of them for TeamNL, aged 14, 16 and 18. All participants participated, at least once, at the (youth) national championship. Thereby, the 18 year old female gymnast experienced a European championship. One of the male gymnasts is performing on the HB only during practice, the other four participants are performing on the HB/UB during practice and events.

All participants make use of crashmats during training and warming up for a specific apparatus. If necessary they make use of crashmats slide underneath them by their coaches, if present in the hall. They would all like to use the transportable crashmat during practice in event halls, as well as the warming up of a specific apparatus. Also they all think that they can perform their routine on HB/UB without errors if they go to events. Therefore, they do not specifically need the mat to slide underneath them. However, the fact that it is sure that there is a crashmat present in the hall does give all of them a feeling of safety.

According to making the mat ready for transportation (Figure

29), all athletes agreed on the fact that it was useful. Two of them agreed that a little practice must be done before it will become easy, but still think it is a cleaver way to secure your mat. However, one of them thinks it is a bit too hard the first time. Nevertheless, they all agreed that the mat will be compact and easy to transport.

Figure 29. User making the mat ready for transportation

While testing the connection of the mat (Figure 30), it stood out that every participant did not really care about which mechanism was used. They were all easy and fast. Some suggested to put the hard elements away in between mats. However, they did not think it was a very big problem, since the bag was also covering it. By filling in the questionnaire, they needed to decide between both. Four of the five participants preferred the click buckle, since it was easier and stronger. The

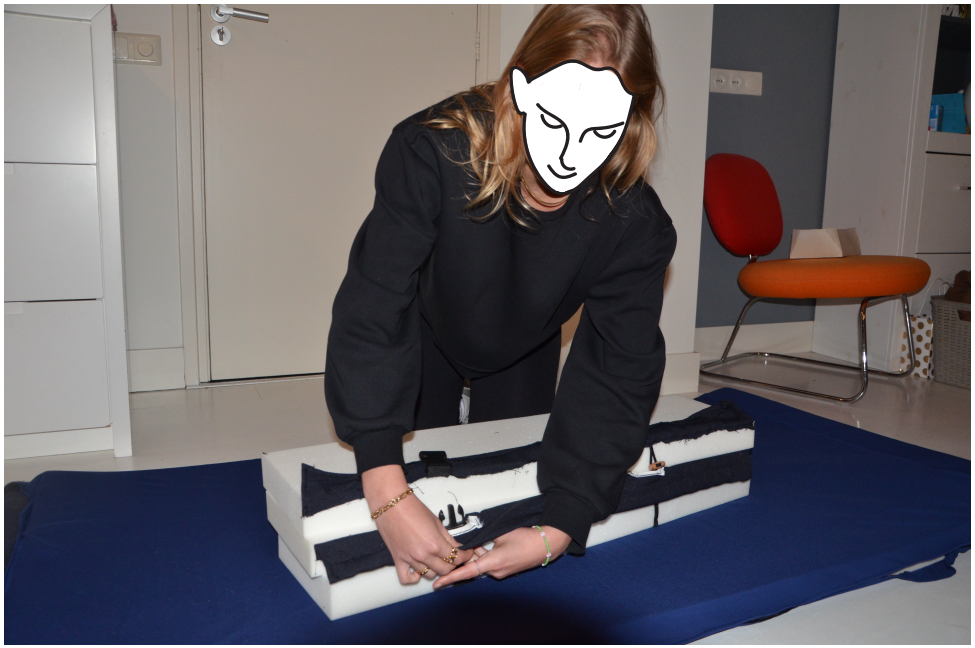


Figure 30. User connecting the mats against each other

fifth athlete could not decide and thought both ways will work.

When having a closer look on the airplane bag (Figure 31) and the experiences of the participants with this, it stood out that all participants experienced this as a useful and helpful contribution to the product. They all liked that it was only there if it was needed and thought it would be very useful if you need to travel by plane. The explanation was clear for all of them. However, they would like to have some steps in front of the vacuum steps of rolling the mat and connecting it with the straps, so that the whole process would be on the explanation. This because they probably will not go to events by plane that often and will therefore not use the airplane bag often. Then an explanation of the whole process would be nice as a reminder.

Figure 31. User opening the airplane bag

Overall, all athletes were enthusiastic about the concept; "it's a good concept, especially when there are no such crashmats present in event halls. During events everything is different, the environment, materials, etc., mats are always pleasant in these situations." (participant 5). "Now we always experience problems with bringing our mats, they are too big and harsh. I believe this is a good solution for that." (participant 4). All three female participants would like to use the product; since "everything is more compact which makes it easier to take a mat with you. I think that is a huge advantage." (participant 4) and "I just like having a soft landing with jeager" (participant 2), in which jeager is a specific move on UB in which a gymnast swings backyard in L-grip or reverse grip and performs a front somersault (see Figure 32). A jeager is a common move in a UB routine and if it goes wrong the athlete will fall face down. However, both male gymnasts answered no on the questions if they would use the product their selves. Participant 5 gave a clear description about why not "the chance that we fall flat on our belly with a HB routine is small. We only have 2 exercises on which this could happen. However, I often see female gymnastics fall flat on their belly, I think it is a really good solution for them.". Were participant 1 suggested "for me it felt a bit unorthodox, however I do believe that 'early adopters' could make the use of such a mat normal.".

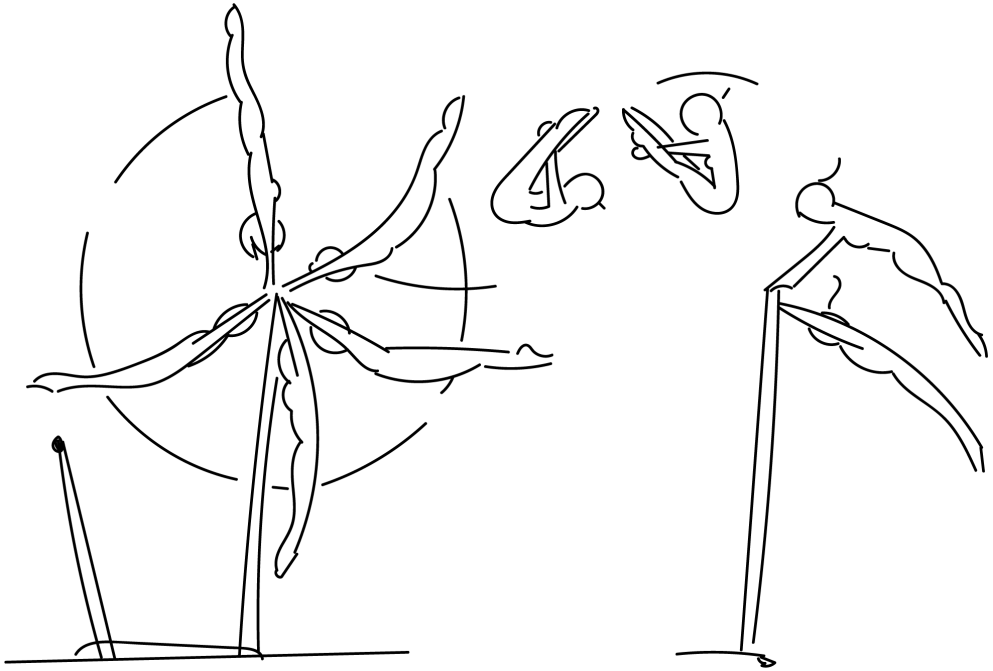
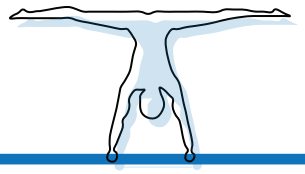


Figure 32. Jeager exercise UB

7. Conclusion



To fulfil the redesign goal: Redesign the current crashmats to enable easier transportation without reducing its functionality, the final concept was created. In this chapter the final concept will be reflected, to evaluate if it meets the set requirements and wishes. Also it is evaluated if the product is feasible to create and desirable for the target group.

7.1 List of requirements

Catch every gymnast:
The mat needs to catch every gymnast despite their weight, length, gender, etc. The measurements of the mat were set based on the co-design session and (drop hammer) research. Measurements are based on actual length and weight of male as well as female athletes. The drop hammer test is performed based on the set FIG test requirements and could therefore reason the chosen thickness which is damping 60% of the peak forces.

No extra actions:
Using the mat must not lead to extra actions while being used during warming up or exercise. The mat only has extra actions for (un)packing and connecting. If the mats are unpacked and connected they can be used without any extra actions during warming up or practice.

(Un)Packing:
(Un)packing the mat must take less than one minute. Unpacking the mat is very easy and will only take a maximum of 10 seconds. Packing the mat is timed during user test, as well as several tests done by other interns in the ISLDB. Packing the mat had an average of 45 seconds, which is less than one minute. This will only become faster, since most tests were done with people who had never packed the mat before.

Length:
The mat should have a minimum length from elbow to knee. The length of the mat will be 160cm. Gymnasts are not tall people, gymnasts have an average length of 160cm (Willem Wever, 2021). By stretching your arms, your elbows will reach approximately to the end of the head. Therefore, gymnasts needs to fit on the mat from knee to head, which gives some monstrosity in length of the gymnast to still fulfil this requirement. Additionally, the mat is tested with a relatively tall gymnast (170cm) and also experienced as safe by her.

Not breaking:
The product needs to withstand high forces without breaking. This is achieved by the material choice and the use of strong yarns and stitches.

Absorbency:
The mat must absorb at least 60% of the peak forces from the first contact. In the material research and selection, it was made sure a material was chosen which damped at least 60% of the peak forces. The use of a cover and a fall flat on the belly (area force) only improves the damping which means the mat will damp even more of the impact. At the same time, the materials tested during the material selection had a size of 20x20cm. The drop hammer felt in the middle of these blocks. The FIG stated

that mats must be tested on 10cm from the border, which is fulfilled by testing 20x20cm blocks in the middle. This means that the border zones do not cause different indentations than on the remaining surface, which means that this requirement is also met.

Cover:
The cover of the mat should be safe material for the skin. The cover is chosen with the help of material experts at the Textielstad Tilburg. Therefore, the cover is approved to be safe and hygienic. At the same time the participants of the tests mentioned that they all liked the material of the cover.

No hurting from mat:
There should be no chance the athletes hurt their selves from the mat. This means that the mat should not have any hard elements or cuts which could hurt the gymnast. This requirement is achieved by covering the hard elements by the bag on the side. This bag contains the sheet for transporting the mat, which is thick when its folded. In this way the gymnast will barely feel the hard elements. However, if an athlete lands on the side of the mat it would be better if the buckles are somewhere inside the foam instead of on the outside.

Freedom of movement:
The athlete should have the possibility to land in the way that they want. This means in practice that the mat should damp point as well as area force with at least 60%, which it does. Also, used materials should give the opportunity to land on your feet without injuring something, this is also achieved by using foam. Foam is also used in current crashmats, which gave the gymnasts the freedom of movement they want to have.

Not relay on human actions:
The products working must not relay on human actions. The product could also be used without connecting the mats together if it is placed underneath the HB or UB. In current situations they constantly stack other mats upon each other. However, the lose bands on the side will remind them to connect the mats. If the mat is used to slide underneath the athlete in case it goes wrong, the mats must be connected. However, if this is not the case the mats will slide of each other, or only the first mat will come up. In this way the gymnast or its coach is remembered to connect the mats.

All hard requirements are met. There are still some slight concerns for not hurting their selves from the mat and the fact that the mat needs to catch every gymnasts. In which the last one is fulfilled, but in practice the mat is best used for WAG based on exercises on the UB. These are both addressed in chapter 8.

7.2 List of wishes
The hard requirements are mainly focused on the actual users of the mat. Nevertheless, the mat will be a team property and would therefore also have other stakeholders with wishes. For example, the coaches do also have some requirements for the product. However, since they are not the end user, these requirements were made wishes. To see if the product also fulfills these wishes, the list of wishes is also analyzed to see if the product met these.

Price:
Current price is estimated around 500 to 600 euros. This is a bit higher than the wish for the crashmat to cost around 400 to 500

euros, based on the current pricing of the crashmats. Nevertheless, these mats are not transportable, do not have a sheet to cover it and does not have the possibility to transport it by plane.

Packaging:
The packaging needs to protect against sharp objects during transport. Because the mat is created to transport, it could get in contact with some materials which are not in the training halls. Therefore the sheet for transportation is created from 100% polyester, which is strong and water- and dirt resistant.

Weight:
The mat must have a maximum weight of 10kg. This is based on the maximum weight which could be carried based on 20% of the weight of an (female) athlete (O'Shea, 2014). 10kg will fit in with all athletes from >50kg. The mats total weight will be 7.2kg, which is less than 10 kg.

Travelling by plane:
A big wish of the coaches was the ability to transport the mat while traveling by plane. Additional luggage costs extra money which the KNGU, TeamNL or the athletes prefer to put in an extra person traveling with them instead of extra materials. Therefore the mat should fit within a suitcase. It may be transported in the check-in luggage. The measurements of a big TeamNL suitcase are 76x50x31cm, which does not met the measurements of the rolled mat. Therefore, the airplane bag will be delivered with the product. By making the mat vacuum, it will have the following dimensions; 75x20x7cm and will fit in the suitcase.

Handles:
The mat should have handles to catch an athlete from the air and slide the mat underneath the athlete if necessary. In the concept the mat have handles on the two blue mats.

Feeling of safety:
Regards the feeling of safety, the feeling and look of the product must feel safe. Which means that the mat must feel soft, look big enough to not miss it and must look thick enough to feel safe. All wishes are discussed during testing and are experienced as safe.

Eventually almost all wishes are met. The only wish that is not succeeded is the price. However, this wish was estimated based on the prices of the current crashmats. Nevertheless, the current product is not only a crashmat, but more. Therefore, it could be discussed if this wish was realistic.

7.3 Feasibility
While making the prototype some insights in the future production of the product were generated. As mentioned in chapter 5.6.1, the product will be made in bulk production in cooperation with JF. Since JF is making more mats, the process of creating the product will be very feasible. JF will have most materials and machines that are needed for production like, foam, covers, sewing machines, and bands. It is only questionable if JF have the specific foam and fabric for the cover and sheet. Nevertheless, they could most likely buy this at their own wholesaler.

Most likely, JF will have machines which will work autonomous. In the end it could be possible to provide JF digital sewing

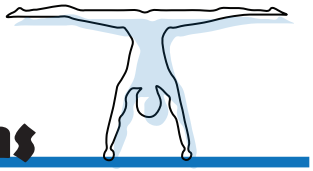
pads, which they could install in their machinery. In that way, making the product will become simple and fast. By selling enough mats, this could eventually also result in a lower cost price. However, in bulk production, this will not yet be the case.

7.4 Desirability

The list of requirements and wishes were based on user research, since all requirements and wishes were met it could be concluded that the product fulfils the user's needs. Simultaneously, the user test shows that the product made its users enthusiastic and willing to use the product, especially for female gymnastics. The interactions with the mat was fast, easy and useful for the athletes, which makes them willing to use the product.

Also some stakeholders were interviewed to involve their wishes in the process as well, think about the coaches of the gymnasts. By adding their wishes in the list, the product will also fulfil their needs. However, an important stakeholder misses as input in the list of wishes and requirements, which is JF. If JF will eventually made the product, it would be important to discuss their needs. Mainly for the requirements regards production. Unfortunately, it was hard to get in touch with them due to sickness of the lab's contact person and their busyness. The requirements and wishes for production were now made based on market and literature research.

All in all, it was most important to meet the requirements and wishes for the athletes and their coaches. The product meet those requirements and wishes and offers them a crashmat which they can take with them to events, even by plane, without reducing its working. Therefore, it is a desirable product.



8. Recommendations

As for now, this will be the end of this design project. However, there are some things that can be researched and iterated on. In this final chapter recommendations for the future development of this product are given.

8.1 Target group

As mentioned in the outcome of the user test, the female athletes were all willing to use the product, while the male athletes were not. The athletes their selves already gave some clear reasoning about this. However, it would be desired to do some more research in this. This because only two male athletes were researched. From observations and personal communication could be concluded that the use of crashmats is very individually based. Therefore, it would be interesting to speak some more male gymnasts to find out if the product will be produced for WAG and MAG, or for WAG only. This certainly since the design question came from the prior national MAG coach.

8.2 Transportation

There were a few remarks while observing the process of making the mat ready to transport. Some participants struggled a bit with pulling the sheet over the mat in the first time. Therefore, it would be interesting to see if this will change if the material of the sheet will become a bit more elastic or that elastic band will be added to the side to make this process

easier. This could make it able for every athlete to secure the mat the first time immediately.

From the user test was also found that some athletes were missing steps on the explanation of the airplane bag. The explanation now gives the steps to make the mat vacuum. However, it does not provide any explanation about rolling and securing the mat with the bands, which is different from the normal system. Therefore the steps in Figure 33 needs to be added to the explanation.

8.3 Hard elements

Another thing that came out of the user test was the use of hard elements for connecting the mats. All participants mentioned it, but did not think it was a big problem since the bag was covering the parts. However, the fact that all participants mentioned it, opened my eyes. Therefore, more research needs to be done in how to connect the mats with each other. There could be some more options with softer materials. However, the athletes were sure that it needs to be a strong connection. Therefore, it is maybe better to find a way to hide the hard elements inside the mat. All athletes suggested this as an option which would solve having these hard elements.

8.4 More material research

From the material analysis in chapter 5 could be concluded that the material of the mat is the most important factor for the damping percentage. I am sure that there is a material that will feel soft and has a high damping percentage, which is very thin. More materials could be tested to see if there is such a material. If so, there could maybe be only one mat used instead of three, which makes it also possible to bring a mat individually.

8.5 Other apparatuses

While this research focused on HB and UB, it could be interesting to find out if the product is also usable for other apparatuses. It could be that some minor changes could

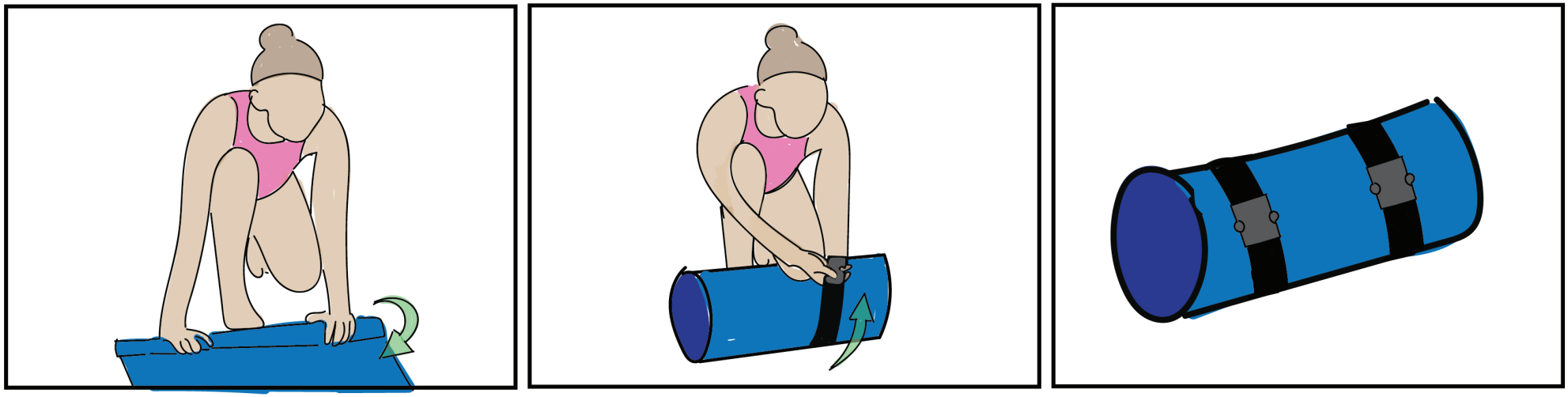


Figure 33. Missing steps in the airplane bag explanation

expand the target group of the product by making the product appropriate for more apparatuses. This because not every gymnast performs on HB or UB.

8.6 Customizable covers/sheets

In some of the first ideas and concepts, a customizable cover or sheet was discussed. The female athletes were enthusiastic about this. Since the product would now mainly focus on WAG UB, this could be an interesting area to explore. This because it could make the mats more personal and it could stimulate other (inter)national teams to buy the product.

8.7 Cost price

On page 32, a rough estimation of the products costs were given. However, this is only a rough estimation. Once JF is contacted and interested in the product, a more clear and precise cost price analysis could be done to get better and more realistic cost price.

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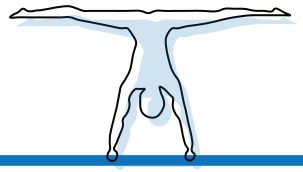

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