thesis report

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IMPROVING TRAINING FOR CLIMBERS BY ENHANCING EXPLORATIVE CLIMBING BEHAVIOR IN INDOOR CLIMBING GYMS

TU Delft
November2015

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November 3rd 2015

ACKNOWLEDGEMENTS

A word of thanks from me towards my graduation 'buddies'. Thank you Mariet Sauerwein and Aniek de Jong for thinking with me in my project, being critical, providing useful tips, musical stimulation and climbing skills. Thanks Johan Bogaart for lending me your car during the building of the prototype.

Next to that, I would like to thank all the participants of the user test and pilot test for their time and enthusiasm: Enne Hekma, Gerbrand Meijer, Jelle Hoekstra, Jelte Doeksen, Lucas van den Elshout, Mariet Sauerwein, Marlike Ridderbos, Simon van Hemert, Thijs Boerrigter, Thomas van der Linde, Ruben Verbaan and Wouter Kuijsters.

Towards the finishing of this report I would like to thank my mum for reading and correcting many of my texts.

-Vera-


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PREFACE

SAMENVATTING

De klimsport wordt steeds populairder en daardoor neemt de vraag naar klimhallen toe. De disciplines voorklimmen en boulderen zijn zelfs genomineerd om opgenomen te worden in de Olympische zomerspelen van 2020 in Japan. Tot op heden bestaan klimmenhallen uit houten wanden met daarop geschroefde plastic grepen, Dit is al jaren zo zonder enige vernieuwing. Tijd dus om met het groeiende enthousiasme voor de klimsport, de training eens onder de loep te nemen en zien of verbeteringen mogelijk zijn.

In de klimhal gebeurt het trainen van klimmen door een route van een bepaald niveau te klimmen. De moeilijkheidsgraad is gebaseerd op het type grepen in de route, de lengte van de route en de hoek waaronder de wand staat. Deze route wordt aangegeven door een aantal grepen van dezelfde kleur. De klimmer mag alleen de grepen van die kleur gebruiken. In deze trainingsmethode worden wel de klimbewegingen geoefend, maar het exploreren van de grepen en bewegingen ontbreekt. De klimmer voert een serie passen uit die de routebouwer van tevoren bedacht heeft.

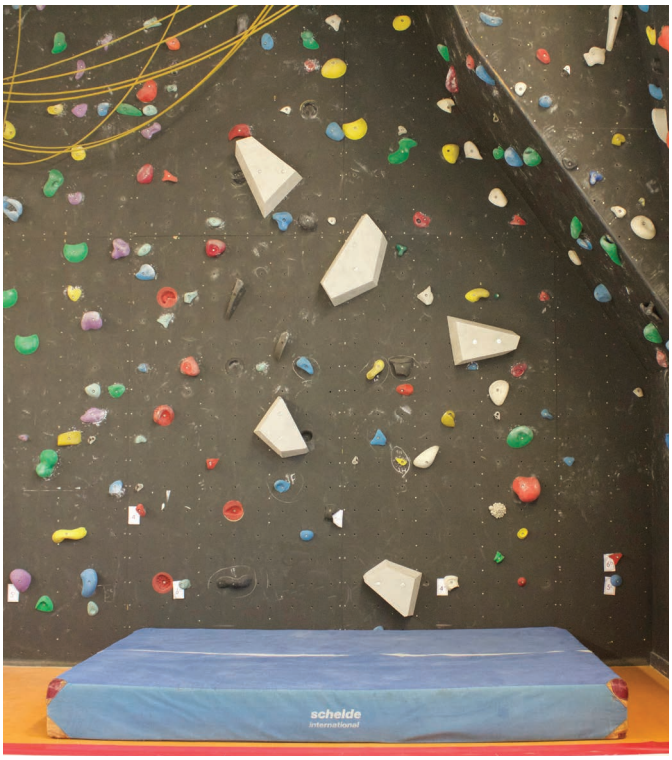
Exploreren van de route gebeurt wel tijdens het klimmen buiten op klimrotsen. Een rots presenteert zoveel mogelijke grepen, dat de klimmer moet kiezen welke hij gebruikt. De klimmer gaat dan op zoek naar de beste plaatsing van handen, voeten en de locatie van zijn zwaartepunt om zijn lichaam zodanig te positioneren dat hij de volgende pas kan maken. Deze zoektocht maakt dat de klimmer beter leert ‘aanvoelen’.
Routes in klimhallen ontnemen die puzzel omdat deze al is opgelost door de bouwer van de route.

Een van de manieren om meer puzzelend gedrag uit te lokken is door de grepen heel groot te maken. Hierdoor moet de klimmer gaan zoeken hoe hij zijn lichaam het beste kan positioneren om verder te kunnen. De grote grepen kunnen hebben lange rechte randen en platte zijden, zodat de klimmer niet geleid wordt door bobbels en deuken om handen en voeten in te leggen. De klimmer wordt gedwongen de randen af te tasten en te zoeken naar de optimale lichaamspositie. De grote grepen krijgen het uiterlijk van blokken, zie ook Figuur 1.

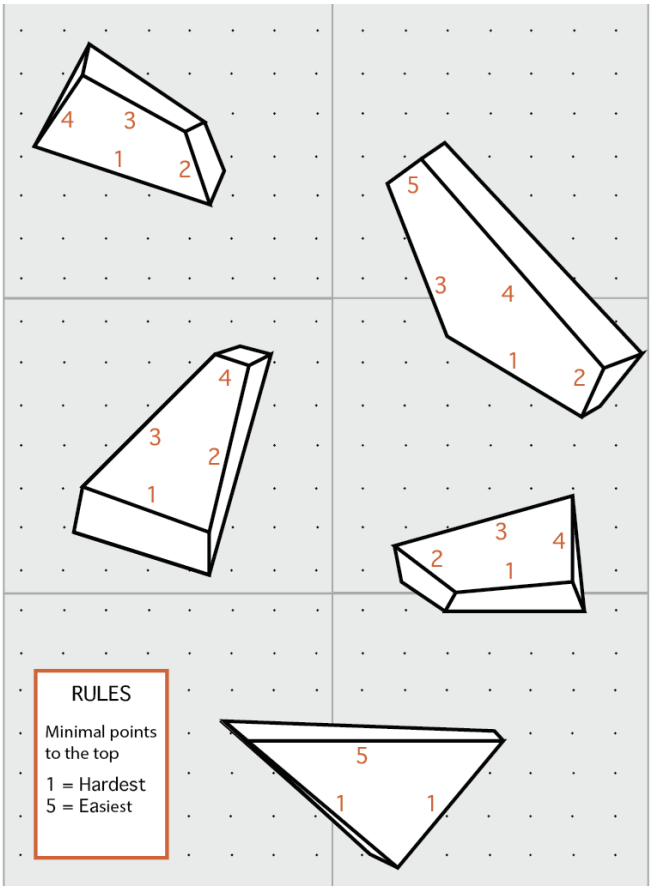
Het bepalen van de moeilijkheidsgraad van een route verandert sterk op het moment dat deze alleen uit grote blokken bestaat en het aantal opties waarop de route geklommen wordt sterk is gegroeid. Daarom heb ik een nieuw puntensysteem geintroduceerd om de route te kunnen kwantificeren en de klimmer te motiveren.
Een rand met een stompe hoek is moeilijker vast te houden dan een rand met een scherpe hoek. Daarnaast zullen sommige zijden van een blok moeilijker te bereiken zijn in de lijn van de route. In het ontwerp hebben alle zijden van de blokken een nummer dat de moeilijkheidsgraad aangeeft. De moeilijkste zijde krijgt een nummer 1, en de makkelijkste zijde een nummer 5, zie ook Figuur 2. De route krijgt een moeilijkheidsgraad door het totaal aantal punten dat wordt geklommen. De opdracht voor de klimmer is om met zo min mogelijk punten boven te komen. De klimmer zoekt hierdoor naar de moeilijkste route tussen de blokken, en wordt uitgedaagd tot aan de toppen van zijn kunnen te klimmen.

In een gebruikerstest werden 10 gemiddelde klimmers gevraagd om op de nieuwe blokken te klimmen en te beoordelen door een vragenlijst. Eerst waren de nummers afgeplakt en was men vrij de handigste grepen te kiezen. Daarna werd de opdracht om te klimmen gebruikmakend van de laagste nummers om boven te komen. Dit werd beoordeeld als veel leuker en uitdagender; klimmers hielpen elkaar meer met suggesties en stimuleerden elkaar om zo goed mogelijke scores te bereiken.
Het blokkenklimmen werd beoordeeld als vernieuwend, spannender en uitdagender dan het gewone halklimmen, maar niet als imitatie van buitenklimmen.

PREFACE



Figuur 1: Vijf nieuwe explorerende blokken op een klimwand. De klimmer moet de witte blokken gebruiken om de route te klimmen.



Figuur 2: Schematische weergave van het blokken ontwerp. De nummers op de zijden geven de moeilijkheidsgraad aan. De klimmer kiest hoe hij de blokken benut.

PREFACE

SUMMARY

Climbing indoors is growing in popularity and is even considered to be included in the Olympic games of 2020 in Japan. Despite the fact that numerous new climbing gyms are being built, there has been little innovation in the gyms themselves. For decades, climbing gyms have wooden walls with plastic holds screwed onto them, and the question arises how the training of indoor climbers can be modernized and improved.

Currently, when climbers train, they climb a route of a certain level. A number indicates the level of difficulty, which is determined by type of holds, the length of the route and the angle of the wall. The route is marked with coloured holds, and the climber is only allowed to use holds of that colour. This way, a climber only practises the separate moves to climb, but does not exercise explorative route finding. Thus, as a climber you are expected to execute the series of steps the route setter has made.

When climbing outside on rocks explorative route finding is apparent. Outside, the bumpy rocks present numerous options of holds, compelling the climbers to decide on their body position, the placement of hands, feet and centre of gravity, and which holds to use. The climber explores what his best body position should be in order to proceed, thus constantly solving a puzzle during the climb.

Indoor climbing routes deprive climbers that puzzle because the route setter has solved that puzzle for them.

One of the solutions to introduce that puzzling feeling is to enlarge the holds. Big holds offer more opportunities the grab the hold, therefore increasing explorative behaviour to find the right body position.

The holds have long straight edges and flat planes without any bumps or dents so that the climber isn't guided. The climber is forced to feel himself where it's best to hold the edge. These big holds have a block-like shape that can be seen in Image 1.

When a route consists of only blocks, the number of options to climb that route increases hugely, making it harder to determine its level of difficulty. Therefore, a new points system is introduced by the designer, to quantify the route and to motivate the climber.
Some edges are tougher to hold due to the angle between the planes. Also, some edges of blocks are harder to reach due to their placement within the route. In the design, the edges get points. The most difficult edge is given 1 point, and the easiest edge receives 5 points, as shown in Image 2. The difficulty of the route depends on which edges of blocks the climber uses to get to the top. The climber is supposed to finish the route with the least amount of points. This way, the climber is exploring his maximal abilities to find the route resulting in the lowest score.

In the user test, 10 medium skilled climbers were asked to clime the newly designed blocks and score their opinions on a questionnaire. In the first round, the score numbers on the blocks were covered, so that the climbers were free to choose how they wanted to use the blocks. In the second round, the climbers were given the task to climb using the lowest total score to reach the top. The blocks were judged to be more fun and challenging; climbers were more engaged to help each other with suggestions and stimulated each other to achieve the best scores. The new blocks were judged as thrilling and more challenging, but not as imitation of climbing on outdoor rocks

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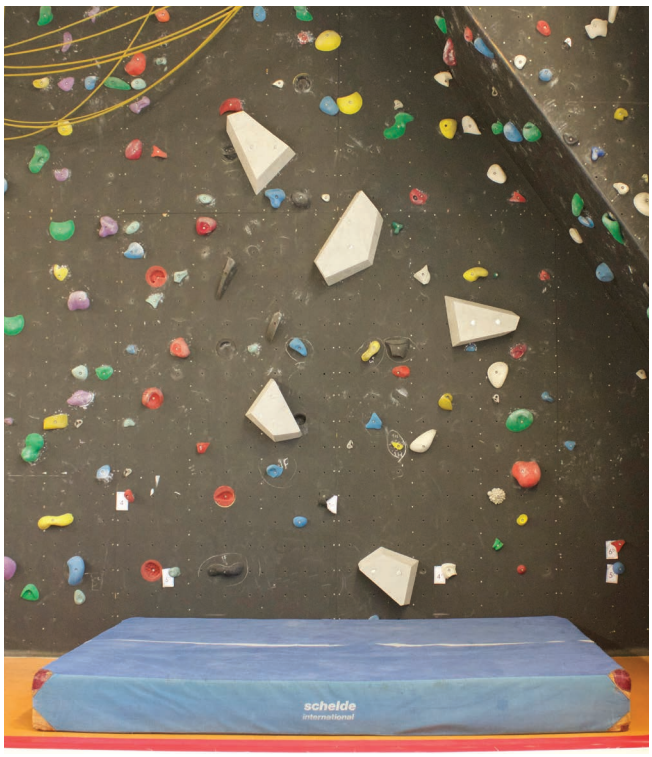

Image 1: Five newly designed blocks mounted on a climbing wall. Climber must only use the white blocks to climb the route.

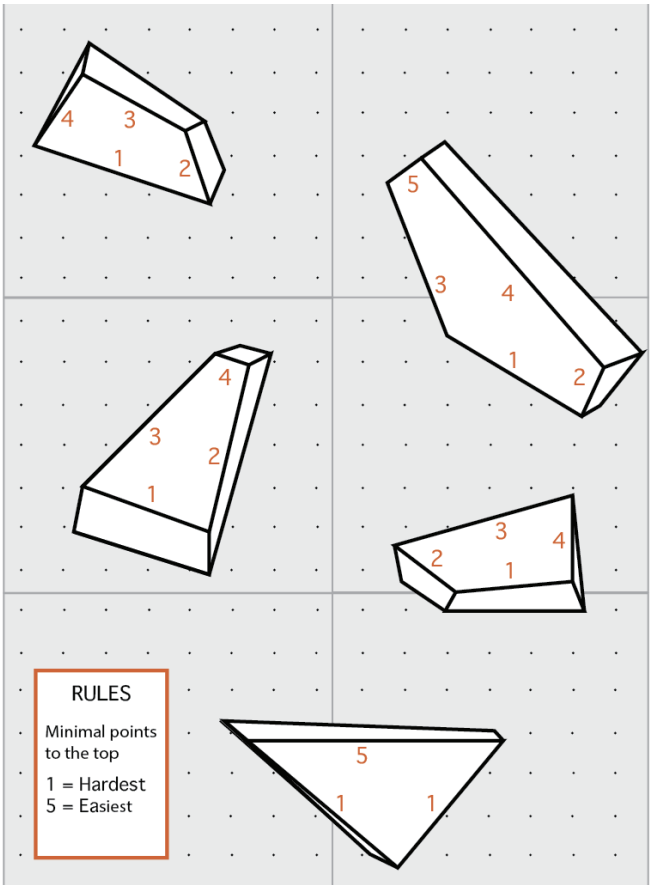

Image 2: Schematic view of blocks with points system. The numbers indicate the difficulty of the edges. The climber decides which blocks and edges he needs to reach the top of the climb.

CONTENT

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PROJECT APPROACH

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Introduction

Starting from part one, this report will describe the content of this graduation project about improving training in indoor climbing gyms. It is a process that started with a roughly defined problem and developed towards a final concept design. Along the design process, a number of tools and methods are used to generate ideas, gain insights and to make selection criteria, following the theory of the "creative diamonds" as described by Buijs & Meer (2013). In this chapter the argumentation of these tools and methods is given.

The designer went through six "creative diamonds", Image 0.1. These are presented as the six main chapters in this report, being Orientation, Analysis, Idea generation, Conceptualisation, Evaluation and Implementation.

Orientation

In the Orientation phase, the designer started with an idea: "I expect there is something that could be done to make indoor climbing nicer". At that point the answers to questions such as "why should it be improved?", "how should it be improved?" and "who benefits from this improvement?" were not clear, but there was an intuitive feeling ("gut feeling") that there could be valuable answers to those questions. Thus, the orientation phase began with observations in climbing and bouldering gyms. Observation is a good way of determining what happens in real life without interrupting the users. In addition, several informal conversations took place with climbers in the gyms discussing what they felt about the facilities and how they liked to train for climbing. From these observations and conversations initial insights arose. The designer took some time to read climbing blogs and news articles to find out whether those insights are more widely spread than in the few gyms that were visited. From these insights a problem statement

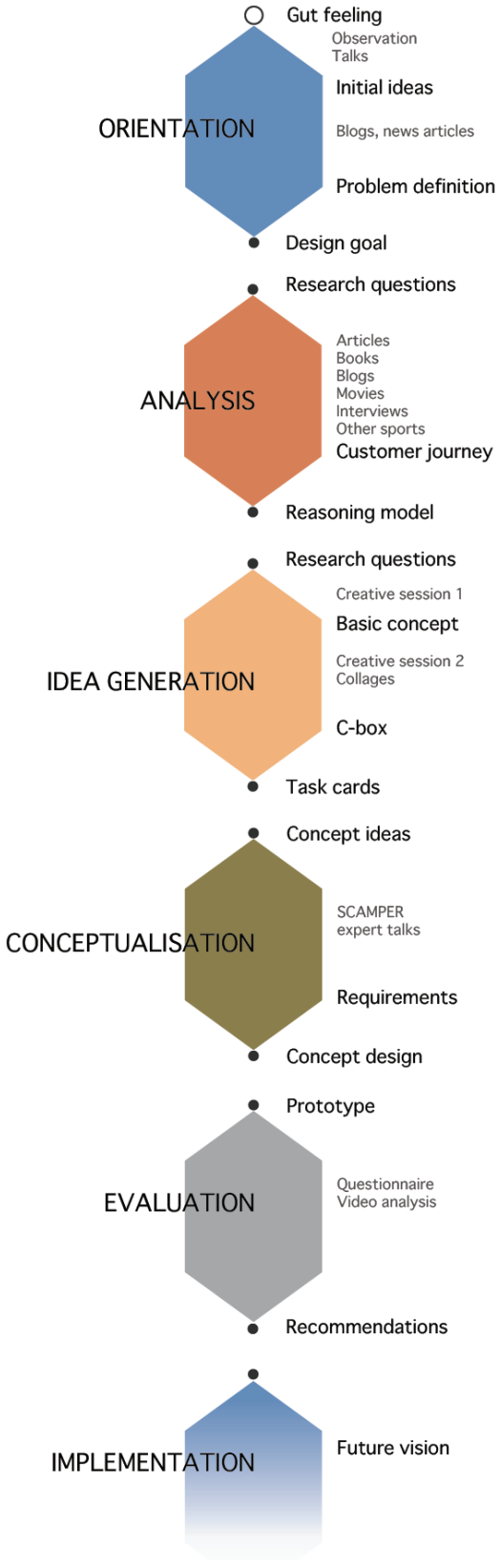


Image 0.1: Creative diamonds along the project

was formulated. The problem statement led to the design goal.
A design goal states the target group, the context of interaction and what problem is solved by the design. Deciding on the exact phrasing of the design goal means that decisions are made by the designer on which aspects to include and which to exclude. Those decisions are made on intuition and on the research done so far. Formulating the design goal shapes the closing of the first diamond.

Analysis

From the problem definition new questions arose. These questions were phrased as research questions and answered by going through literature articles, books, blogs and movies. Ten climbers and a climbers coach were questioned in a structured interview to get an impression of the wishes and needs of the expected target group. A customer journey was made to map the habits of climbers during their training. To get a wider view on training possibilities, climbing was compared to other sports. A swimmer was interviewed and movies and blogs of breakdancers, urban boulderers and gymnasts were assessed. This led to the creation of a framework (called Reasoning model) in which the vision on how climbing indoor should be improved was described.

Idea generation

At that point the theory of what should be done was clear and to get ideas on how to solve the problem, an idea-generation session was held. The designer had the opportunity to participate in four creative sessions as problem owner. Four groups of five industrial design students applied numerous idea-generating methods in order to provide the designer with a lot of (crazy) ideas that answered the design goal.
In addition to the design goal, an “Interaction vision” was formulated. This is aimed at the emotion that an user should have when using a product.
The combination of the design goal and the interaction vision gave a direction towards a solution. It this point, an initial solution arose, which the designer called “Basic concept”.
A subsequent creative session was organized to build on the Basic concept. This time, the designer facilitated the session herself. The design goal was given and the initial design and its underlying theory were explained. Then, the participants of the session were asked to create ideas that made climbing more fun through “How to” questions. After that, the participants had to rank which ideas they thought were the most fun and the most challenging. The words “fun” and “challenging” became key words in the design goal. From the ranked ideas the participants generated concept ideas. After the session the designer took all the ideas, post-it notes and sketches to analyse. The selection of useful ideas was done with a C-box. A C-box orders ideas on two axes, creating four quadrants. According to the indicators on the axes one most useful quadrant is determined. The ideas that are placed in that quadrant are worthwhile to contribute to a design (Boeijen, Daalhuizen, Zijlstra & Schoor, 2013).
Next to creative sessions, the designer went to search for inspirational images in terms of children’s play and shapes. A collage was made to indicate the vision in design in terms of shape. A second collage was made with inspirational climbing racks for children to get an idea of designs that evoke explorative play (the desired behaviour).

Conceptualisation

The selected ideas from the creative sessions and the collages were input for conceptualisation by the designer. A few concept ideas “popped up” whilst others were created using a provocative questioning method, SCAMPER. This is a force-fit technique in which you try to sketch an idea that Substitutes, Combines, Adapts, Modifies, Magnifies, Minifies, Put to other uses, Rearranges or Reverses from your initial idea (Boeijen, Daalhuizen, Zijlstra & Schoor, 2013). The initial concept ideas were discussed in another round of informal conversations, only this

time the participants were two people considered ‘experts’ by the designer. They were a boulder gym owner and a climbing hold producer. The conceptualisation diamond was closed with the selection of six concepts that were compared to the requirements. The requirements evolved from the design goal, interaction vision and some practical aspects mentioned by the experts.

Evaluation

From the six concepts, the concept that scored best on the requirements was picked to be tested in a user study. The user study evaluated whether the selected concept design evoked the desired behaviour and compared it to the current climbing behaviour. From the user test recommendations arose to improve the concept design.

Implementation

It can be argued that this last diamond is not fully closed, because the project concludes with a vision on the further improvement of indoor climbing and the future of climbing as a sport.

PART ONE

In the first part climbing as a sport is explained and the elements that play a role in training for climbing. This part ends with an explanation of the problem definition of this graduation project.

INTRODUCING CLIMBING

CLIMBING

Climbing is one of the most basic sports together with running, as people start doing it when they are small kids. Although climbing may seem to be an individual sport, it is rarely done alone. Climbers more commonly go climbing with buddies. A buddy is belaying or for good company. Buddies highly trust each other and motivate each other to succeed tough routes (Stevens, 2015). Although in climbing the achievements are individual, climbers describe it as a team sport or family-like bonds that they have with their climbing buddies (Verschoof, 2015).
The sport of climbing can be divided in multiple disciplines such as route climbing, bouldering, alpine climbing, ice climbing and speed climbing.
In this project, the focus lies on climbing and a little on bouldering. These disciplines are practiced both indoors and outdoors.

A short climbing history

The sport of climbing exists for over centuries, but it was only until the 1890s that there are reports on training for climbing. These 'early' athletes practised other sports before turning to climbing. Around the 1950s the first ideas of training arose with push-ups and pull-ups on one or two fingers to improve finger strength. The climbers were climbing on rock and lived or camped near the climbing sites. In the surrounding woods they build training equipment with beams on trees (see image 1.1 and 1.2). In image 1.2, the first signs of a man made climbing wall are showed. (Horst, 2003)

In those days the hardest route climbed was a 6a (see side note Levels on page 8). In the 1960, parts of the climbing training was done on lower rocks. No rope was required and when on top of the block, the climber could just jump off it. This is how bouldering was born.

Route climbing

Climbing is the general term of the sport, but mostly referred to as two climbers with a rope climbing on a rock or an indoor wall, this is more accurately called route climbing.

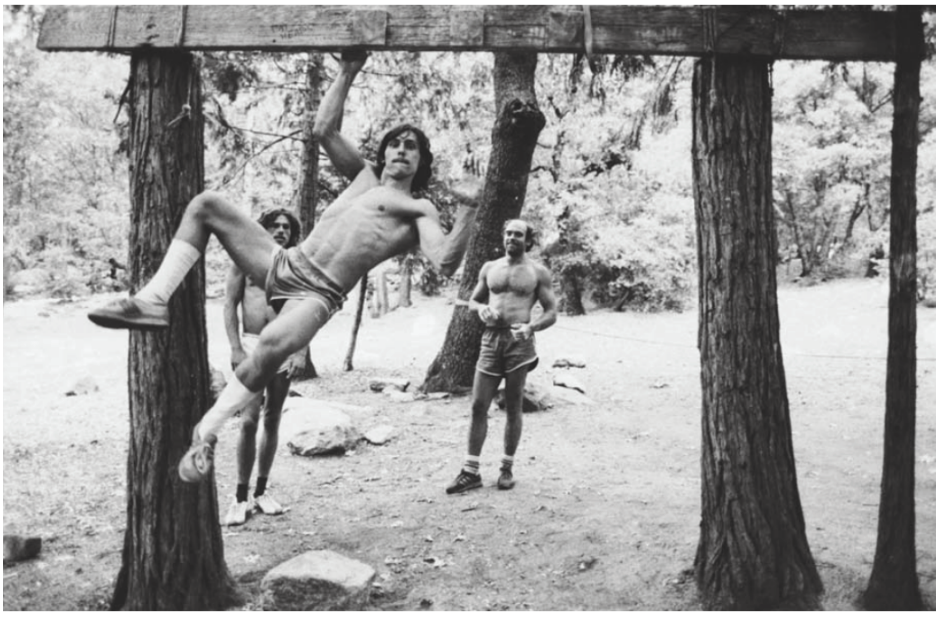


Image 1.1: Climber doing one-arm front lever

Image 1.2: Climber on practise wood

Climbing outdoors

Climbing outside is an event that to most climbers feels more like a day on holiday with friends than just climbing. They enjoy being outside and the company of friends (Verschoof, 2015; Phillips, 2015; van Weert, 2015). Most people don't have a rock or mountain in their backyard and therefore travel for hours to a climbing site. When they arrive at the site, there is no rope hanging in the rock yet, in contrast with the gym. You have to do that yourself which is called lead climbing. This means that the climber is belayed from below and clips the rope every 2 to 4 meters in an anchor in the rock as can be seen in image 1.3 and 1.5. If the lead climber falls, he falls until the rope meets his last anchor. These falls can reach 2 to 8 meters. This risk makes lead climbing a much bigger mental challenge than following.

When the lead climber has reached the top of the route, he secures the rope in the top anchor and descends. The rope is now fixed at the top and another climber can climb the route. This situation is called top-rope and is illustrated in image 1.4. All indoor walls use a top-rope situation. If the top-rope climber were to fall, he would fall one or two meters maximum due to the stretching of the rope. This makes falling in a top-rope route much less scary. Climbers feel more confident to practise high level routes in a top-rope situation (Verschoof, 2015, Phillips, 2015).

Image 1.3: Schematic view of lead climbing. The lead climber secures the rope in the anchors he/she passes during the ascent.

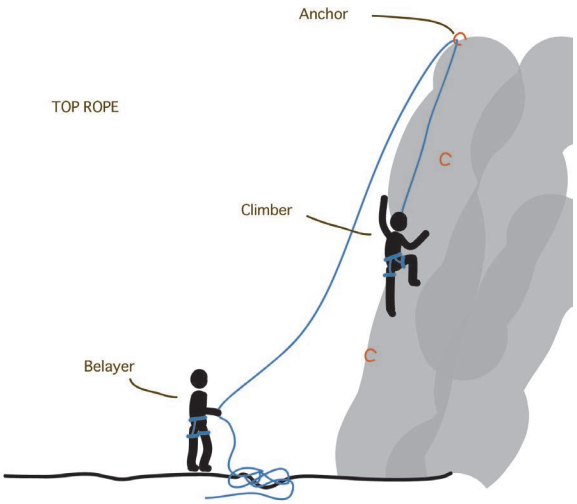


Image 1.4: Schematic view of a top-rope situation

Image 1.5: Lead climbing Outdoors, the anchors are a lot more difficult to spot. Photo from personal collection Mariet Sauerwein and Vera Konietschke climbing in Freyr, Belgium.

Climbing outside can feel very different depending on the type of stone (granite, chalk, basalt, gneiss). because the shape of the holds differs. Next to that, the shape of rock itself (for example plate, crack, chimney or overhanging) requires different climbing techniques. An overview of some of these climbing techniques is given in Appendix A. Weather conditions play a big role in outdoor climbing, rain, thunder and mist are circumstances a climber has to avoid.

Increasing popularity indoor climbing

It was not until the 1970s that purpose built indoor climbing walls became used in Europe. (Eden & Barratt, 2010) The first walls were wooden plates with wooden holds screwed onto them. Indoor walls originate as a rainy-day alternative but have grown to a culture and sport in its own right in the 1990s. Between 2005 and 2015 the number of indoor climbing gyms has grown to 944 gyms in the USA and Canada (Noble, 2015).

Climbing indoors

Indoor climbing walls are a safe and controlled environment for climbing. The climbing routes are secured top-rope. Everybody who wants to climb first has to take belay lessons and pass a belaying exam.

The walls of an indoor climbing gym are 5-20 meters high and covered with wooden plates with a rugged sandpaper-like surface. Onto these plates plastic climbing holds are screwed. A sequence of holds in a certain colour represents a route with a certain level of difficulty given at the bottom of the route. An impression of an indoor climbing gym is given in Image 1.6.

Image 1.6: Indoor climbing gym seen from above. The routes are secured top-rope. Climbers practise in duos, one is belaying and one is climbing.

Side note: levels

To give a rough impression on levels in climbing:

- 2 is comparable with a ladder, because placement of hands and feet are very clear and your bodyweight always rests on the legs.
- 3 can be compared with a climbing rack on playgrounds for children. You might have to search for the next hand or foot hold
- Up to 5a you are able to do with minor sports background, minor flexibility and limited climbing practise.
- From 5a to 5c you need practise and experience of previous routes. Here, specific moves as “flagging” and “undercling” are needed to complete the climbs. Increased finger and upper arm strength is preferred.
- From 6a to 7a a lot more practise and training is required. Finger, under and upper arm strength is a must in order to finish any route. To reach 7a, low body weight, a lot of training and effort are required. 7a is the minimum level to compete in national championships.
- 9b+ is the hardest route ever climbed when this report was written. Two climbers (Chris Charma and Adam Ondra) attempted this route for 5 months before making it to the top. It is called La dura dura (“the hard hard”) in Oliana, Spain.

The rating of routes is no exact science, it is a combination of length of the route, the angle of the wall and the type of holds. A route of the same level of difficulty in a different type of rock may feel very different to the climber (Ragus, 2013).

The holds that are used are available in a broad variety of shapes and sizes. Holds too have a level of difficulty, although this is not specifically graded. Holds that are not easy to grip are always used in more difficult routes (Kardolus, 2015, van Weert, 2015).

Most climbing gyms have a ‘strength training corner’ with fingerboards, campus boards, and power balls, weights and yoga mats to do climbing related strength exercises.

Fingerboard

Board with series of bigger and smaller holes, that allow the climber to train to hang on just a few fingers. On top (as shown in image 1.7) there are three slopes in different angles to hang from.

Image 1.7: Fingerboard. This board has series of holes and slopes to train finger strength. The holes have different depths, so hanging from three down to just one phalanges can be trained. At the top there are slopes in different angles presented. The hands in this image show how a climber hangs from those.

Power ball

Power balls are wooden balls hanging from a rope in the gym ceiling. The climber can practise holding on to holds by pinching them. Next

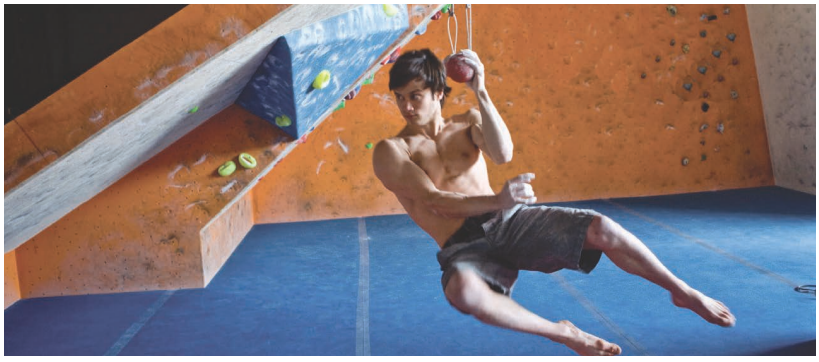


Image 1.8: Climber pulling himself up with one arm from a Power ball.

to that, climbers pull themselves up from power balls to improve core strength, as shown in Image 1.8.

Campus board

A campus board is a plate with numbered crossbars. Hanging on three or four fingers only on one crossbar at the bottom the climber can pull himself up and reach to farthest possible crossbar. In Image 1.9 a climber reaching the fifth bar is presented.

These tools are used by experienced climbers that want to do strength exercises next to their climbing. Using the campus board is very demanding for the relatively small muscles in your fingers. If climbers try this without proper practise it is likely that they get finger injuries.

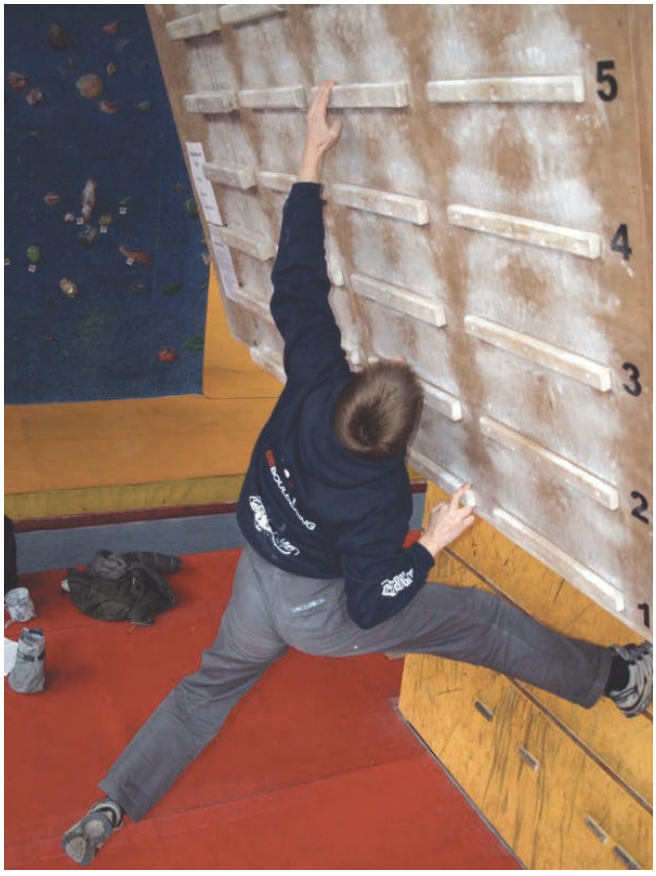


Image 1.9: Climber hanging from a campus board. He hangs from the first bar at the bottom and has just reached the fifth bar.

Bouldering

Bouldering is a form of climbing done on 'boulders' with a height up to four meters. Due to this limited height, there is no need for belaying with ropes. Instead a thick mat is placed under the route to break a climber's fall. A climbing buddy in this situation is called a spotter. He stands behind the boulderer with his hands in the air. When the boulderer falls he does not catch him but steers him upright making sure the boulderer lands on his feet (see image 1.10).

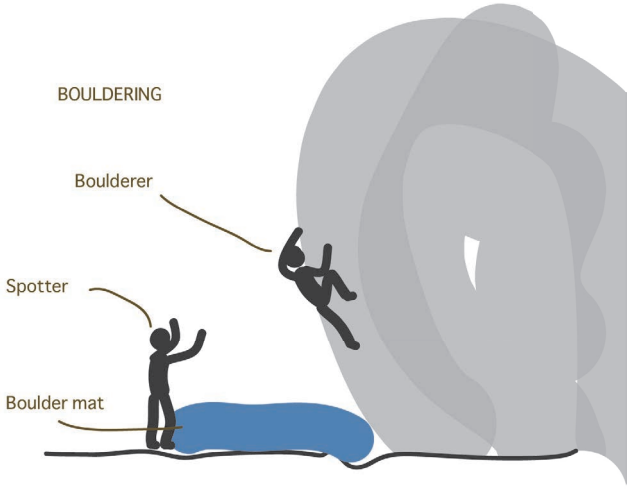


Image 1.10: Schematic view of boulder buddies, boulderer and spotter.

A boulder route takes around seven steps to get to the top of the boulder. These moves can be much more difficult in terms of power, flexibility and technique than in route climbing. Boulder routes are therefore called 'problems'. Boulderers generally need to be more powerful climbers than route climbers (Fanchini, Violette, Impellizzeri & Maffiuletti, 2013).

The atmosphere in an indoor boulder gym is comparable to a climbing gym. It is relaxed and buddies chat a lot with each other. In a boulder gym it is more likely to start a conversation with a climber you do not know. Boulderers discuss a problem with each other and quickly become new and temporary buddies. Everybody is looking how the others are climbing, an example of this atmosphere is given in Image 1.11.

Image 1.11: Indoor bouldering gym (at Delfts Bleau, Delft, The Netherlands

Buddy duos have different forms of relationships. Some duos have equal levels of climbing and they solve the problem together. They discuss how the moves might be done and try that alternately. Some duos have a different level of climbing skill, in that case a teacher-pupil relationship appears. The better skilled climber show-cilmbs the route and the lesser skilled boulderer tries to copy his moves.

Indoor and outdoor bouldering do not differ as much as in -and outdoor route climbing. In an indoor boulder gym the thick mats are already placed. When bouldering outside, climbers take the portable boulder mat, called a 'crash-pad' with them. This is a much thinner, smaller and lighter version of the mats that are used inside. They are not as soft but break a fall sufficiently. Boulderers carrying and using crash-pads are shown in Images 1.12 and 1.13.

Image 1.12: Outdoor bouldering. Buddy is spotting the climber and actively placing the crash-pad in the right position in case his buddy boulderer falls down.

Image 1.13: Outdoor boulderers carrying their crash-pads on the way to their next boulder problem.

PRE-READING

Both boulderers and route climbers 'pre-read' a route before they start climbing. By looking at the shape, angle and position of a climbing hold, you can predict in which way the hold should be held, Images 1.14 and 1.15. Then, you can determine on which side of the hold your centre of gravity should go, roughly left, right, above or below the hold you are using. This position is then transferred to the next hold. By deciding with which hand or foot the holds should be held, you can pre-climb the route in your head while still standing on the ground. Next to the movements, rest points are spotted and even the most difficult step (the crux) of the route can be seen from the ground.
When lead-climbing outside, the climber searches for the already placed anchors and the end of the pitch (Phillips, 2015; van Weert, 2015). In rock these metal anchors are often hard to spot on the grey wall. Next to that, the possible handhold and footholds are also hard to spot in rock, especially when you are looking at rock that is far away. Therefore only the first few meters of outdoor lead-climbing are carefully studied, after that it is a guess.
In bouldering, where the routes are only 4 meters high, it is much easier to study it entirely from the ground.

Pre-reading makes the climb faster and easier while you are on the rock or wall. The biggest advantage is that when you know where to go, you are faster and therefore save energy. Good pre-reading takes practise and not all climbers do this thoroughly. All climbers agree that it is a very useful skill, but some are too lazy or lack knowledge to always pre-read properly.

Image 1.14: Professional climbers pre-reading for competition. Together they discuss how the big red module can best be climbed. Pre-reading is rarely done in words, climbers use hand gestures to communicate to each other and to themselves how they think the route should be climbed.

Image 1.15: Climber discussing and enacting the step from one hold to another.

ROUTES

Indoor climbers are dependent on the routes that are available in the climbing gym. The routes are a series of holds placed in a specific order by the 'route setter'. The route setter has to build a route of a certain level of difficulty and determines the sequence of movements to make that route. Route setters use common tools such as drills (Image 1.16) and ladders (Image 1.17) when building routes. Just as every climber has his style, a route builder also has a specific style. A good climbing gym makes sure that many different styles of route setters make routes. A good route leads to a nice flow in the movements. A good boulder problem is a nice puzzle and should look aesthetically pleasing. The climber should be triggered to think "'Woah I want to climb this one!" (van Weert, 2015).

Holds

Routes are build with holds that are made of plastic. Small holds are solid, and bigger holds are made hollow to save weight. Holds are sold in series, these series are a family of shapes.

Occasionally there are 'modules' on the walls. There are blocks, commonly pyramid shaped, that are screwed onto the wall to give it more structure. These modules are made from the same material as the walls, so holds can also be screwed onto the modules. On example of a module is given in Image 1.18.

Image 1.18: Blue modules with pink holds screwed onto them

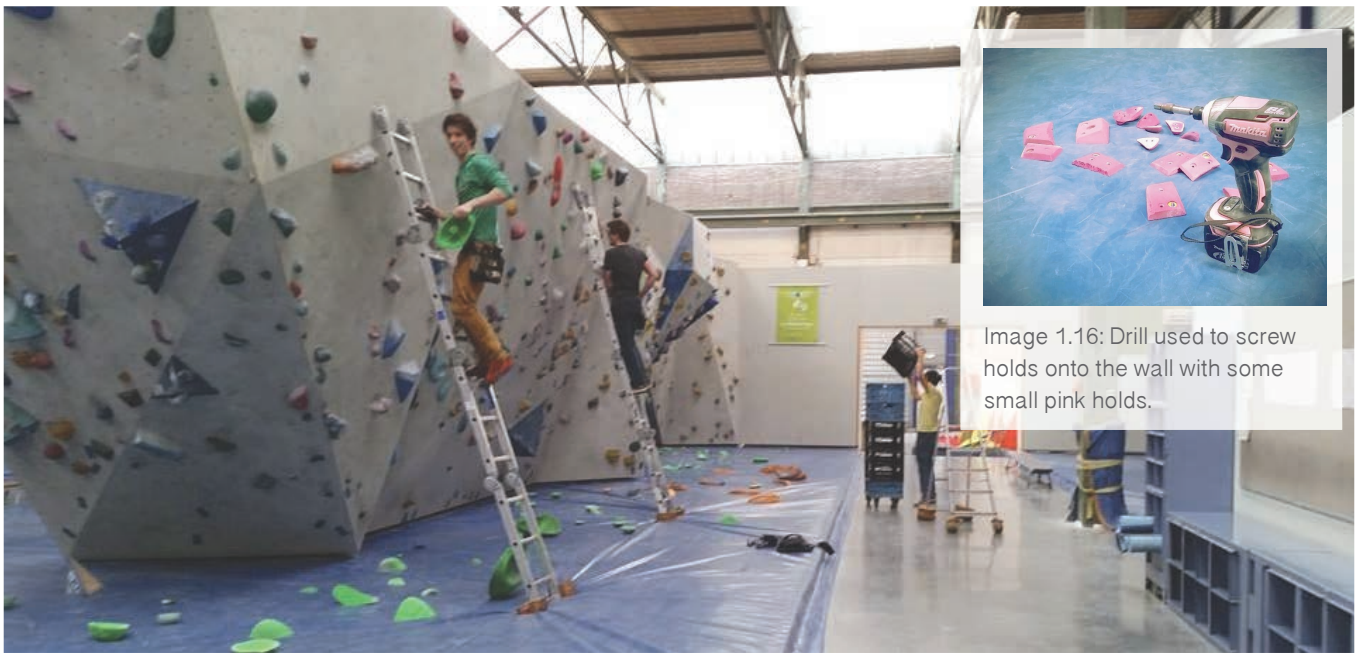


Image 1.16: Drill used to screw holds onto the wall with some small pink holds.

Image 1.17: Route builders at work using ladders and drills to screw the holds onto the wall. Routes are created during the screwing of the holds. Photo taken at Boulder centrum Delfts Bleau in Delft.

COMPETITIONS

Competitions in climbing appear in different formats. There is lead route climbing and bouldering. In both disciplines, the focus is on the difficulty of the route. The climber who finishes the toughest routes, in the least number of attempts, within a time limit, wins. Although the focus is on the difficulty of the route, the time limit is what climbers in competitions find the hardest (Dutch National Boulder Championships 2014). Climbers have the opportunity to pre-read the routes before the competition starts, but they are not allowed to touch the holds (with exception of the starting holds) (Dutch National Boulder Championships, 2014). After pre-reading, the climbers are brought to an isolation room. They are not allowed to see each other, because part of the competition is finding the solution to the various problems, and the climbers later in the competition will have an advantage. Competitions are held on (indoor) walls to ensure fair-play, since every climber has exactly the same tools holds to finish the route. Impressions of a boulder competition are shown in Images 1.19 and 1.20.

Within route climbing there is another type of climbing competition where time is the leading factor and is therefore called: speed climbing. A certain, not specifically difficult, route is build and the fastest climber wins.

Image 1.19: Boulderer happy with his achievement and raising his fist to celebrate with the crowd behind him.

Image 1.20: Impression of boulder competition (Dutch national championships Boulder 2014, Delft. The crowd is watching as the candidates try to reach the top of the boulder problems.

INTRODUCING CLIMBING

PROBLEM DEFINITION

Indoor and outdoor climbing

When comparing indoor and outdoor climbing, indoor climbing is easier accessible and not dependent on weather conditions. Outdoor climbing requires different styles and more climbing techniques according to the type of stone and the shape of the rock. These techniques can not be practised indoors because it is rarely available in gyms (Verschoof, 2015).

Almost all climbers that climb both in- and outdoor state that outdoor climbing is superior to indoor climbing. To them, outdoor climbing represents an adventure and an achievement whilst indoor gyms are used as a convenient training method (Verschoof, 2015; Bogaart, 2015; Phillips, 2015).

DESIGN GOAL

In general, indoor climbing gyms are considered not as challenging as climbing outdoors, but I feel they can be improved in terms of training opportunities. This graduation project revolves around the question, how to make indoor climbing gyms a better training facility and more fun and challenging for the climber? Therefore a design goal is formulated:

"Improve the quality of a training session at an indoor climbing gym for medium level climbers by amplifying the fun and enhancing the challenge of that training."

PART TWO

In this part research is conducted to answer the posed research questions. The research questions evolve around three themes: Sports Performance, Behaviour Change and Training for Climbing.

ANALYSIS

INTRODUCTION

This chapter captures the analysis done in order to answer three research questions that emerge from the design goal.

RQ1: How can training for sports be optimized?
This question is addressed in part one 'Sports Performance.

RQ2: How do you motivate people to behave differently?
This question is answered in part two 'Behaviour change'.

RQ3: What is currently happening in the indoor gym during training?
This question is answered in part three 'Training for climbing'. Here, a reasoning model arises that captures the current behaviour of climbers and indicates what should be changed to improve the training.

Information to answer the research questions was gathered from literature studies and interviews with climbers as well as climbing trainers.

PART ONE

SPORTS PERFORMANCE

Research question 1: How can training for sports be optimized?

An athlete, whether it is a professional athlete or someone who practises sports on an amateur level, is looking to increase his sports performance. Increasing this performance is done by practising different aspects of his sport; in other words: training. A good training should have a clear goal. That goal might be to improve strength, prepare for a match or to practise certain techniques.
In addition to sport specific exercises, someone who does sports in general performs at his/her best when going through the following steps:

1. Readying. The athlete should get in optimal emotional state. A Self-confident psyched state of mind.
2. Imaging. The athlete goes through all the motions he will perform mentally.
3. Focussing. He focuses on one relevant cue for the performance, a detail of the target (this suppresses other non-relevant thoughts).
4. Executing. He executes the movement without thinking.
5. Evaluating. The athlete assesses the outcome of his movement and plans adjustments for the next trial. (Wulf, 2007)

In climbing, imaging in known as pre-reading. Going over the moves in your head while still standing on the ground. Imaging helps the athlete to prepare for executing the movements. It makes it easier to stay mentally tough, be self-confident and feel in control. (Boyd & Munroe, 2003)

In this chapter several beige blocks will mark paragraphs that point out the link between the theory and the climbing sport.

When looking at these steps, it appears that only step 4 (executing) requires physical effort, whilst the others are all mental. Sport performance may rely on the brain as well as on the body. Which of these factors has the most influence on the performance in that sport depends on the type of sport. In figure 2.1 three examples are given (Magiera et al., 2013).

One could argue that the 100 meter sprint performance depends for the largest part on the physical performance (muscle power and oxygen uptake). On the other hand, golf is a sport that requires a lot less physical power yet much more technique for hitting the ball just right. Technique is a factor that implies how well the athlete can execute the movement (van Weert, 2015). If a golf player has a good technique, he will be able to hit the ball right in the middle of his club so that the ball bounces off the club in the right direction and with maximal speed. If a golf player is not able to asses how to his the ball in the middle, he will have a less refined technique. Technique is a factor that can only be trained by doing exercises specific exercises for that movements (Ericsson, 1996), (Starkes & Ericsson, 2003). Whilst physical performance can be increased by doing exercises that are less related to the sport. A golf player may also cycle in order to train his endurance, whilst cycling and playing golf are non-related movements.
The third performance factor is mental, which means the state of mind of the athlete. If an athlete feels good, is happy and is excited to play his sport, he will perform better. Interestingly, a climbing performance (not during competition) relies equal on all three factors.

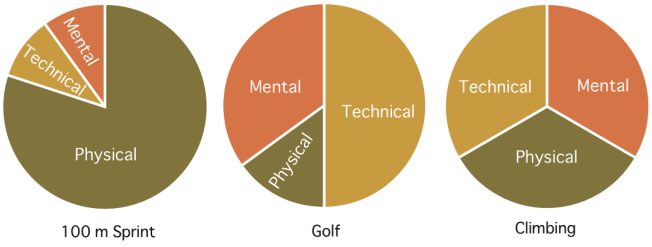


Image 2.1: Divisions of mental, technique and physical in sport performance of different sports

The pie charts of image 2.3 are estimations to indicate differences between sports, rather than absolute findings. (Magiera et al., 2013; Starkes & Ericsson, 2003)

In a situation of a game or competition the mental factor becomes much more important, Image 2.2.
In a competition, the environment (the atmosphere, climate, crowd) will greatly influence the athlete's performance. In competitions a forth factor starts to play a role: tactics. (Magiera et al., 2013) The tactical factor implies the decision making skills and the adaptability of the athlete. If an athlete is able to adjust to use the behaviour of his competitors (and use this in his advantage) he is tactically strong (Starkes & Ericsson, 2003), (Delfos, 2014).

Motor skill learning

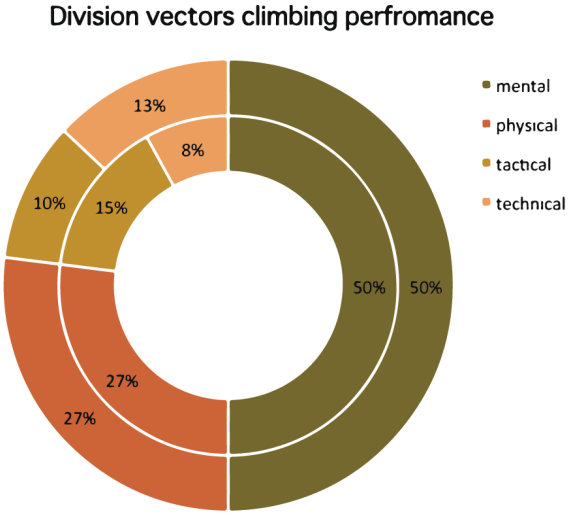


Image 2.2: Division of mental, physical, tactical and technical factors in sports performance during competition.

The brain plays an important role in sports, in both executing movements and especially in learning new movements. The human brain is an organ that is both very lazy and very good at pattern recognition, making it a very effective 'machine'. For example, when a person looks around him, he is aware of what objects are around him without actually looking at all of them. Conscious observation and processing of that data consumes a lot of (brain) energy. Therefore the brain

uses pattern recognition to minimize the processing of conscious observation. It uses just a few clues from the environment to 'fill in the gaps' based on previous experience. Resulting in a fast awareness of what is around the person.

Something similar happens when learning a new (bodily) movement, for example during training. The human brain controls the muscles and therefore the body. Controlling can, just as observation, be done consciously. This too takes a lot of energy. The brain knows some basic and fundamental movements, these are called Locomotor skills. These are skills such as running, hopping and leaping. The brain has also learned Object Controlling Skills, in its toddler years, such as throwing, catching and rolling. These skills can be interpreted as patterns of movement. When a human learns a new movement he takes parts of known patterns to create the new pattern. All this is done to lower the energy that is needed to execute that new movement. The process of combining elements of known patterns into a new pattern is called Motor Skill Learning. At the end of the process the athlete masters the new movement. The process of motor skill learning towards mastery happens in three stages (Wulf, 2007).

1. Cognitive stage. This is also called the verbal stage, as many athletes talk themselves through the movements and reference points. In this stage the athlete is still thinking in actions rather than goals.
2. Associative stage. In this stage parts of the movements are associated with movements that are already known. Thus parts of the movement are executed autonomously.
3. Autonomous stage. In the last stage all movements are executed fluent and autonomously. The mental effort in this stage is so low that additional tasks can be executed such as talking, or counting backwards.

Along the three stages of motor skill learning, the athlete uses proprioception more and more. Proprioception is a sense of the position of the limbs, a sense of movement, effort, force and heaviness. Receptors in the muscles send this information to the brain whom translates it into a bodily awareness. Some even call it the sixth sense of the human brain. (Bennington-Castro, 2013). Being aware of your body position is important when you are learning to control your body position and movements.

An athlete performs well when the performance is constant and the "lucky shots" appear rarely. A well performing athlete is also one who learns new movements rapidly. A efficient learner can be recognized when the number of co-contractions decreases rapidly. Co-contractions are contracting muscles that are not specifically required for the intended movement, and are therefore a waste of energy. As the co-contractions decrease, the mental effort needed to execute the movement also decreases (Wulf, 2007). Learning fast can be achieved by focussing on the target or aim of the movement instead of focussing on the movement itself. Motor skill in itself is the effectiveness to achieve a goal using movement as a tool (Higgins, n.d.).
In the course of the three stages co-contractions and mental effort decrease as skill increases, see image 2.3. (Wulf, 2007).
There are four factors that help improving motor skills, thus coming to the autonomous stage. These

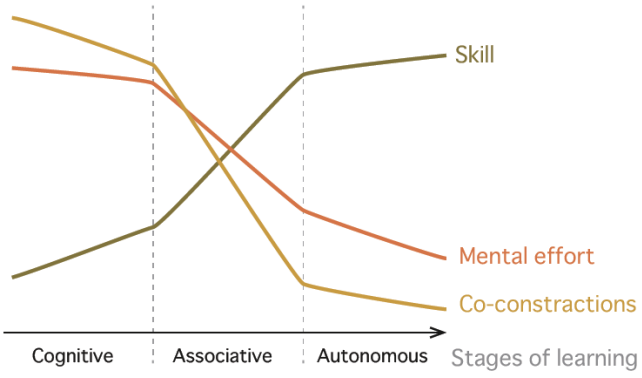


Image 2.3: The process of Motor Skill Learning evolves in three stages: cognitive, associative and autonomous. Along this process the skill increases, the mental effort and co-contractions decrease.

factors should be included in every training in order to increase the performance of the athlete the fastest. They are observational practise, focus on attention, feedback and self-controlled practise (Wulf, Shea & Lewthwaite, 2010).

The first is *observational practise*. It helps to see somebody else perform the movement and then try to copy it. When you are looking at somebody moving, certain parts of the brain become active as if you were doing those movements yourself. This is called neuroimaging and it speeds up the learning process. In addition, alternating between observation and practise with a buddy increases motivation and possibly enjoyment (Wulf, Shea & Lewthwaite, 2010).

In route climbing it is common to climb with a partner that is your belayer. The belayer looks at the climber, while belaying. Climbers are thus already doing observational practise. In bouldering the climbing buddies (climber and spotter) alternate more frequently, as the routes are shorter. Climbers indicate that solving a boulder problems with their buddy is nicer because they solve the problem more quickly than alone (Bogaart, 2015; Phillips, 2015; van Weert, 2015; Verschoof, 2015).

The second factor is *focus of attention*. This is already woven into the definition of motor learning and states that the attention of the athlete should be on the intended trajectory of the movement.

The third factor is *feedback*. Feedback is information about the results or the performance from an external source. Feedback may also be motivating when it emphasises what went well and when it ignores the bad, because athletes are generally well aware of how they performed. Giving positive feedback increases the learning speed. Giving negative feedback slows down the learning process and lowers self-confidence. Giving feedback on the performance while the performance is ongoing is contra productive. It distracts the athlete, and increases the change of demoralisation (Wulf, Shea & Lewthwaite, 2010).

The fourth factor is *self-controlled practise*. Most of the time, the coaches dictate the training in terms of exercises, duration and focus points. Giving the athlete some control over the exercises creates a more efficient training because the athlete is actively involved.

Most climbers are usually self trained athletes and are used to have full control of their training. They decide for themselves what needs to be trained. This makes climbers relatively autonomous, yet independent and not always easy athletes to train (van Weert, 2015). When climbers go climbing, they commonly refer to it as a “climbing session” rather than a “training“. Despite the fact that a climbing session looks a lot like a training, yet with the absence of a trainer. Climbers can still benefit from including the four aforementioned factors into their “climbing session”.

Conclusion

To conclude, how can training for sports be optimized?
The aim of training is for the athlete to learn how to perform better at his sport. The search for how to become better is a discovery of the athlete's body. He has to learn to *feel* which muscles should contract in order to make the right movement. (Ericsson, 1996; Williams & Hodges, 2015; van Weert, 2015.

In order to learn new movements, it is wise to train. This training should contain elements of observational practise and motivating feedback. Next to that, the athlete should have some control over the exercises done.
During training, the athlete must be aware of the fact that he is teaching his brain something as well as your muscles. The most efficient way to do that is to focus on the trajectory of all movements. These insights are summarized in the reasoning model of Image 2.4.

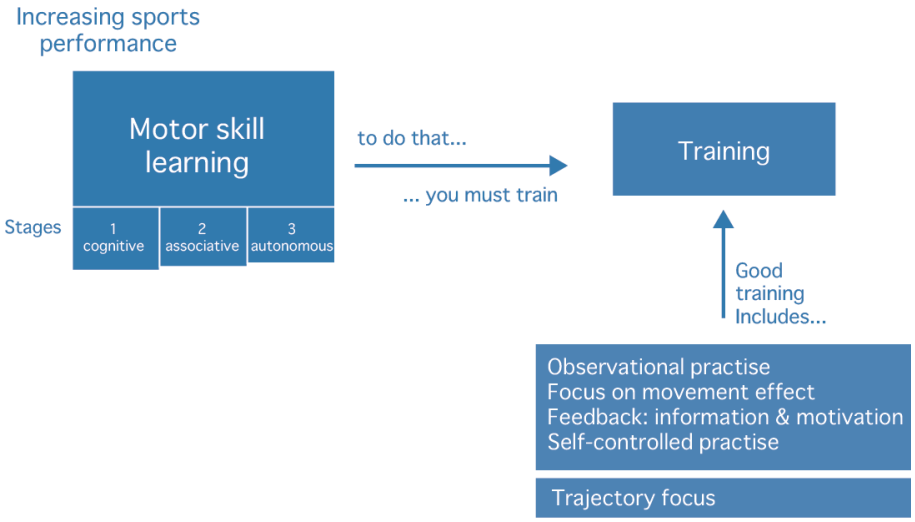


Image 2.4: Reasoning model that summarizes how an athlete's sports performance can best be improved.

PART TWO

BEHAVIOUR CHANGE

With indoor climbing gyms and motor learning in the back of your head, the core of this design project is to change the way climbers train, which is a behaviour change.
The second research question therefore is:

How do you motivate people to behave differently?

At first, the current behaviour and the target behaviour should be identified to create a focus on what specific behaviour should be changed. Behaviour occurs in the context of "patterns", a sequence of behaviours or actions.

There are three ways to change the user's behaviour. These range from more compulsory to more voluntarily. The first type is enabling. Here the target behaviour is promoted as easier than the current behaviour. The user still have the choice to perform his current behaviour. The second method is motivating. Here the user is educated on which is the best (the target) behaviour. The user is still free to choose which behaviour he uses. The third and most compulsory type is constraining. Here the target behaviour is enabled and the alternative (or current) behaviours are made almost impossible. (Lockton, Harrison & Holley, 2015)
Constraining is the most effective way to achieve the desired behaviour, but might also feel the most forced and unpleasant to the user. Using constrains in a design is called persuasive design. Changing behaviour through design means that the designer suggests a different pattern for the user.

A user has to be persuaded to act in a different way then before. People experience two types of motivation, intrinsic and extrinsic. Intrinsic motivation implies that the user experiences joy in the activity itself and therefore wants to do it. Extrinsic motivation is aimed at an external and indirect goal that the user wants to achieve. He does not feel satisfaction in the activity itself but in the effect the activity will have, such as rewards, praise and enhanved skills (Bittner & Shipper, 2014; Ryan & Deci, 2000). Intrinsic and extrinsic motivation are seen as extremes on one axis. A person experiences a combination of intrinsic and extrinsic motivation for one task.

In training for sports there is a lot of extrinsic motivation. Most athletes do not enjoy the exercises per se, but are motivated to do them to become stronger in order to perform better at their sport.
The need for exercise and movement can be an intrinsic motivation.

Gamification

A tool to achieve behavioural change and to create motivation for this behavioural change is Gamification. Gamification is a theory that is based on the fact that there are two worlds involved in our lives and people hover between those worlds. There is aa game world and a real world, The real world represents our daily life. Within the game world there are different "rules of life", the consequences of one's actions are less severe, it is a place for social interaction and a feeling of belonging. In games one can improve one's skill levels due to faster feedback and gain rewards for improving skills. All this together makes the game

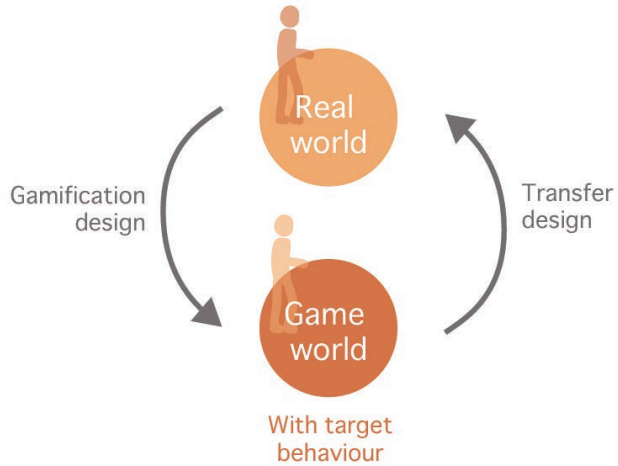


Image 2.5: Model of gamification design and transfer design between the real world and the game world.

world a more fun and motivating place to be in than the real world. Due to this different set of rules, the user behaves appropriately to the game in the game world. Transferring some elements of the game world, into the real world therefore triggers 'game behaviour' in the real world (see also figure 2.5 for schematic overview). (Blohm & Leimeister, 2013; (Visch, Vegt, Andriessen & van der Kooij, 2013).

In order to successfully design for gamification certain aspects must be taken into account.

1. The target group should be defined. This group of users responds to particular set of values.
2. Use both intrinsic and extrinsic motivations. Users are the most motivated when they want to achieve something (extrinsic) and the task needed to get there is also pleasurable (intrinsic).
3. Focus on flow. In game design it is of vital importance to design a good 'flow' of the game. Flow is the balance between the skills of the user and the challenges he faces. When the level is not challenging enough for the user's skill set he will be bored. When the challenge is too difficult for his skill set the user will feel anxious and stop playing the game. The user voluntarily stretches to his mental or bodily limits to reach a difficult yet worthwhile goal. (Csikszentmihali, Harper & Row, 1990) A graphical presentation of this balance can be found in Image 2.6 (Koster, 2005; Bittner & Shipper, 2014). In game design the course of the flow goes somewhat like the red line drawn in the flow channel of figure 2.6. The challenge will increase with a step, and therefore the skills of the user must increase before mastering the next 'level'. Then a new challenge is presented. The game elements that are transferred into the design and the real world should always be challenges that feel just within reach, so within the orange tunnel in the image (Deterding, 2011).
4. Focus on enjoyment. The game or game elements should be fun in order to be succesfull. (Blohm & Leimeister, 2013; Bittner & Shipper, 2014).

There are two pitfalls when designing with the gamification theory that need to be taken into account. At first, gamification is sometimes sarcastically called "pointsification". The seemingly easiest way to motivate people to change their behaviour is to reward them, by giving points, levels or badges. Focussing on rewards giving and receiving means that the intrinsic motivation to do something becomes an extrinsic motivation. The user is now controlled by the system giving the rewards.
Secondly, giving rewards that are overdone for the accomplishment result in devaluation of the game or product. It gives the user the feeling he should act in a certain way to get the reward instead of enjoying the game or product itself. (Nicholson, 2012; Deterding, 2011).

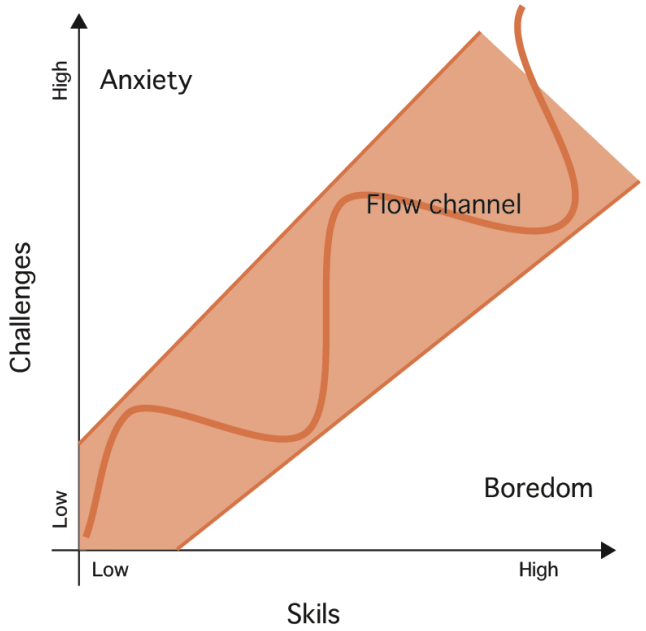


Image 2.6: Flow model depicting the balance between skills of the user and the challenges he faces. When the flow isn't well balanced the user will either feel bored or anxious (Koster, 2005; Bittner & Shipper, 2014).

Conclusion

In conclusion, there is a current pattern of behaviour that needs change. A way to change that behaviour is by presenting a 'game world' in which intended interactions and 'rules' are at play. Through the design the target behaviour is transferred towards the 'real world'. And so the target behaviour is reached within the target pattern, as is depicted in the scheme of image 2.7. At the end of part three this scheme is be "filled in" with the current behaviour, game world and intended behaviour.

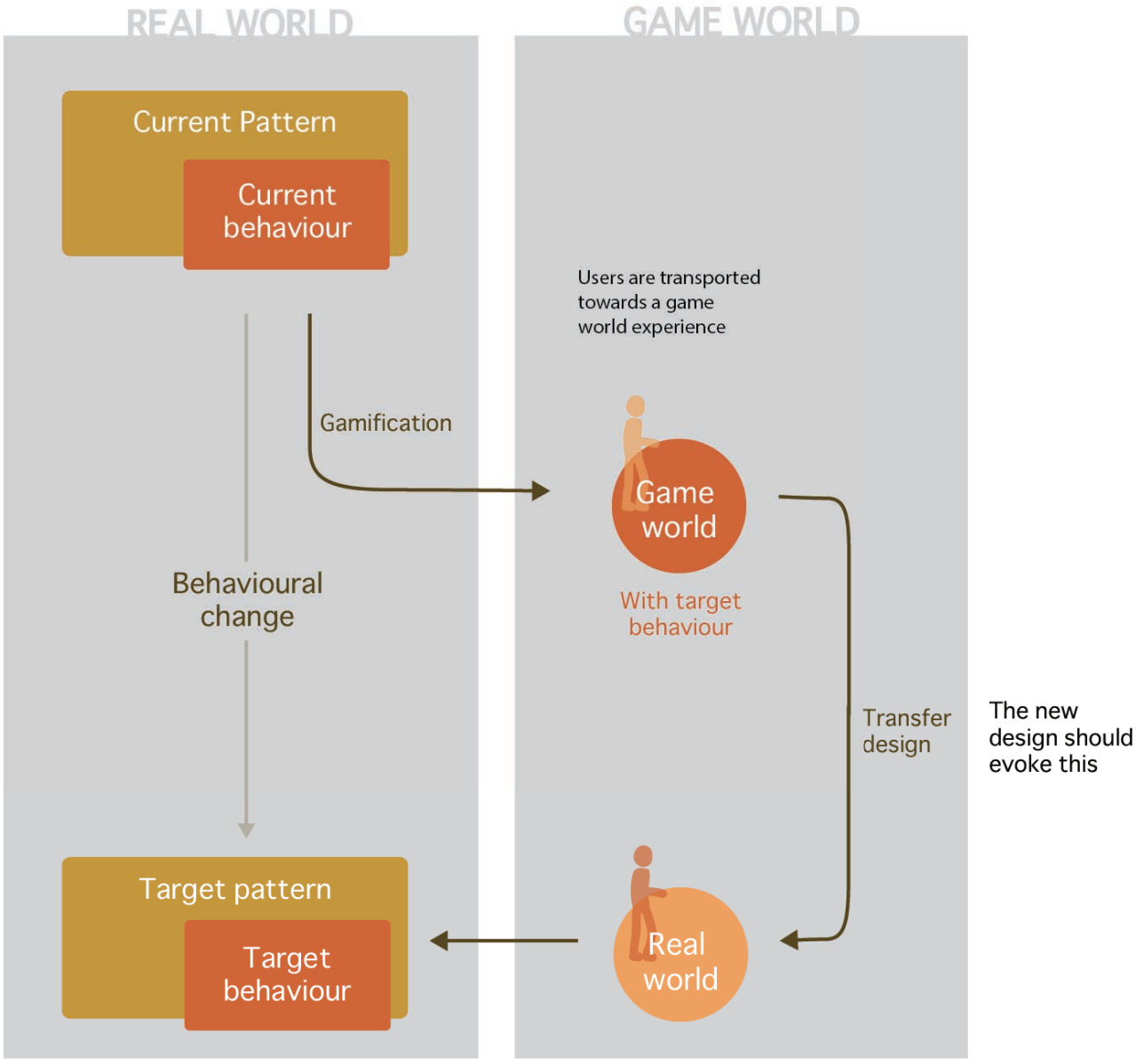


Image 2.7: Reasoning model behaviour change

PART THREE

TRAINING FOR CLIMBING

In order to be able to fill in the current behaviour of the previousy presented reasoning model, the thrid research question is:

What is currently happening in the indoor gym during training?

Indoor versus outdoor

As mentioned in the introduction to climbing, indoor climbing is less adventurous and challenging than climbing outdoor. This is the result of interviews that were held with four amateur climbers that climb both indoor and outdoor. As a control, one swimmer who swims both indoors (swimming pool) and outdoors (open water, lakes) was also interviewed.
The transcriptions of these interviews are presented in a matrix that maps “what I like about indoor”, “what I dislike about indoor”, “what I like about outdoor” and “what I dislike about outdoor”. The matrix with all the quotes and clusters can be found in appendix B, in Image 2.8, the main insights of the interviews are presented. The issues that were addressed most frequently are marked with a darker shade of blue.
The arrows indicate potential issues to improve the experience of indoor climbing. This can either be done by introducing positive elements of outdoor climbing indoors, or to improve negative elements of indoor climbing.

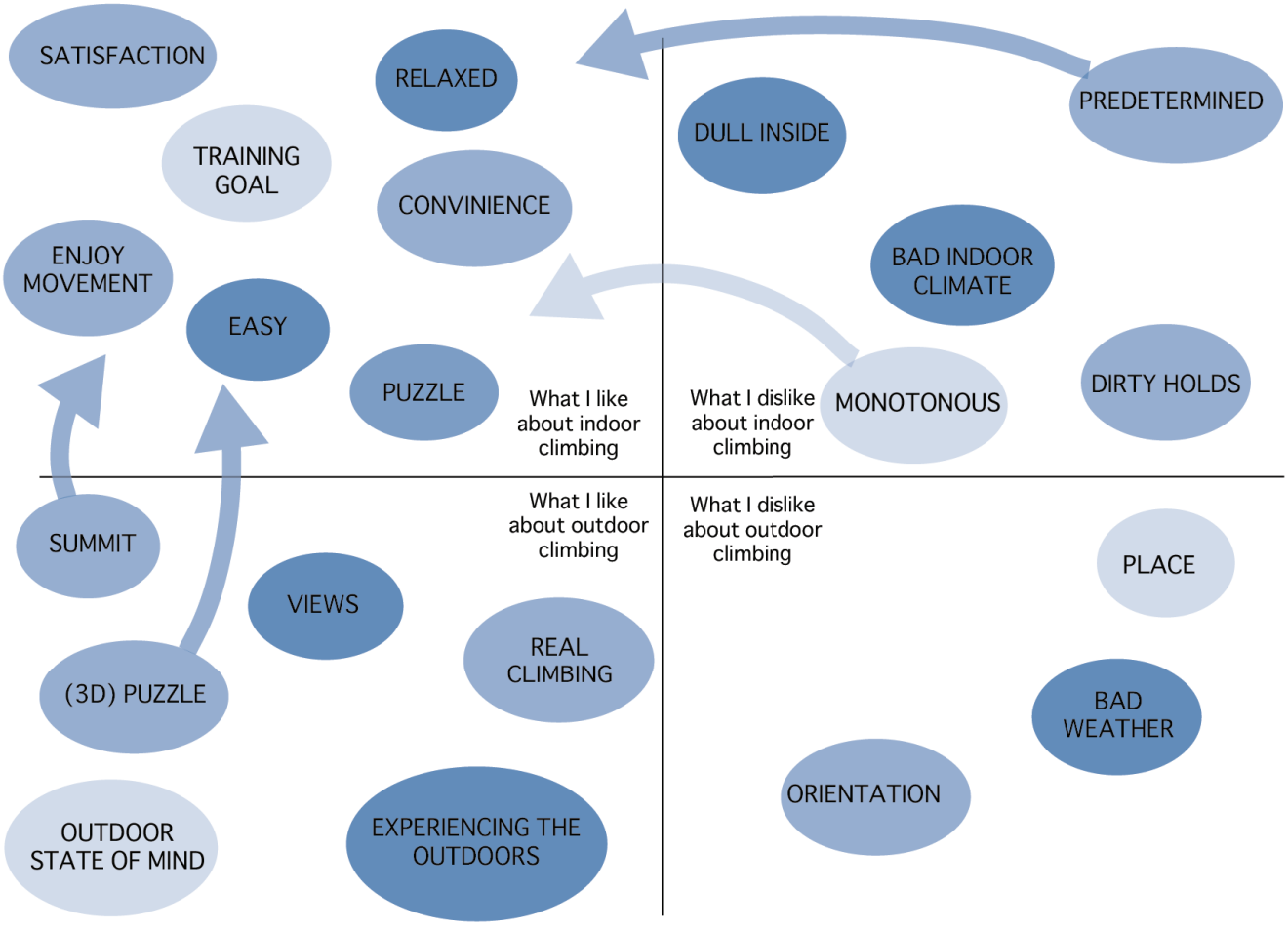


Image 2.8: interview results indoor versus outdoor matrix

ANALYSIS

In the quadrant “what I like about indoor climbing” ‘easy’ and ‘relaxed’ are highlighted. Easy refers to the fact that the climbers don’t need to worry about finding the route or lead-climbing, because the gym has prepared the routes. Next to that, ‘satisfaction’ and ‘puzzle’ are also highlighted. The satisfaction refers to succeeding, climbers are happy when they finish a route of a certain level. Climbing is also described as a puzzle that you need to solve with your body. Solving the puzzle is what many climbers like about the sport in general.
In the quadrant “what I dislike about indoor climbing” ‘dull inside’ and ‘bad indoor climate’ are marked the bluest. The indoor climate is a factor that can’t be changed by design of a route, and is therefore out of the scope of this project. ‘Monotonous’ and ‘predetermined’ are factors that can be designed for. Monotonous means that the routes and the holds all feel the same. Holds are always made of plastic with a rough surface and although shapes differ, the touch is predictable. The second cluster is predetermined. The route is meant to be executed with certain moves, as a climber you enact what the route setter has designed. Partly, this is in conflict with the sense of puzzling that outdoor climbing evokes even more.

In the “what I like about outdoor climbing” quadrant the ‘views’ and ‘experience the outdoors’ are most important when climbing outside. In addition to that, the ‘summit’ cluster is highlighted. People find joy in reaching a summit. There you take a moment to be proud of your accomplishment before descending. Strikingly, people mentioned that while indoor climbing also feels like a puzzle, outdoor like a ‘3D puzzle’. The sense of puzzling is the same, but there is an extra dimension in having to search for the hand and footholds, as they are not predetermined as in indoor gyms.
In the “what is dislike about outdoor climbing“ quadrant, ‘bad weather’ is considered the most annoying. Cancelling a climbing trip due to bad weather conditions is always a pity. The ‘place’ were outdoor climbing is practised is not always near, so climbers need to travel before they can start climbing. Finding the right route and navigating the right way up is not always easy, so ‘orientation’ in rock climbing is harder than in indoor climbing.

The aim of the project is not to have indoor climbing look or feel more like outdoor climbing per se, but to make indoor climbing more exciting. ‘Satisfaction’, ‘puzzle’, not-’predetermined’ and ‘the feeling of reaching a summit’ are keywords that could be incorporated in the new design.

Training sessions

Climbing gyms are used as a training facility. For outdoor climbers it is the place to practice techniques and to keep in shape for the next outdoor trip. For indoor climbers it is training to improve their level.

The training of climbing is done in sessions from around 3 hours (Bogaart, 2015; Phillips, 2015; van Weert, 2015; Verschoof, 2015) including warming-up, the training and a cooling down. In between there are breaks to drink water. Due to the social aspect of a climbing session, these breaks can be quite long, up to 20 minutes (van Weert, 2015; Verschoof, 2015) During a training or climbing session at the gym climbers climb 10-15 routes in total.

Warming up is done by climbing around 3 to 5 easier routes that are at least two points below the top performance of the climber (ter Steege, 2015). These routes are climbed in a slow pace to neatly make the movement to the next hold. (Appendix C) After the warming-up, 3-6 harder routes are climbed. Some keep increasing the level of difficulty until they are tired and then start the cooling down. Others prefer to interchange easier and harder routes within their training.

Climbers keep track of how many routes of what level they have climbed. If they climbed a tough route with two rests, the climber will try to climb it with just one rest the next time. “To an outsider, climbers must seem like a bunch of very athletic accountants”

(Noble, 2013). Keeping track of the routes, attempts and levels makes indoor climbing an mathematical activity. It is easy to keep track of your level and progress.
Climbers are in general self trained athletes. The gains are always individual, although it is nicer to climb with a buddy, he or she suffers no consequences when you perform badly. Only you take the blame or the pride. This evokes a culture of individuality and also individuality in training. There are many different styles of climbing and one style fits you better than another, which is accepted within the climbing community. This also means that climbers help each other and are open to suggestions “maybe it is better (for you) if you try to stretch your right leg before you grasp with your right hand“. This climber will try to make the climb without finding the other tip-giver arrogant (Appendix C).

Climbing culture

One could argue that there is a specific ‘climbing culture’ in route climbing gyms and boulder gyms. Climbing buddies motivate and encourage their friends but climbers also encourage strangers when they try to get to the top of a route. This makes the climbing community a very open one.
In Image 2.9 a short comic is shown that gives a nice example of this culture. In Appendix D there are more comics added that make fun of climbers when climbing and giving tips to others. They sketch a nice impression of this typical culture and might amuse you.

Learning pre-reading

Pre-reading can only be mastered through thorough practice. In learning how to pre-read there are four stages to be determined these are depicted in figure 2.10. As a beginner (stage 1) you look where the holds are and make a rough estimation if the holds should be held with either the left or the right hand. With a little more experience (stage 2) the climber is able to predict in which order the hand holds should be taken. When the climber invests more time and effort (in stage 3), not only the hands but also the order of foot holds is imagined. In fourth stage the placement of hands and feet is translated to a movement in the

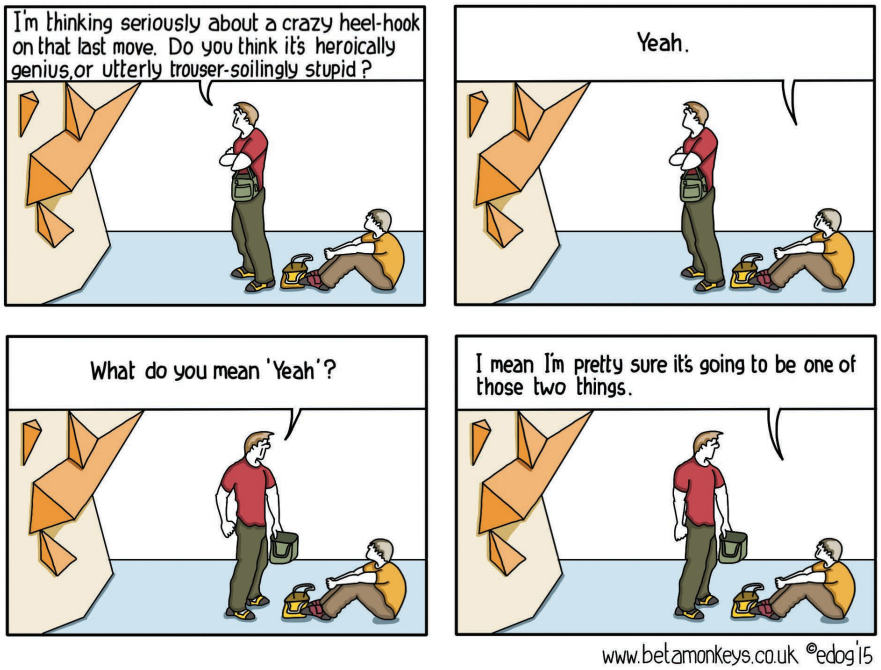


Image 2.9: Short comic by BetaMonkeys giving an example of how climbing buddies ‘help’ each other during climbing. In climbing those tips are called ‘Beta’.

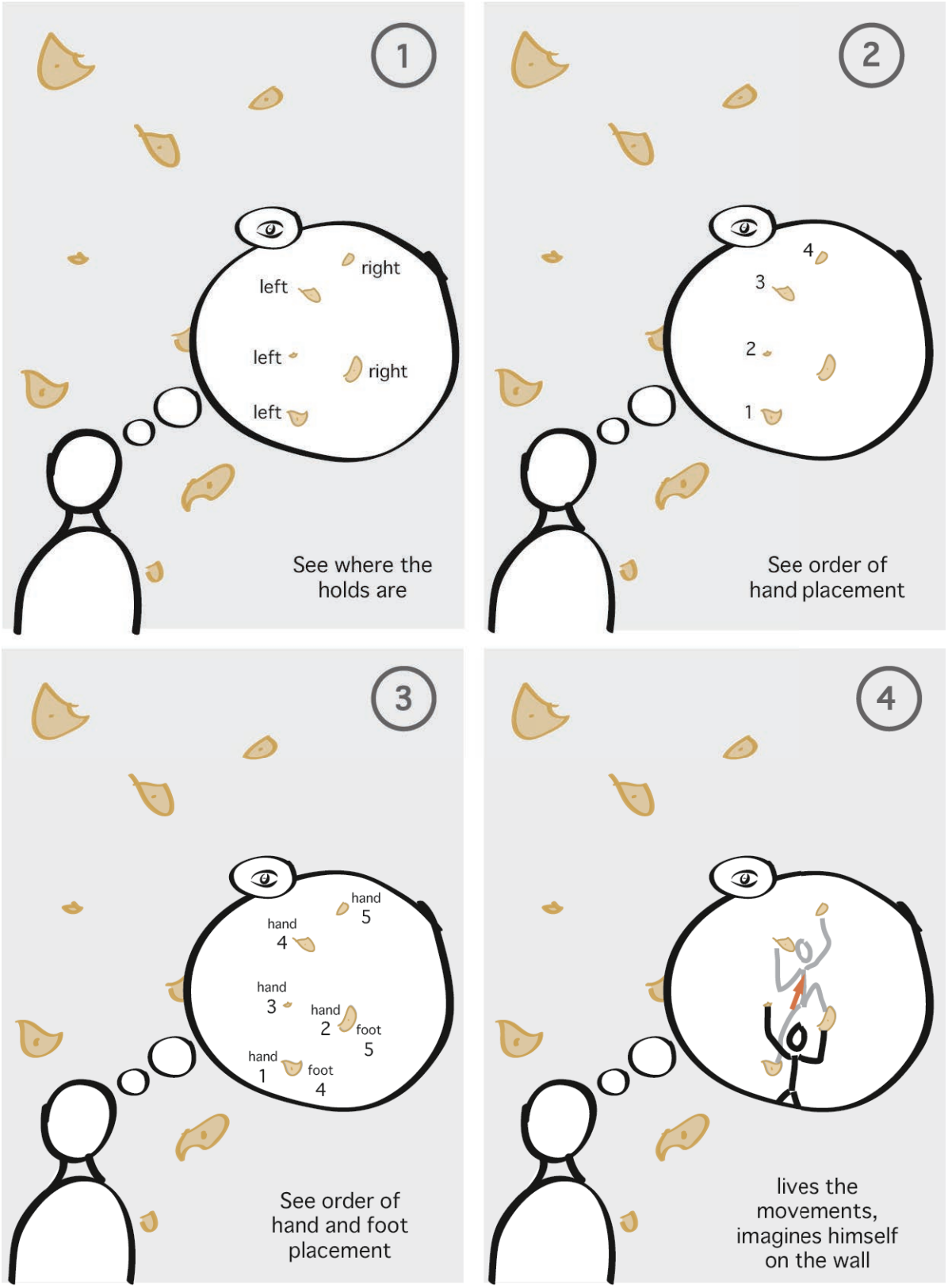


Image 2.10: Pre-reading times and climbing experience

climber's head. The climber imagines himself while standing on the holds and thinks of the movement that has to be made to reach the next hold (van Weert, 2015). These are the first steps towards autonomy in motor learning.
The time it takes to pre-read becomes longer in every stage. The more experienced the climber is in pre-reading, the closer the pre-reading time is to the actual climbing time (see Image 2.11). In stage 1 the climber is only localizing the holds, which is quickly done, whilst in stage 4 the climber pre-runs all the movements in his head exactly. Thinking the exact movements takes as much time as actually executing the movements (van Weert, 2015).

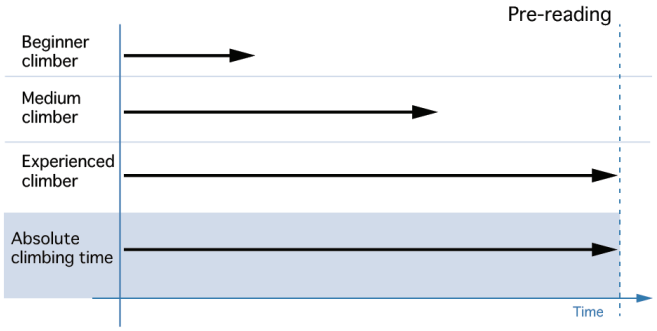


Image 2.11: The time it takes to pre-read becomes longer as you become better at pre-reading. An expert climber needs as much time to pre-read the route as to actually climb the route.

Parameters of performance

There are 45 possible parameters of climbing performance that are related to the climbing level of the athlete. To assess which factors are the most important. The significance is not overwhelming but conclusions were drawn on the seven most important parameters for expertise in climbing.

1. Finger strength
2. Mental endurance
3. Technique
4. Isometric endurance fingers
5. Number of complex reaction time errors
6. Oxygen uptake anaerobic
7. Ape index

The seven parameters together are responsible for 77% of a climber's performance. Only one parameter (ape index) is determined by genetics and can't be trained. Isometric endurance in fingers means that these small muscles recover fast after contraction, making is possible to perform over a longer period of time. The isometric endurance of fingers and anaerobic oxygen uptake are values that improve with more intense physical training. Technique is a combination of a mental and physical parameter. (Magiera et al., 2013)

Climbers have, in comparison to non-climbers, more strength in upper arms and shoulders. (Watts, 2004; Fuss & Niegl, 2008; Macleod et al., 2007; Wall, Starek, Fleck & Byrnes, 2004).
Within the group "climbers", boulderers have even more upper body strength due to the more powerful (yet shorter) routes they climb (Fanchini, Violette, Impellizzeri & Maffiuletti, 2013).
When a climbing wall has an overhang of 10 degrees, the climber's body weight hangs from 43% on the arms, compared to 5% of body weight on arms if you stand upright on the climbing wall. Expert climbers in general are athletes with a petite body posture and low body weight (Watts, 2004). Less developed lower body muscles are favourable to save weight.

CONCLUSION

To conclude this chapter the reasoning model of behaviour change can be filled in, shown in image 2.13.

The *current pattern* is how a climbing session looks right now, which contains of climbing 10-15 routes, with some breaks (Customer journey in Appendix E). Climbers experience the indoor climbing gym as a social environment.

The *current behaviour* in focus is climbing a route. Currently all routes built with plastic holds and modules. Although the routes are changed regularly climbers indicate that indoor climbing feels monotonous and pre-defined. A sense of reaching a summit is missing.

The *game world* will be stated in the next chapter Idea generation.

The *target pattern* of the climbing session is similar to the current pattern. Climbers climb as many routes and it takes a similar amount of time. The new design and the traditional routes should exist in parallel. This way climbers can alternate between the two types of training, lowering the monotonous experience of a climbing session.

The *target behaviour* that the design should evoke, is a climber that feels where his weight, hands and feet should be instead of looking at the holds and predicting the position. This contradicts the art of

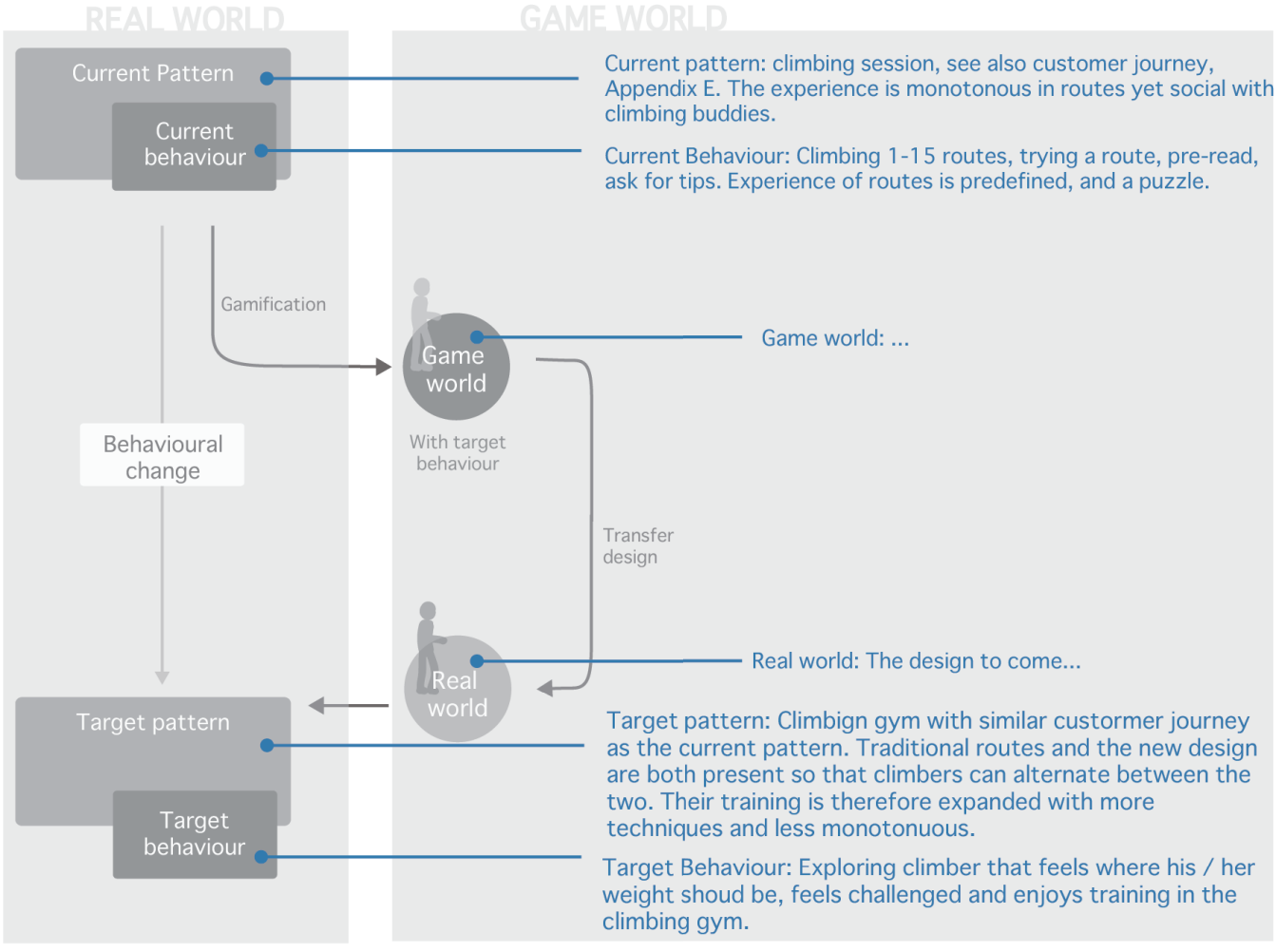


Image 2.13: Reasoning model of behaviour change filled in with the current and target patterns and behaviours.

pre-reading but strengthens a sense of positioning and exploring within your own body and muscle power. The goals that are mentioned in the target pattern and behaviour shape the first boundary conditions for the design.

STAKEHOLDERS

Besides the theoretical analysis, there are a few stakeholders that play a role when designing for an indoor climbing gym. They are the climbers, the owners of indoor climbing gyms, the route setters, and the gym builders.
The medium level climbers are the aimed target group. This group has already some experience and has learned some basic techniques. They are at the point where it becomes important to understand and feel the effect of their body position and will therefore benefit from the new training the most.

The owner of the climbing gym is the one who makes the investment for a new design in training. He has to be convinced that the design can work. This is also the stakeholder that is responsible to guarantee the safety.
The route setters are the ones concerned with the level of the route they are building and how the holds can be attached. Climbing gyms change the routes regularly because it gives their customers new challenges. Next to that, holds need to be cleaned because they get slippery from the rubber of the shoes, the magnesium and sweaty hands. For them, holds need to be easily attachable and detachable.

The gym builder might not play a big role in any concept design, but generally the walls are made once and stay the same for a long time. The climbing holds are the elements that interchange.

PART THREE

This part bridges the theory on sports performance, gamification and climbing towards the first ideas for a design with the help of creativity techniques such as collages, brain writing and creative sessions.

IDEA GENERATION

INTRODUCTION

From the analysis a focus and some boundary conditions arise that the design of the new climbing route should take into account. Previously mentioned boundary conditions are:

1. Fit onto traditional climbing walls
2. Exist next to traditional climbing routes
3. Stimulates the climber to focus on feeling his body position
4. Evokes a feeling of challenge, fun and exploration

The first two mentioned boundary conditions are practical rules. The third condition aims at the behaviour of the climber, while the fourth is aimed at the experience of the climber.
A way to present intended interaction is by creating an interaction vision. This is a metaphor that is linked to the intended interaction. It forces the designer to look at the interaction from another angle. A design goal states *what* function the product should fulfil, while the interaction vision describes *how*. (Pohlmeyer, 2013)

INTERACTION VISION

The interaction vision in this design revolves around the experience of challenge. A challenge is something that you don't have the skills to do yet, but will have soon with some practise. Completing that challenge then feels as an accomplishment, which makes the challenge fun. The metaphor for this is walking on a slack line, see Image 3.1.

It looks like you should be able to do it, but it is much harder in reality. Getting one foot on the line is doable, the first step too. The second step is harder, at third step you fall of... but there is hunger for more. "This can't be so difficult" says one smiling. It is a sporty activity with a low threshold because there are no severe consequences when falling off. Counting the number of steps enable you to track your improvement, which feels good.

The ideas that will be generated in this part fit the boundary conditions as well as the interaction vision.

Image 3.1: SVAC Yeti, Fontaine Bleau, Roeland Rademakers (Private collection)

INSPIRATION

A children's playground was found to be good source of inspiration for the design because children are trying out new movements to get on top of climbing racks. They learn by doing and feel barely ashamed when they don't seem to have as much skills as the other children.

Children play in an unstructured manner, running from one climbing rack to another. They might stop climbing one rack before getting to the top because another game caught their attention. This unstructured characteristic demonstrates explorative behaviour that is wanted when climbers learn climbing.

The children's playground is therefore stated as the game world and the reasoning model of Image 3.2 can be filled in.

There are climbing-related games available in the game world playground, a twister wall, an obstacle-run like climb, a race, a game with a dice, wobbly climbing racks and jumping from one wall to the other.

A more elaborate description of the games in the game world is given in Appendix F.

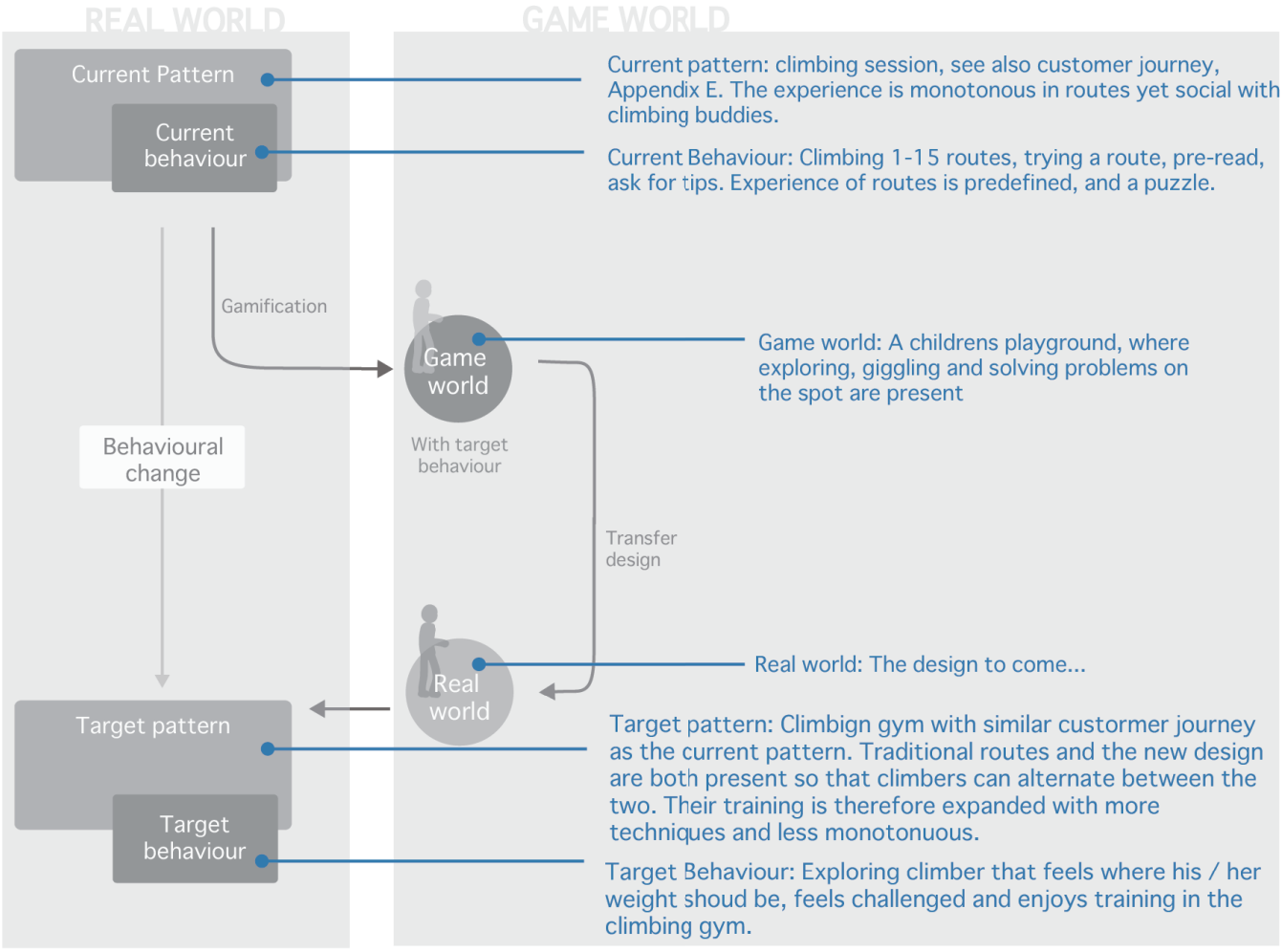


Image 3.2: Reasoning model of Gamification with the game world filled in.

IDEA GENERATION

To get inspiration of what kind of design evokes this kind of behaviour (exploring, challenge and fun) in kids, a photo collage was made (Image 3.3) to capture some interesting and inspiring climbing racks in existing playgrounds.

It is remarkable that most play elements are meant to be climbed though, onto or between. Most have unidentified futuristic shapes yet some are recognizable shapes such as the crocodile. Children have the ability to imagine the most interesting game worlds with so little objects around them.

Outdoor playground, big tunnel of climbing rack with curved shapes inside to climb up or slide down from

Indoor playgrounds with wall that children can climb through

Playing with a recognizable shape: the crocodile

Outdoor playground, climb up and slide down

Outdoor playground with climbing rack integrated in the building.

Image 3.3: Collage of the designs of children's playgrounds

IDEA GENERATION

Creative group watching video to get an idea of what climbing is.

First brainstorm on ways to make climbing more thrilling.

Process of clustering initial ideas from how-to sheets, a way to generate ideas.

Students working on ideas individually.

Making design decisions by ordering ideas on axis. On the axis are words that aim for the intended interaction.

Designer listening to concepts presentation of students at the end of the session.

Image 3.4: Collage of creative session. All participants were students participating in the elective “Creative facilitation” taught by Marc Tassoul and Jan Buijs. The four groups were facilitated by students from the elective, they prepared their own session with information provided by the designer. So thanks to Annelijn Vernooij, Nemos Kostoulas, Stein Wetzer and Maja Bosch.

CREATIVE SESSION

In order to generate ideas for making the indoor climbing gym more fun and challenging, a creative session has held amongst four groups of eight students of the faculty of Industrial Design Engineering. These students were all non-climbers, a mixed group of male and female. They were aged between 22 and 25 years old. One group worked on the sub-question “how can you improve the relation between climber and belayer”, and one group worked on the question “how can you incorporate fun and challenge in the entire context of the gym (so also cafeteria, changing rooms etc)” and the other two groups worked on the question “how to make the climbing of the route more fun and challenging”.
The outcomes of the sessions were concept ideas of what could possible improve the gym. An impression of these sessions is depicted in the collage of Image 3.4.

All the ideas on post-its, sketches and concept ideas were analysed. A rough shift in “bullshit” and “usable” was made from all the sketches from the session. The “bullshit” pile contained very non-feasible ideas due to costs or safety or statements that were off-topic. The “usable” pile contained ideas that either were feasible or sparked the designer for inspiration, Image 3.5.
At this stage, The first concept ideas arose. All those ideas were placed in a so-called “parking lot”, a place to keep your ideas in order to clear your mind. These ideas will be used in a later stage, but should not block the open-minded view needed for further research. The Parking lot ideas are shown in Image 3.6 and in Appendix G.

BASIC CONCEPT

With the theories of motor skill learning; learning a new movement by feeling and the idea of focussing on the awareness of position and balance (proprioception) the idea arose to make the climbing holds very large. This way the climbers have to *feel* where they have to stand and where to hold their hands instead of easily seeing where your hands or feet should go. The current holds are quite small, which gives the climber not many, different options to grip a hold. When the

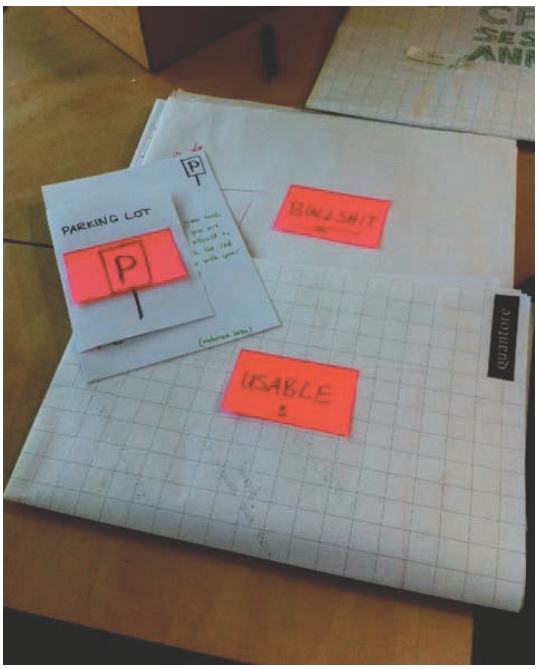


Image 3.5: Organizing the outcomes of the session in piles of ‘bullshit’, ‘usable’ and the ‘parking lot’.

Image 3.6: The best ideas from the session organized in a “Parking lot” in the designers workspace

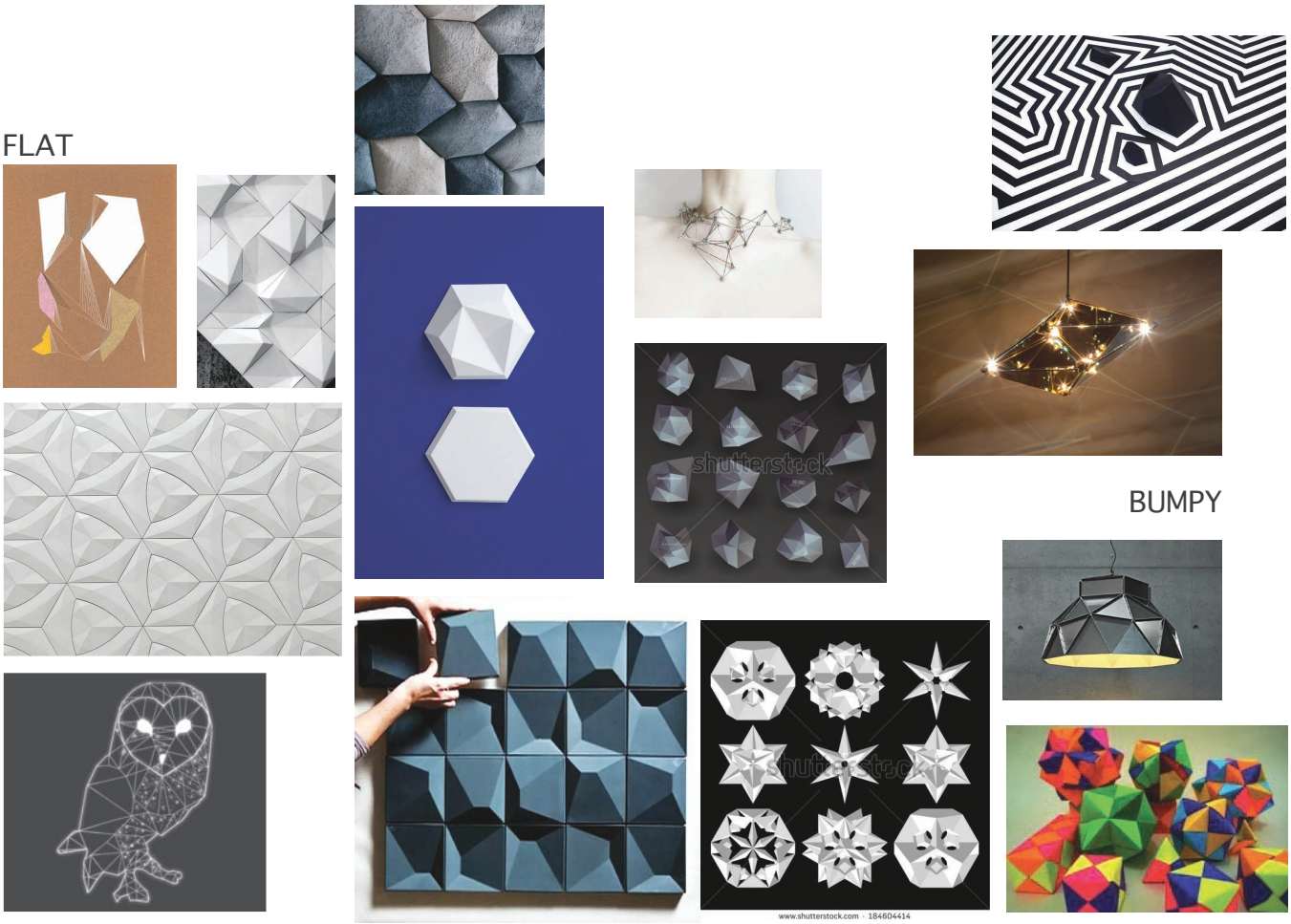
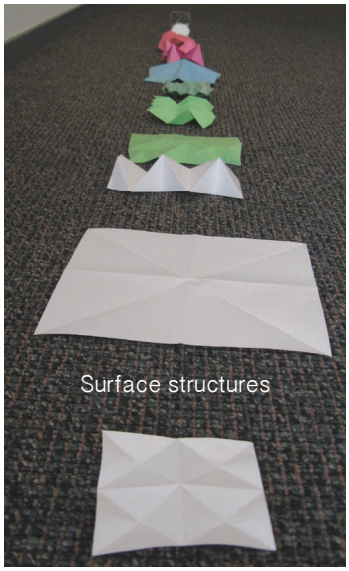


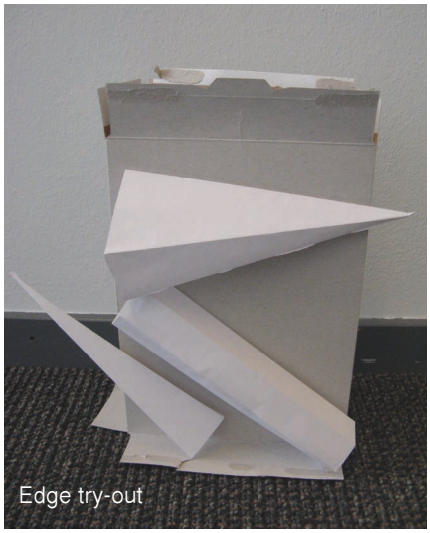
Image 3.7: Inspirational collage of faceted shapes. Images are sorted from flat two-dimensional shapes on the left, towards more three-dimensional shapes of the right. Sorting them in this way helped the designer to get a feeling for the complexity of these shapes.

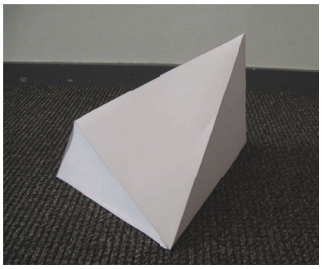
hold is enlarged, the number of options for holding increase accordingly.
To give the climber as many holding possibilities as possible, it makes sense that the shape of the hold has long edges. These edges can be straight or curved. Creating a shape with long straight edges leads to faceted shapes. An inspirational collage was made to collect ideas around faceted shapes, image 3.7.

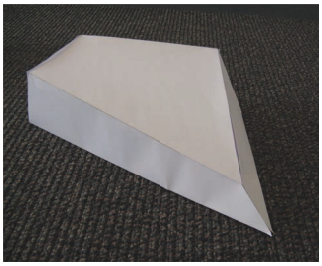
Having a rough idea of the shape, time was taken to play around with initial ideas for a big hold for the design, which can be found on the next page.
At first, folded paper structures were made. Then some green foam pieces were created. The base plane of the hold that is mounted to the wall and has to be flat and should have three, four or five corners. These shapes give long straight edges along the holds. Up from six corners in the baseplate, the shape becomes round and chaotic because there are so many surfaces. The designer turned to CAD programme Rhinoceros to construct the exact surfaces to make paper models. Finally a 1:1 scale foam model was made and screwed onto a plate to demonstrate a small part of how it should be in the gym. All the models are shown in Image 3.8.

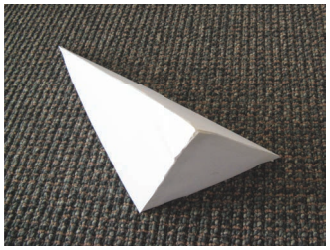
IDEA GENERATION

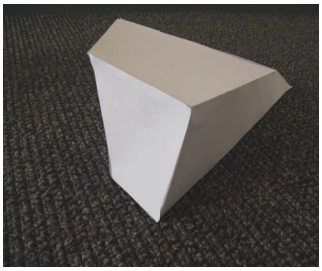












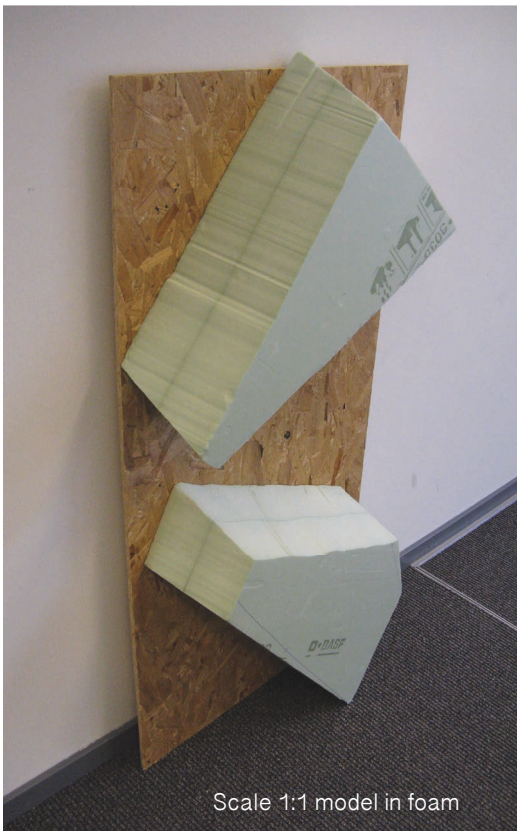


Image 3.8: Tinkering models and prototyping the design ideas

As described earlier in the current gyms there are some modules screwed on the walls. The Basic concept looks like a module but it is smaller and used in a different way. Modules are mainly used to give the wall more structure, and climbing holds are screwed onto them. In the basic concept that is not the case, because as soon as you place a hold on a standard module, climbers think they need to use the hold instead of the edge of the module. In the basic concept all the surfaces are free from holds, dents or bumps.

In special competition routes one may occasionally find a module used as a hold. This is done to make the route harder because pre-reading is more difficult and it is not a familiar shape like a hold. Modules are used less often in climbing gyms, so climbers have little experience climbing on them. As can be seen in image 3.9, modules are often oriented in such a way that the edges are hard to hold at all. The basic concept presents an easier module. From now on, the shape of the basic concept will be called block to indicate a difference between block and modules.

Image 3.9: Climber struggling to hold a module.

STRUCTURAL CONCEPT

The foam prototype on page 40 represents the structural concept (Boeijen, Daalhuizen, Zijlstra & Schoor, 2014.). It fulfils the way of improving training, yet the experience of challenge and fun are not yet clear. In order to get ideas of how to improve fun and challenge in the design, another creative session was held. This time, it was a group of sporty students from the faculty of industrial design engineering, mechanical engineering and Human movement sciences participating in the minor Sports Innovation. Most of them had climbed once in their life but none of them practised climbing as a regular sport.

The foam prototype was shown to them and explained. Then they were given “how to” questions. There were two types of questions. The first set of “how to” questions revolved around climbing with a restriction, one arm, one leg, being as small as a mouse etc. The second set of “how to” questions were game related, such as how to do a vertical Twister game when climbing or how to reward a climber at the top. Some sheets are shown in Image 3.10. When all the “how to” question sheets were full of ideas, the students could mark the ideas that they found the most fun

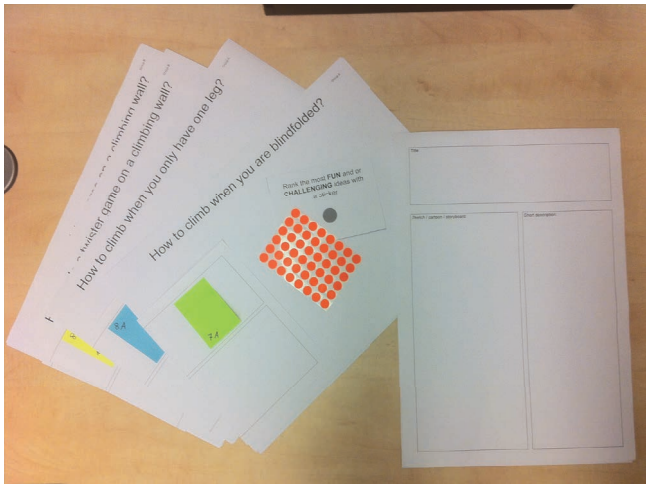


Image 3.10: Materials provided for the session.

and or challenging with a sticker, Image 3.11. After that, they made concepts out of these ideas in duos. The deliverables from the participants were filled in sheets with “how to” questions and at the end templates with concepts designs.

All the “how to” sheets were taken and sorted out what was usable, feasible or a good source of inspiration. These ideas were written on separate idea cards shown in image 3.12.

To rank the ideas, a C-box was made (Boeijen, Daalhuizen, Zijlstra & Schoor, 2014). This is a technique in which all the ideas are ranked onto two axes. On the ends of the axes words are written that are opposites from each other. In this case, the aim was to put the leading words of the interaction vision on the axis. The word ‘challenging’ is a statement with a range, so the axis went from ‘easy’ to ‘hard’. Somewhere halfway towards ‘hard’ there is a region that we call challenging. The same story goes for ‘fun’. This axis ranged from ‘dull’ to ‘excitement’, with a range of ‘fun’ presented somewhere halfway. These regions are marked red in image 3.12. Design ideas that can be placed in the upper right quadrant of the scheme are fruitful for this project, indicated with the blue spot in image 3.13.

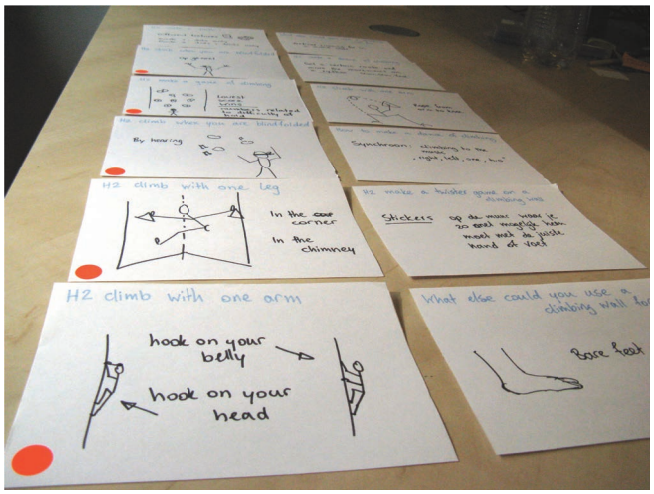


Image 3.12: Session outcomes on idea cards

Image 3.11: Students working on the concepts during session

The ideas that landed in this upper right quadrant were used as input for the conceptualisation. The ideas that came out this session were designs including exercises that could be done climbing on big blocks. Interesting designs were rephrased onto nine 'task cards' as shown in Image 3.14. A more elaborate explanation of the session procedure is added in Appendix H.

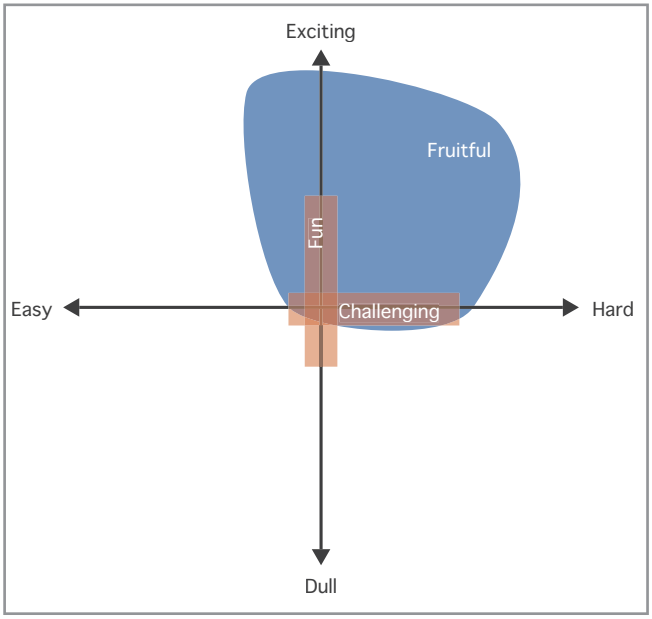


Image 3.13: Axes of the C-Box before placing the idea cards

Image 3.14: Nine task cards that evolved from the creative session. They present different types of exercises that can be done in a climbing gym to make climbing more fun and challenging.

PART FOUR

In this chapter the inspiration from collages, the parking lot and the task cards are translated into concepts. The concepts are explained, ranked and one is chosen and tested in chapter five.

CONCEPTUALISATION

INTRODUCTION

Six concepts arose from the idea generation. All concepts are a variation to the Basic concept (shown in Image 4.1 and 4.2). They are presented and evaluated in a similar manner. First a short description is given and a sketch of how it would look in the gym. Then the concept is scored on seven requirements and wishes. At the end of this chapter the scores are evaluated and one is chosen to test in the user test.

The evaluation is done by rating the concept, from 1 to 5, on seven requirements and wishes. Requirements are more important, so the scores given to these are multiplied by two, while the wishes keep their score. To evaluate the scores, they are presented in a radar graph.

Requirements and wishes

- The concept should link to the design goal. Meaning that it has a use in training for medium climbers (1) by enhancing fun (2) and challenging aspect (3) of the training. (Requirement)
- The concept should link to the interaction vision. Meaning that is feels like a challenge that is just within reach and the climber is hungry to practise more (4). (Requirement)
- The concept should be feasible for all the stakeholders involved: the route setters, the gym owner, and the producers of holds. The concepts are ranked on feasibility for the route setter (5) because all concepts are produced in similar manner. (Wish)
- The concept should be able to be implemented in a current climbing gym (6). (Wish)
- The concepts should be able to vary in level of difficulty (7) in order to create routes for climbers of a wide range of expertise. (Wish)

Image 4.1: Keeping in mind that this is the basic concept on which all the concepts described in this chapter are based

Image 4.2: Also keeping in mind that this is the aimed size of the basic concept.

Implementing level of difficulty

One of the wishes in the scoring system is implementing level of difficulty.
When a (boulder) route only consists of blocks, there are less blocks needed than holds in a current route. The blocks are big and can be used for at least two hands and possibly a foot as well.
When the options to hold a hold become numerous, it is harder to predict the level of difficulty of the movement that needs to be made to the next hold. Traditionally, holds can be roughly divided into levels of difficulty. One would not find a 'slopy' handhold nor a very small foothold in a level 4 route because it's too difficult for that level. When using blocks there are two options to vary the difficulty within a block. At first, the 'slopy-ness' of the hold can be determined by increasing the angle between two plates. Secondly, the edge can be very close to the wall so there is room for only one or two phalanges, as in a crimper hold. This is shown in image 4.3. Increasing the level of difficulty for footholds can be done in the same way. Both a very small foothold and a 'slopy' foothold is scary to stand on.

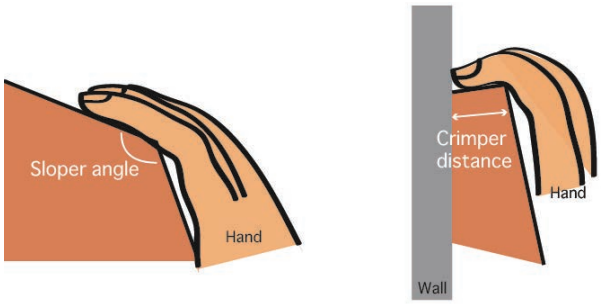


Image 4.3: Influencing level of difficulty, slopyness and crimper distance

CONCEPTS

Now that the requirements and wishes are clear, the concepts are explained and rated.

1. "Athletic Accountant"

Changing the angle between planes means that a specific edge of a block can have a certain level of difficulty. The variety in difficulty that can be made this way may be divided in for example 5 steps, numbered from 1 to 5. Whenever the climber grabs or stands on an edge, he gets the amount of point that edge is worth. The climber then climbs a route of a certain amount of points to score the difficulty. Starting with an edge of level 3, then onto an edge 4, a 1 and level 3. This adds up to a climbed route of 11 points. The climber may set a goal for himself, stating that he wants to finish a route with only 10 points used. He now has to either skip the 1 point edge, or use a 3 point instead of a 4 point edge. The 'assignment' in this points system is that the climber should try to climb the route with the least amount of points.
A sketch of how this concept would look on the wall is given in Image 4.4.
A possible downside of this points system is that the climber has to count while climbing, which might be experienced as annoying. Another option is that the buddy counts the points of the climber and that means he has to pay attention well.

The scoring of this concept on the seven requirements is presented in Table 4.1. A visual representation of this scoring is presented in Graph 4.1.

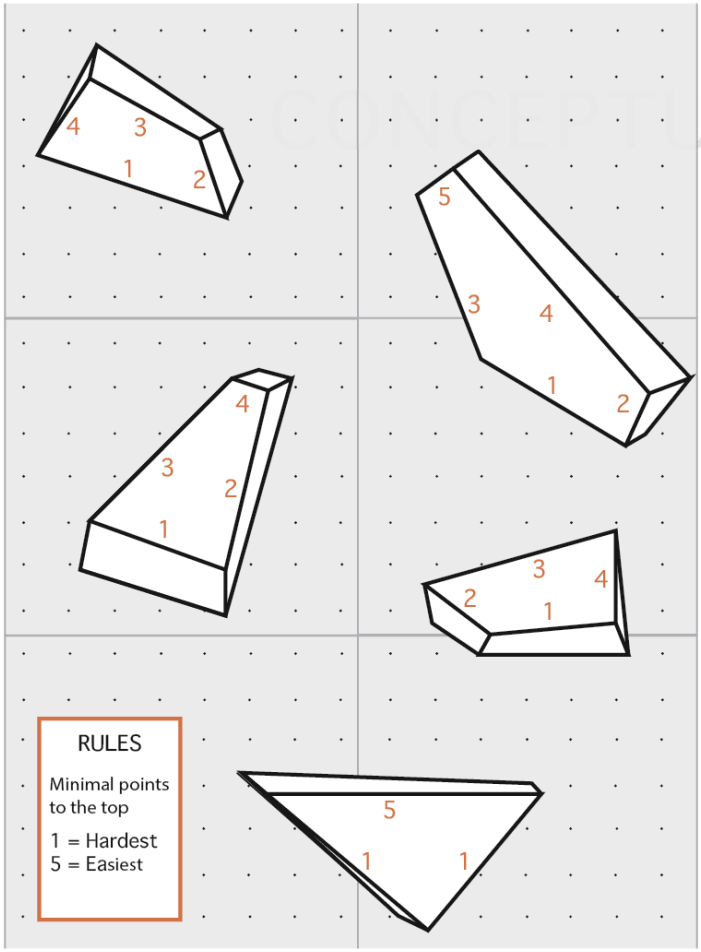
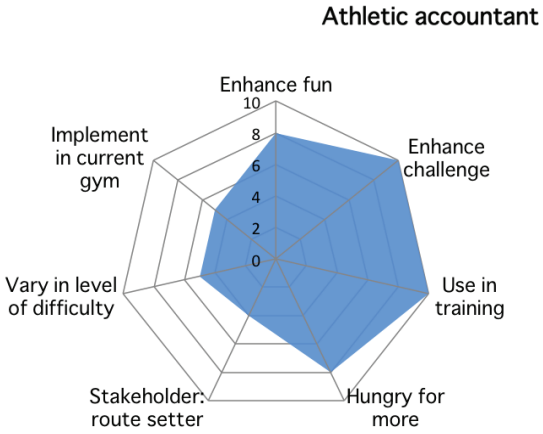


Image 4.4: Sketch Athletic Accountant blocks on a climbing wall. The rules of the points system are explained at the bottom of the route.



Graph 4.1: The Athletic Accountant concept ranked on the seven requirements presented at the axes.

	Requirements	Argumentation	Scoring
Design goal	Enhance fun	Yes. Reaching your self-set goal	8
	Enhance challenge	Yes. Climb the route in the least amount of points possible.	10
	Use in training	Yes. It adds to self-controlled training, because you set your own goal. Big holds should evoke climbing more on balance.	10
Interaction vision	Hungry for more	Yes. You are given direct feedback on how you performed and the ways of improving yourself are clear.	8
Practical manners	Stakeholder: route setter	Building a route with only blocks requires no special skill for the route setter, yet it is a different way of setting. You have to take into account that there should be multiple possibilities to finish the rout. These possibilities should have a range in difficulty.	4
	Vary in level of difficulty	Yes. The block themselves have a level of difficulty indicated by a number on the block	5
	Implement in current gym	Yes. Works like current modules	5
			Total 50

Table 4.1: Athletic Accountant concept's scoring and argumentation

2. "The Chimney"

There is style in climbing that is called chimney climbing. It occurs mostly outdoors where you have to climb through a big crack in the rock. The technique for this to use your back and to lean on one side and move arms and legs on the other side. It is a good exercise for positioning your weight and leaning on limbs. Chimney climbing is rarely found in climbing gyms. The modules are not only big but also deep (they come out of the wall), with that you can create a chimney on the flat wall or in a corner, without having to rebuild the walls, Image 4.5. The chimney does present a possible danger because climbers can fall into the blocks because they are so much bigger than traditional climbing holds.

The scoring of this concept on the seven requirements is presented in Table 4.2. A visual representation of these scoring is presented in Graph 4.2.

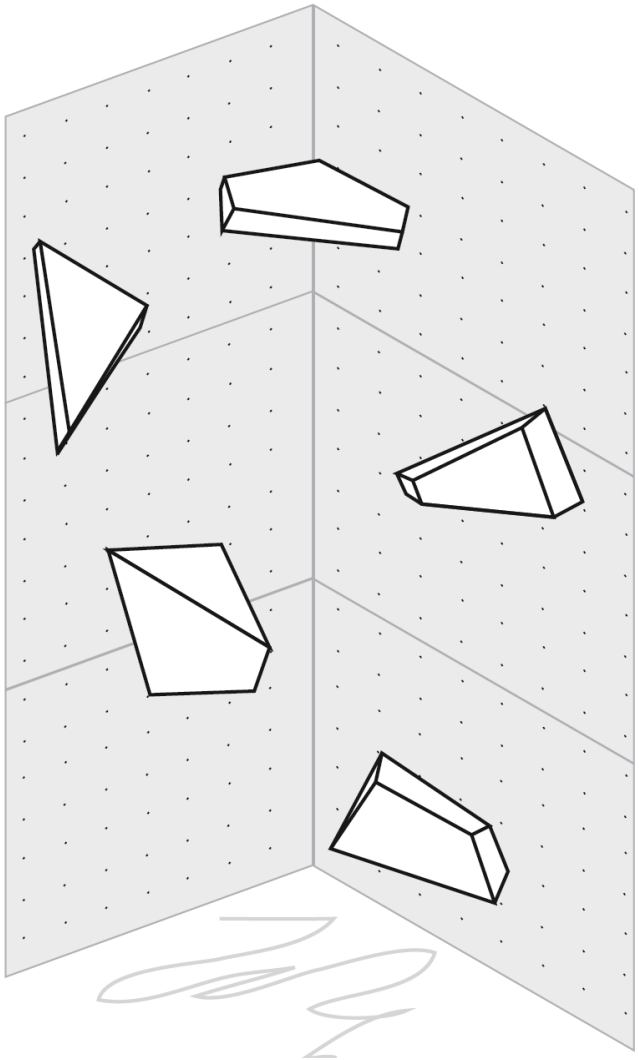
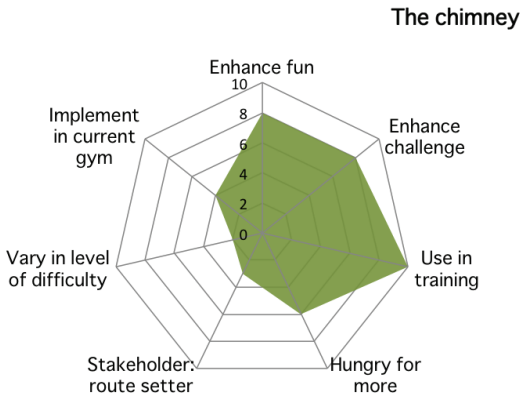


Image 4.5: Sketch Chimney

	Requirement	Argumentation	Scoring
Design goal	Enhance fun	Surprising to be able to train chimneys in indoor gyms.	8
	Enhance challenge	When it's new it is probably a challenge for climbers, as chimney climbing does not occur often.	8
	Use in training	Yes. Climbers are able to train chimney climbing indoors	10
Interaction vision	Hungry for more	There is probably a curiosity to try it out, but whether it stays interesting on the long term is doubtful.	6
Practical manners	Stakeholder: route setter	Setting a chimney route is different from a route on a flat wall, you have to take into account that the climber also uses his back as 'extra limb'. It might be an interesting challenge for the route setter.	3
	Vary in level of difficulty	Medium. In combination with 'slopiness' on the blocks	2
	Implement in current gym	Yes. Works like current modules but needs to be placed in a corner to create a chimney effect.	4
			Total 41

Table 4.2: The Chimney concept's scoring and argumentation



Graph 4.2: The Chimney concept ranked on the seven requirements presented at the axes.

3. "Gradient Levels"

One block has multiple edges. The 'slopiness' and crimp distance differs per edge. Every edge therefore has a different level of difficulty. If these levels are marked with a colour, the climber is able to climb 'the green route' as is done traditionally. A sketch of these blocks are presented in Image 4.6. Colour coding makes pre-reading easier than mono colour blocks.
The blocks come in sets. Meaning that all the blocks of that set have a green, blue and purple edge. When the blocks are on the wall there is always a green, a blue and a purple route created. The route setter can determine the order of the blocks.
On the downside, it makes the route pre-defined as traditional holds do.

The scoring of this concept on the seven requirements is presented in Table 4.3. A visual representation of these scoring is presented in Graph 4.3.

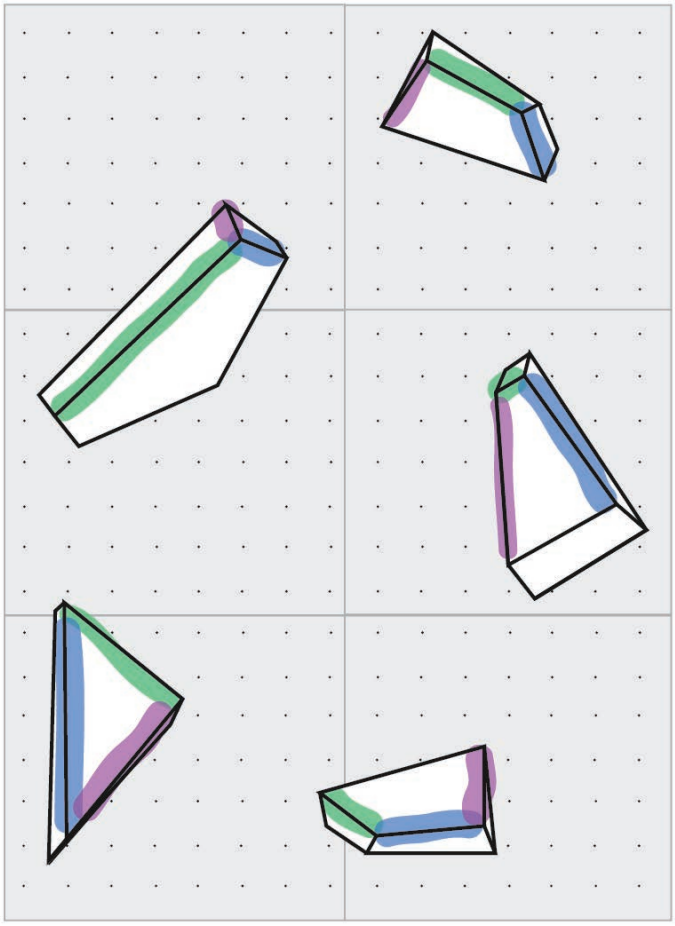
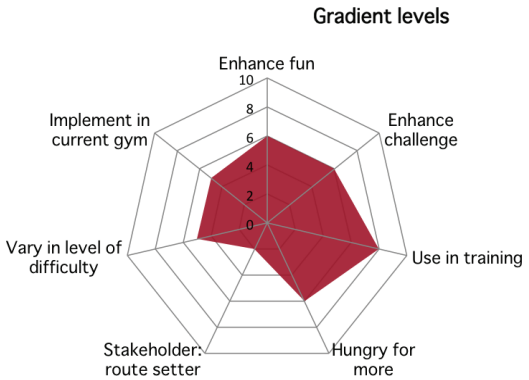


Image 4.6: Sketch Gradient Levels

	Requirement	Argumentation	Scoring
Design goal	Enhance fun	Unclear	6
	Enhance challenge	Medium. Colour coding a levels of difficulty is very similar to current walls, yet the block shapes are new	6
	Use in training	Big holds should evoke climbing more on balance.	8
Interaction vision	Hungry for more	Unclear. The colour coding might evoke the same interaction as current holds do.	6
Practical manners	Stakeholder: route setter	Building a route with pre-set sets of blocks might give the route setter fewer options to build a exciting route.	2
	Vary in level of difficulty	Yes. Edges present the level of difficulty	5
	Implement in current gym	Yes. Works like current modules	5
			Total 38

Table 4.3: Gradient Levels concept's scoring and argumentation



Graph 4.3: The Gradient Level concept ranked on the seven requirements presented at the axes.

4. "Size Does Matter"

This concept is a series of blocks that vary in difficulty by size. The smaller the hold, the less options there are to hold it and the more it looks like a traditional climbing hold. Enlarging the same shape will make climbing on the hold harder because you have to learn to feel how your body position should be, Image 4.7.

The scoring of this concept on the seven requirements is presented in Table 4.4. A visual representation of these scoring is presented in Graph 4.4.

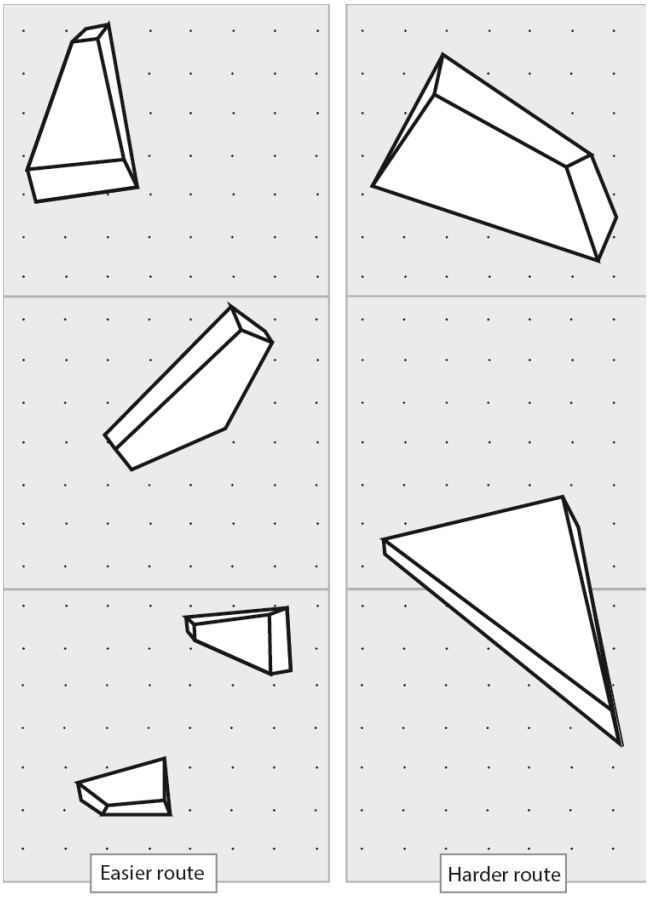
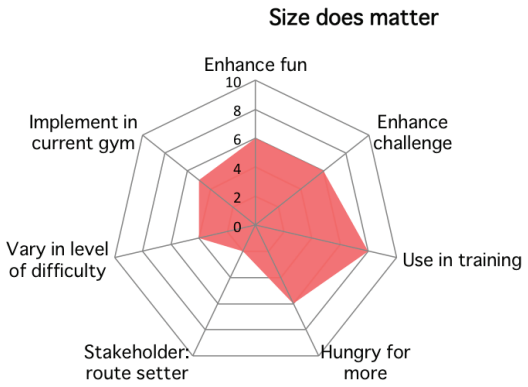


Table 4.7: Athletic Accountant concept's scoring and argumentation

	Requirement	Argumentation	Scoring
Design goal	Enhance fun	Unclear	6
	Enhance challenge	Medium. Gradually learning how to climb on modules. A climber may set himself the challenge to use the biggest blocks.	6
	Use in training	Bigger holds should evoke climbing more on balance.	8
Interaction vision	Hungry for more	Unclear	6
Practical manners	Stakeholder: route setter	Setting a route with blocks is not very different from setting a route with holds. The biggest blocks might be hard to handle.	2
	Vary in level of difficulty	Yes. By size, so number of options to hold differs	4
	Implement in current gym	Yes. Works like current modules	5
			Total 37

Table 4.4: Size does Matter concept's scoring and argumentation



Graph 4.4: The Size does Matter concept ranked on the seven requirements presented at the axes.

5. "Say Cheese"

This concept consists of big modules with big holes in it. The holes are good for practising undercling grips. And when the holes are big, there is room to place your hand in an optimal way.
With a big frontal hole, you can put your hand everywhere, bottom, left, right, and determine on which side you climb past the this hold. A sketch of this concept is shown in Image 4.8.
A possible downside of big holes in a block is that climbers will think they need to use the hole and always will reach there. Just as putting smaller holds on modules it may guide climbers too much.
The scoring of this concept on the seven requirements is presented in Table 4.5. A visual representation of these scoring is presented in Graph 4.5.

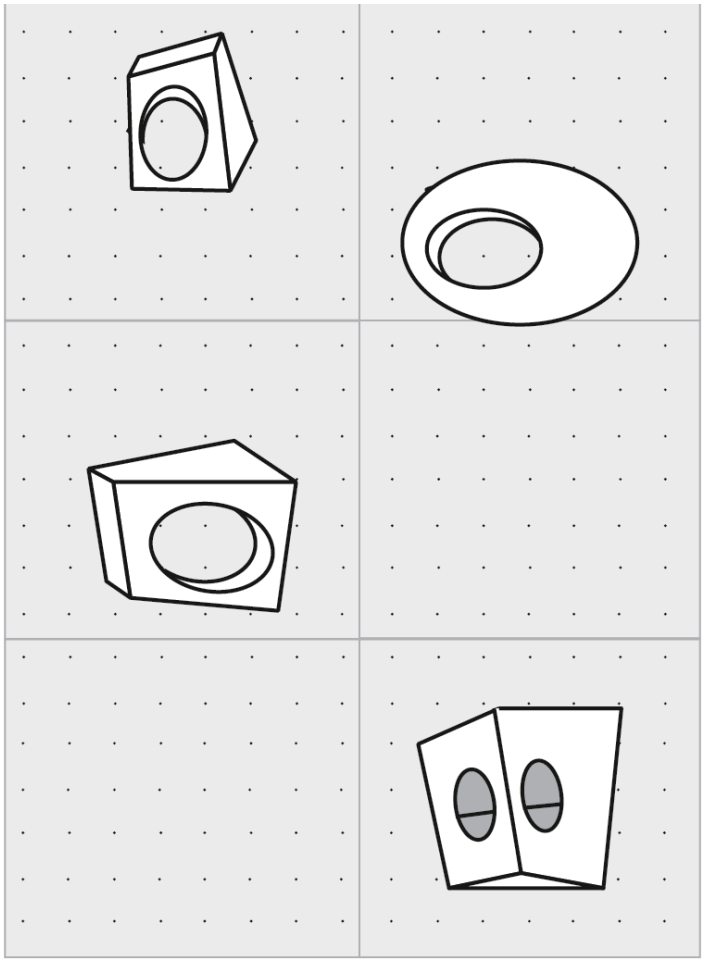
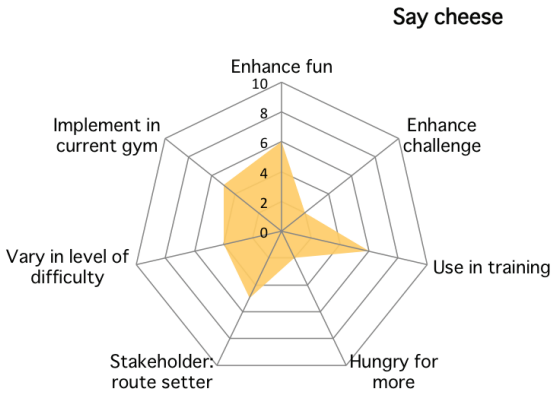


Image 4.8: Sketch Say Cheese

	Requirement	Argumentation	Scoring
Design goal	Enhance fun	Medium. The type of hold already exists, though this one is in a bigger block.	6
	Enhance challenge	No. There are already cheese-hole holds available	2
	Use in training	Practise undercling and conscious positioning of hands and feet.	6
Interaction vision	Hungry for more	Medium. There are already holds available that have a similar shape.	2
Practical manners	Stakeholder: route setter	Building a route with blocks with holes should not present a bigger challenge than building a route with normal holds.	5
	Vary in level of difficulty	Yes. There can also be a slope in the hole.	4
	Implement in current gym	Yes. Works like current modules	5
			Total 30

Table 4.5: Say Cheese concept's scoring and argumentation



Graph 4.5: The Say Cheese concept ranked on the seven requirements presented at the axes.

6. "The Lizard"

A series of holds on the wall can shape a figure, a kind of drawing on the wall, Image 4.9. The route can be for example in the shape of a lizard. Climbing a route with a recognizable shape enhanced a feeling of reaching a summit, because you get on top of the lizard. That is also how climbers amongst each other will talk about it "did you climb the lizard yet?". This concept is very demanding for the route setter to create a recognizable shape with the blocks available.

The scoring of this concept on the seven requirements is presented in Table 4.6. A visual representation of these scoring is presented in Graph 4.6.

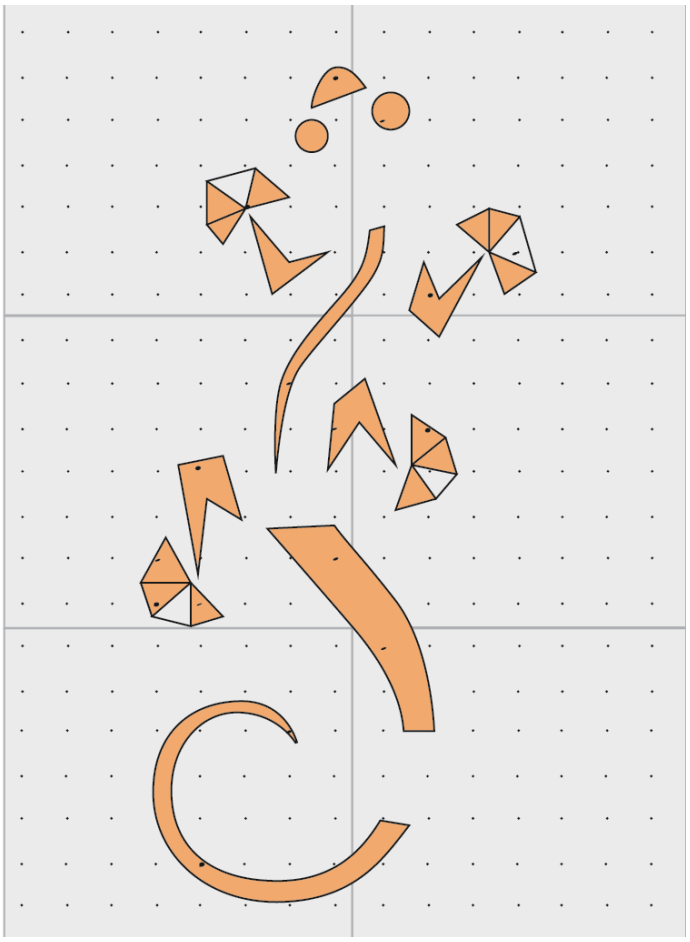
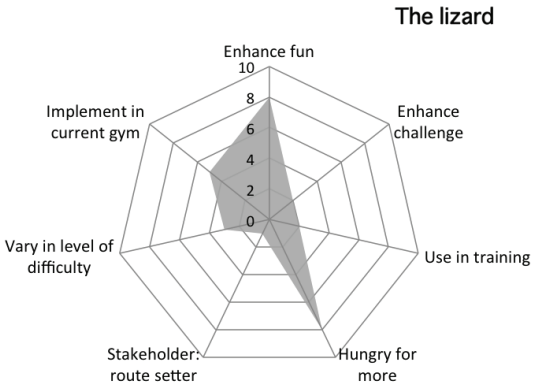


Image 4.9: Sketch Lizard

	Requirement	Argumentation	Scoring
Design goal	Enhance fun	Yes. Enhance feeling of reaching the summit	8
	Enhance challenge	No. Not more than traditional	2
	Use in training	No special training element.	2
Interaction vision	Hungry for more	Routes get personified by their names, from others you hear you must try 'the shark' for example. That might motivate you to climb that route.	8
Practical manners	Stakeholder: route setter	Building a route and keeping the image intact is very hard, if not impossible. The placement of the holds should make sense in the sequence of steps and in the image.	1
	Vary in level of difficulty	No different than in current routes.	3
	Implement in current gym	The holds are normal sized and mounted on the wall like current holds.	5
			Total 29

Table 4.6: The Lizard concept's scoring and argumentation



Graph 4.6: The Lizard concept ranked on the seven requirements presented at the axes.

CONCLUSION

In Image 4.10 an overview of the scoring radars of the six concepts is shown. The concept with the biggest surface area scores the best on the requirements.
The Athletic Accountant concept has the best score according to the wishes and requirements. It presents a different way of approaching the difficulty of a route, as the climber sets his own goal. It is likely that climbers will puzzle to find their best score.
The second, third and fourth best have scores that lie close together.

The Lizard concept is very hard to implement for the route setters. It is an almost impossible job to make a route that looks both like a recognizable shape and has a good flow of movements. Therefore this concept is discarded.
Say Cheese is a doubtful case. It might work, but adds little improvement as big round holds with a big hole in it are already used. It is doubtful that a box shaped block with a big hole in it feels very different for a climber.
Size Does Matter can be seen as a concept that provides a learning tool. Since the behavioural effect of big blocks is not yet validated in itself, it is hard to evaluate if this would be the best way to learn it.
The Gradient Levels concept contradicts with one of the aims of this project: to make the holds not pre-defined as holds currently are. Colour coding makes it easier as well as more boring. This concept is therefore excluded from further development.
The Chimney is an interesting concept. It is easy to implement and could be combined with the Athletic Accountant concept, resulting in a route with blocks put up in the corner of a gym with the point system.

The argumentation in scoring the concepts on the wishes and requirements is based on assumptions of the designer. In order to evaluate whether the concept evokes what is assumed, a user study is conducted. In this study the Athletic accountant concept will be tested, because it was the best score. In addition, the use of big blocks in general will also be tested (the Basic concept). The Athletic accountant concept is the Basic concept with the points system added to it. In order to evaluate the climber's behaviour on the blocks and the effect of the points system, they are both included in the test.

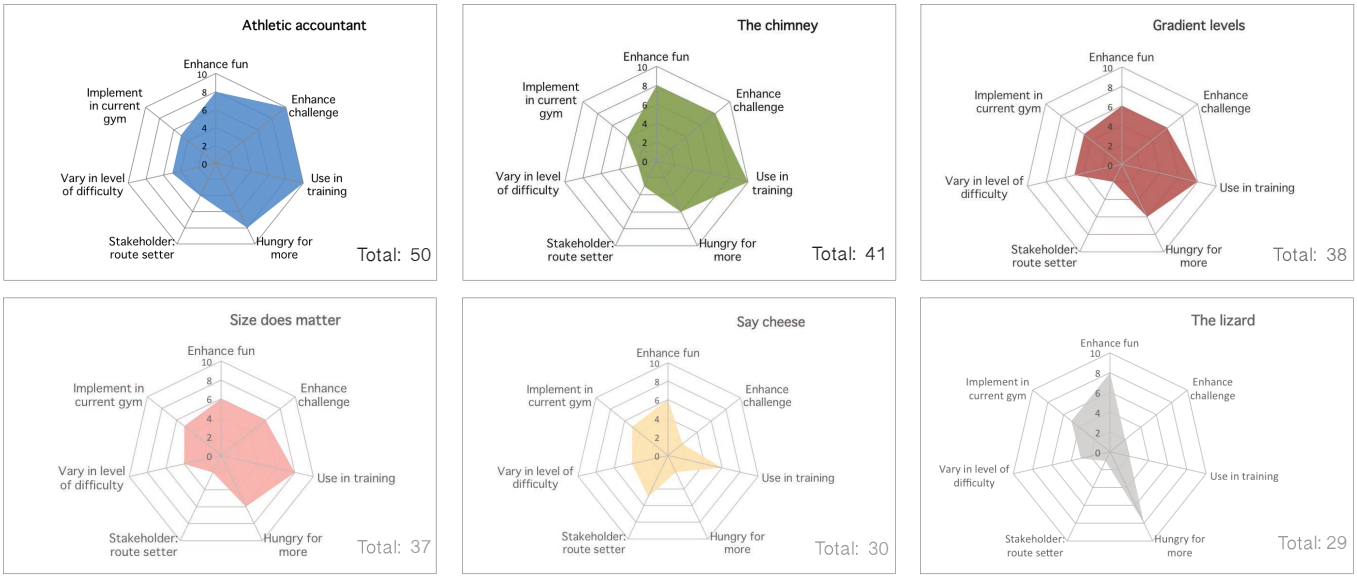


Image 4.10: Overview of the scoring on requirements graphs of the six concepts. The bigger the surface area of the shape, the better the concept scored on the requirements.

PROTOTYPE

In the user test the participants should be able to experience climbing on the Athletic accountant concept. Thus, they climb a boulder route on the blocks, to get a feeling of the design. This means that there should be five blocks and they should be sturdy enough to climb on. Climbers depend on the rough surface of holds for friction and thus grip. The surface of the prototype should be copied as good as possible in order to able to copy the experience of an actual hold. The blocks will be tested on an existing climbing wall so the prototype should fit that particular wall. Climbing walls have pre-fabricated threaded holes in a fixed grid, which is commonly 20x20 cm.

The shape of the blocks has been determined in Rhinoceros. In Rhinoceros a technical drawing can be made of the planes that construct the shape. The plates were printed on scale and used as template to saw the wood, Image 4.11.

An initial prototype was made of 12 mm thick MDF. MDF is a soft wood that is easy to handle. All the edges of the plates were sanded by hand in the right angle, Image 4.12. Then the plates were glued together and the initial prototype existed, Image 4.13.

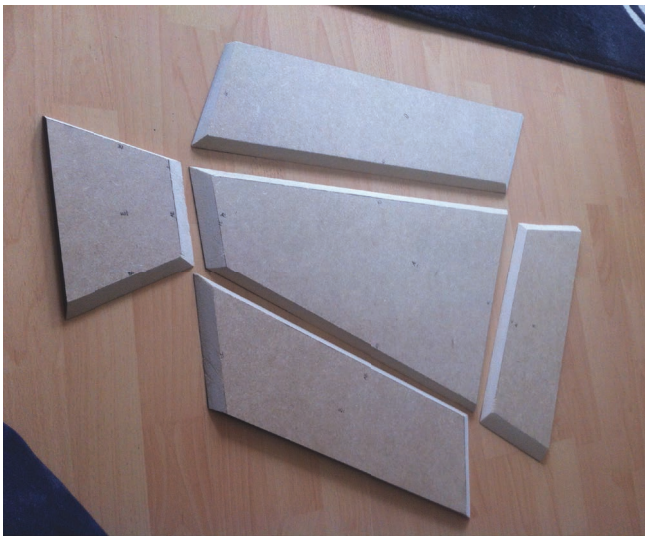


Image 4.11: Template of initial prototype in MDF

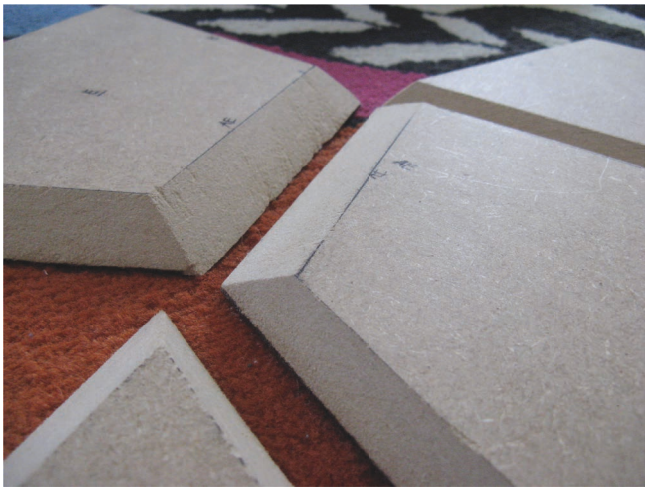


Image 4.12: Close-up of sanded edges of the MDF planes in initial prototype

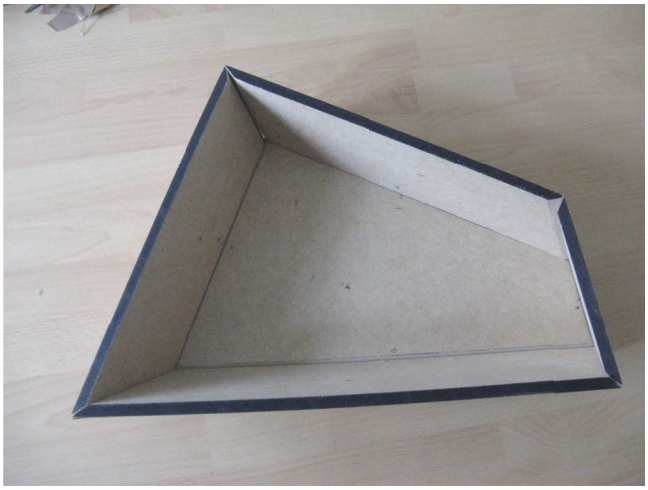


Image 4.13: Inside of the finished initial prototype

The second prototype was used in the user study and was made of 18 mm triplex, Image 4.14. Triplex is a stronger wood that is still relatively lightweight.

Climbing walls are made of 22 mm triplex wooden plates, and modules are generally made from 15 mm triplex. The blocks do not need to carry as much load as a wall, yet they must feel sturdy enough to make sure the climbers can trust them during the test. The block sides are glued, so to make sure the gluing surface area is fairly large an 18 mm plate was chosen to build the prototype.

The blocks are mounted to the wall like normal holds, with an Allen key bold that is screwed through the block into the wall. The block is a shell structure that is put on tension from the top plane. Therefore a slat was glued to the top plane where the holes for the bolt are. This was done to prevent the top plane from bending and tearing the structure apart, Image 4.15.

In order to copy the rough surface of a climbing module, a few surface tests were done. After a few tests it was found that lacquer-paint with construction sand gives the best result. (Construction sand is sand that can be bought in any DIY store and is commonly used to level or raise surfaces.) The construction sand sticks to the lacquer-paint so well that is needs to be sanded afterwards. During sanding the designer can determine precisely how rough the end result will be, Image 4.16.

In total, there were five blocks made to set a boulder route that was used in the user study. There were three different shapes and two blocks were made twice. Images of the finished prototype can be found in image 4.17. Brainstorms done on the building and construction of the prototype, as well as surface structure tests can be found in Appendix I.

Image 4.14: Detailed view of 18 mm triplex material. Triplex are thinner sheets of wood glued together.

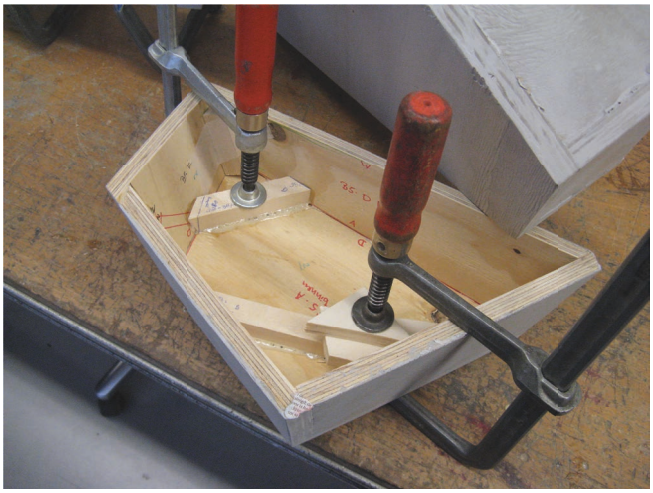


Image 4.15: Gluing the slats into the block structure

Image 4.16: Finished Block on the climbing wall for user test

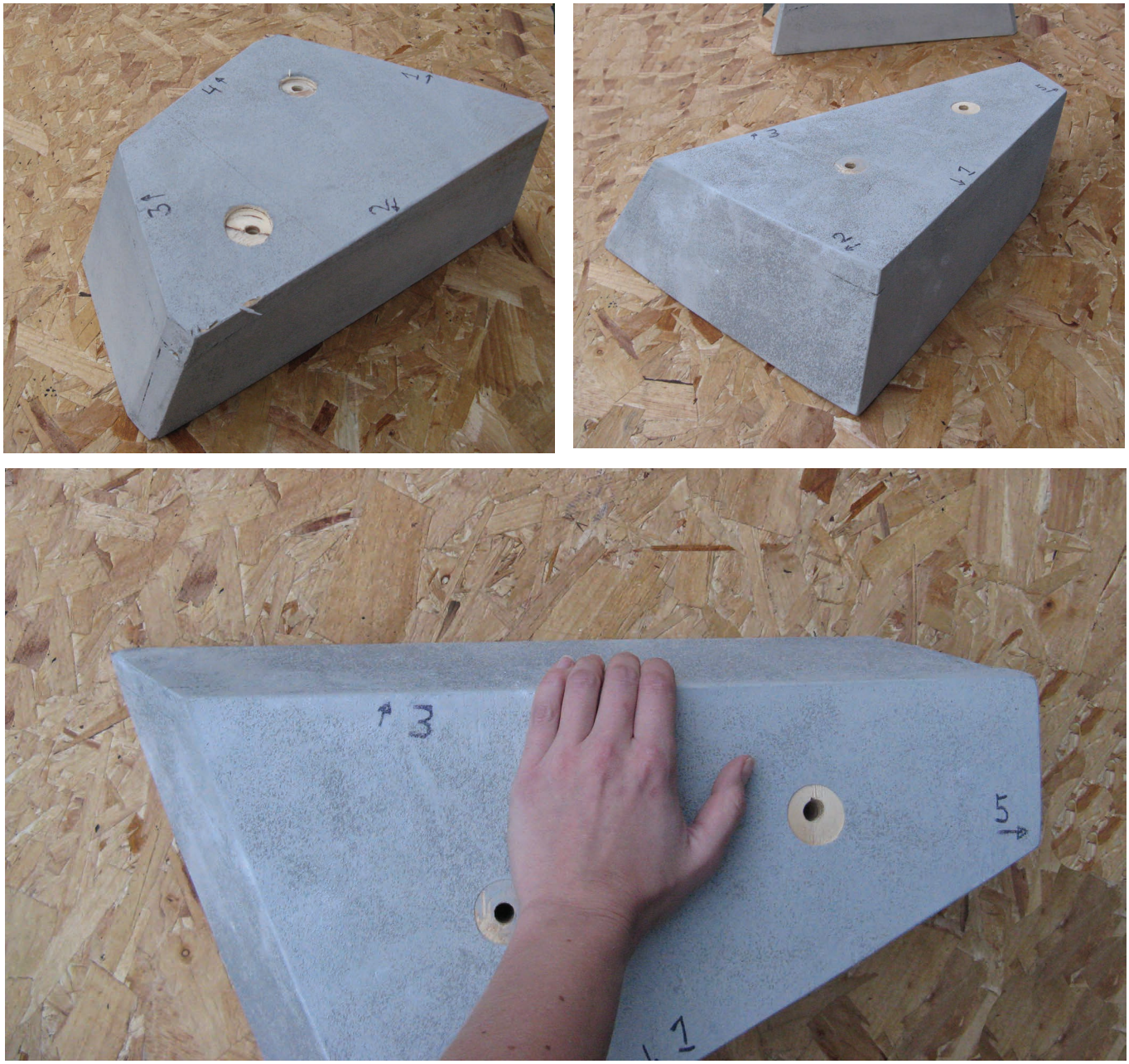


Image 4.17: Finished blocks. With the number written on the sides to indicate the level of difficulty.

PART FIVE

Part five describes the user test that is done to evaluate the Athletic accountant concept. The procedure of the test is explained and the results conclude this chapter.

EVALUATION

USER TEST

Introduction

In the design goal it is stated that the design should improve the challenge in a climbing session. The challenge for the climber (who climbs a route) is to find the solution to the climbing puzzle. The puzzle is presented to him by the route and the sequence of holds. The climber has to find out what is the best way to the top. In other words, he needs to explore the route with his body in order to find the solution.
Climbing a route in an exploring way is a behaviour that is not done consciously. Climbing with an explorative character means that the climber makes decisions (about where to grasp and stand) on the spot. In the test, the explorative behaviour of the participants is evaluated to see if the design does evoke this explorative behaviour.
Exploring the route on the spot can be challenging, and therefore the experience of the climber when climbing a route is also evaluated.

Research Question

Does the design evoke explorative behaviour and pose a challenge to the climber?

Objectives

The objectives for this test are to evaluate whether the following two hypothesis are true.
Hypothesis 1:
Big blocks evoke more explorative behaviour than climbing on 'current' smaller holds.
Hypotheses 2:
Climbers climbing with the points system will challenge themselves by setting a goal in points.

With the first hypothesis, the basic concept can be tested and the behaviour of the climber evaluated. The second hypothesis refers to the concept design and evaluates the experience of the climbers. The two hypotheses are tested in separate conditions in one test. A third condition is added as a comparison study in which the participants climb a route on 'current' holds.

Hypothesis 1 is always tested first because climbing on blocks is a relatively new, and the climbers get a chance to get used to the new blocks, before testing the concept design of Hypothesis 2. The participants will experience a learning effect between Condition 1 and 3.

End points

The results of this test are video material of the participants climbing and their answers to a questionnaire after climbing.
The answers to the questionnaires are gathered per condition and clustered or analysed through averages and graphs. The questionnaires consist of open questions, picking and give argumentation on the three emotion cards out of a set of 12 (shown in Image 5.1) and rating statements on a scale from 1 to 5. The open questions are slightly different per condition but the other parts are the same.
From the videos a scoring of re-positioning of hands and feet and shifting of weight is made by the designer. This indicates whether the climbers were exploring the route and searching to find the right position.
The combined results will state which of the hypotheses is true.

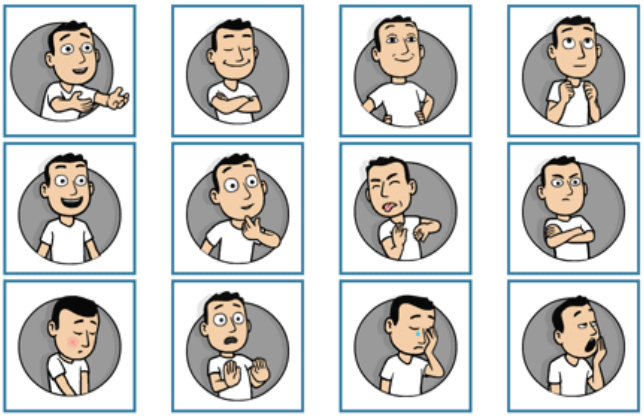


Image 5.1: 12 emotion cards used in the user test to evaluate the feeling during climbing.

EVALUATION

Pilot

The pilot test is done by running through the procedure to evaluate whether the tasks run fluently and whether the questions are understood correctly. The video footage of the two pilot test climbers is used to evaluate the scoring system and possibly add or change scoring subjects.
The two participants of the pilot test and the designer together built the route for the test, as can be seen in Image 5.2. Through their expertise and experience the difficulty of the test route was set to be 5c.

Image 5.2: Pilot test participants (Mariet Sauerwein and Wouter Kuijsters) helping the designer to set the route for the test.

EXPERIMENT DESIGN

Conditions

The test will be executed in three conditions. Condition 1 and 3 represent the two hypotheses, and Condition 2 represents a reference point for the current climbing behaviour, Image 5.3. After each part the participants fill in a questionnaire.

Condition 1:

Climbing wall with blocks in a route estimated to be level 5c.
Questionnaire after climbing (unique open questions, ranking statements and pick emotion cards)

Condition 2:

Climbing on 'current' route with traditional holds.
Questionnaire after climbing (unique open questions, same rating statements as Condition 1 and pick emotion cards)

Condition 3:

Climbing on blocks with points system (same route as Condition 1)
Questionnaire after climbing (unique open questions, same ranking statements as Condition 1 and 2, and pick emotion cards)

Points system rules

The Points system of Condition 3 has the following game rules:
All the edges of the blocks have a sticker to indicate the number of points the climber gets when he uses that edge. If the climber uses a corner of the grip, he is touching two sides of the block and gets the points of both sides. When he has only one finger on another side, that side does not count.
The 'front' plane of the block gives no points.
When you use a particular side with your hand first, and place a foot on the same plane later on, that plane does not count twice. Placing two hands on one plane only gives points once.

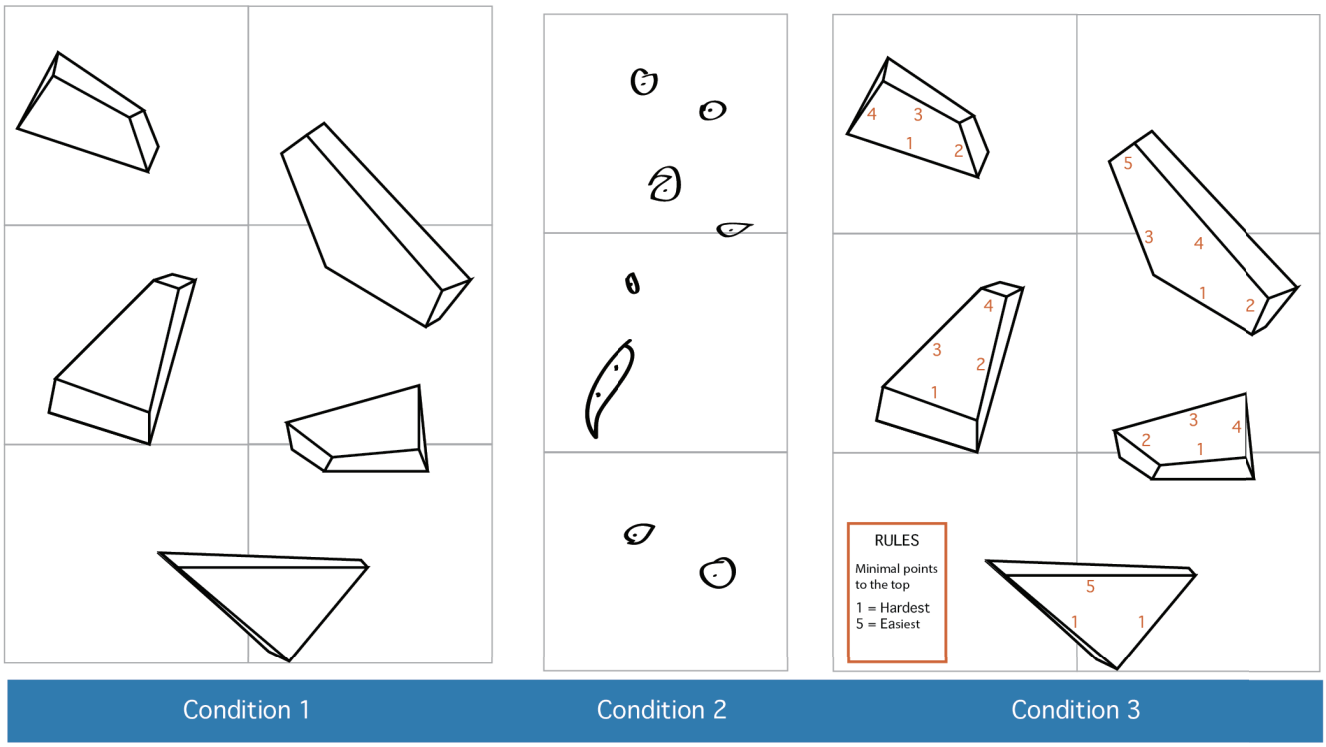


Image 5.3: The set-ups of the three conditions during the test

Context

The test has taken place at the Sports centre of TU Delft. There is a hall with a climbing wall available. On the existing wall the Blocks were bolted while the other routes stayed intact as can be seen in Image 5.4.

Participants

There are 10 Climbers taking part in the user test, divided in three shifts. Per shift, they climbed the three conditions simultaneously. Their ages range between 23 and 26 years old and their climbing level was aimed at 5c on average.

Independent variables

The independent variables in this test are the blocks. In Condition 3 the blocks have numbered sides and a short explanation on the points system and its rules are given.

Dependent variables

The dependent variable is the physical climbing behaviour of the participants, which is measured by number of re-positioning of the limbs before making the next move. The experience of the participants is another dependent variable and is measured through the questionnaire.

Materials

During the test, the following materials were used.

- Five blocks on the wall that present a route of level 5c (the mean level of participants)
- Mat to fall on
- Cameras to film the climbers from behind
- A route with 'current' holds
- Stickers with numbers
- Participant forms
  - Informed consent that was signed before climbing
  - Approval of using video material that was signed before climbing
  - Three questionnaires after each condition

Image 5.4: Blocks on the climbing wall at the TU Delft Sports centre, set for the user test.

Researchers

There is one researcher to conduct the user study. He makes sure the forms are signed before climbing as well as motivating the participants to discuss the route and keep climbing during the test.

Procedure

The participants were guided through the following structure.

	Time
Condition 1	
• Participants welcome	3 min
• Participants fill in and sign declaration forms (sheet 1 in Appendix J)	2 min
• Participants climb the blocks on the wall. • They may try 5 times. They may try alternating and may talk to each other about it.	10 min
• Participants answer questionnaire (this questionnaire is added in sheet 2 of Appendix J)	7 min
Condition 2	
• Participants climb on 'current' route. They may try alternatively and talk to each other about it.	3 min
• Participants answer questionnaire (sheet 3, Appendix J	7 min
Condition 3	
• Participants get short description of the concept with levels (this can be found in sheet 4 of Appendix J)	2 min
• Participants climb the blocks with numbers. They may try five times. They may talk to each other while trying the route.	20 min
• Participants answer questionnaire (sheet 5, Appendix J)	7 min
• Closing of test and participants receive small gift for participating	3 min
• Informal chatting about the test	
	Total time
	66 min

EVALUATION

ANALYSIS

The outcomes of this user test are six sets of data from 10 climbers.

Condition 1 Hypothesis 1 Basic concept	**Condition 2** Reference study 'current' route	**Condition 3** Hypothesis 2 Points system
Answers to questionnaire	Answers to questionnaire	Answers to questionnaire
Video material	Video material	Video material

Answers to questionnaires

The questionnaire has open questions, eleven statements about the climbing experience that are ranked on a scale and participants had to pick three out of twelve emotions cards that depicted how they felt during climbing. They were also asked to describe why they picked a certain emotion card. At the end of the questionnaire after Condition 3, participants were asked if they could formulate recommendations for the design.

The answers to the open questions were clustered to get a general impression of what the participants thought of the design. The average scores of the rated statements were used to indicate the difference between the three conditions. The picked emotion cards are gathered and clustered on their argumentation.

Video analysis

In the video analysis the repositioning of hands and feet were counted as well as the shifting of weight. These were scored in the following categories:

Add hand
: One hand is already holding an edge and the other hand is placed next to it. Weight and force is now distributed on both hands.

Switch hand
: Edge is held with one hand and the other hand is placed on that spot. The weight or force is now put on the other hand.

Relocate hand
: With a small 'hop' the hand is relocated to another place on the same edge. The other limbs and center of gravity stays in the same position.

Add foot
: On foot is on a plane and the other foot is placed next to it. Weight of the climber is now distributed amongst two feet.

Switch foot
: Weight is on one foot, and the other foot is (with a small hop) placed on the location of the first foot. The weight is now on the other foot.

Relocate foot
: With a small hop the foot is relocated on the same plane. Distribution of weight and body position stays the same.

Relocate core
: Deliberately shifting the body (the core) and therefore distribute the weight differently amongst hands or feet without relocating any hands or feet.

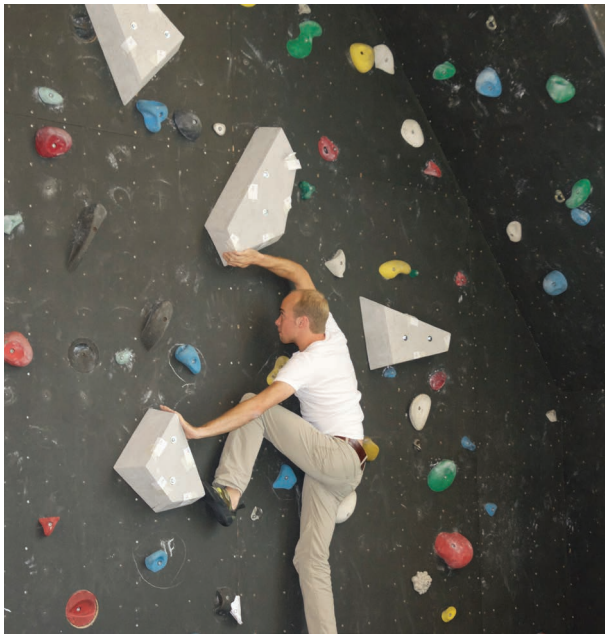


Image 5.5: Impression of participant climbing on the blocks

EVALUATION

RESULTS

The user test was analysed per condition so that the difference in behaviour and experience between the concept blocks and the normal holds becomes clear.

Questionnaires

General info

The mean age of the 10 participants was 24,5 years old and the climbing level varied between 4a and 6b with an average of 5c.

Open questions

In Condition 1 (climbing on the blocks) the participants indicated that they found it fun and mentioned that it took a more creative style of climbing than normal holds. Two participants noticed that the blocks were less pre-shaped for hands.

In Condition 2 (climbing on 'current' holds) participants felt comfort in the familiar holds.

In Condition 3 (climbing on blocks with the points system) the participants thought it was fun and challenging. Some mentioned that they looked at the blocks differently and tried to think of more possibilities to climb the route.

Emotion cards

Participants were asked to pick three emotion cards after climbing. These are gathered per condition and presented in Image 5.6. The more often an emotion was picked, the bigger the circle of that emotion is depicted. These outcomes give a general impression of the most dominant emotions during climbing in the user test.

After the first encounter with the blocks in Condition 1, all participants were curious during climbing. Finishing the route on this unfamiliar type of blocks felt satisfying. Many were happy just because they were climbing.

During the second test on 'current' climbing holds, participants were satisfied and happy, some recall that these are emotions they always feel when climbing regardless on what and where they are climbing. Boredom was also mentioned when they compared normal holds to the blocks.

During Condition 3, the points system on the blocks was introduced. Participants felt curious in exploring their abilities and desired to get better and try the route again. Anticipation was mentioned when the participants were waiting to see how the other participants solved the route.

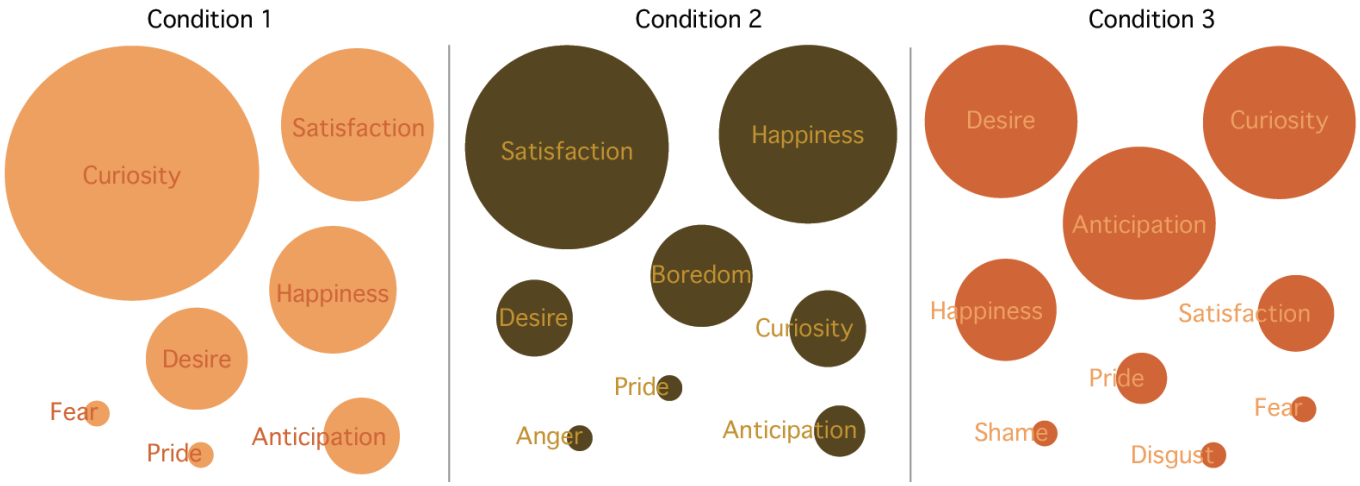


Image 5.6: Frequency of picked emotion cards during Condition 1,2 and 3.

Statement rating

After the open questions participants had to rate eleven statements, these statements were the same after each condition. This way the change of opinion between the different styles of climbing can be seen, Graph 5.1.

Q1: "The climbing felt challenging"

Climbing on 'current' holds was the least challenging. Climbing on the blocks with the points system was felt to be a lot more challenging than the other two test situations.

Q2: "The big blocks/holds presented a challenge during climbing"

Just as Q1, the 'current holds are considered least challenging and climbing on the blocks with points system the most challenging

Q3: "I was looking for the best body position to proceed climbing"

Climbing on the blocks (test 1 and 3) evoked this positioning more than climbing on normal holds.

Q4: "I discovered how to get to the top the best way"

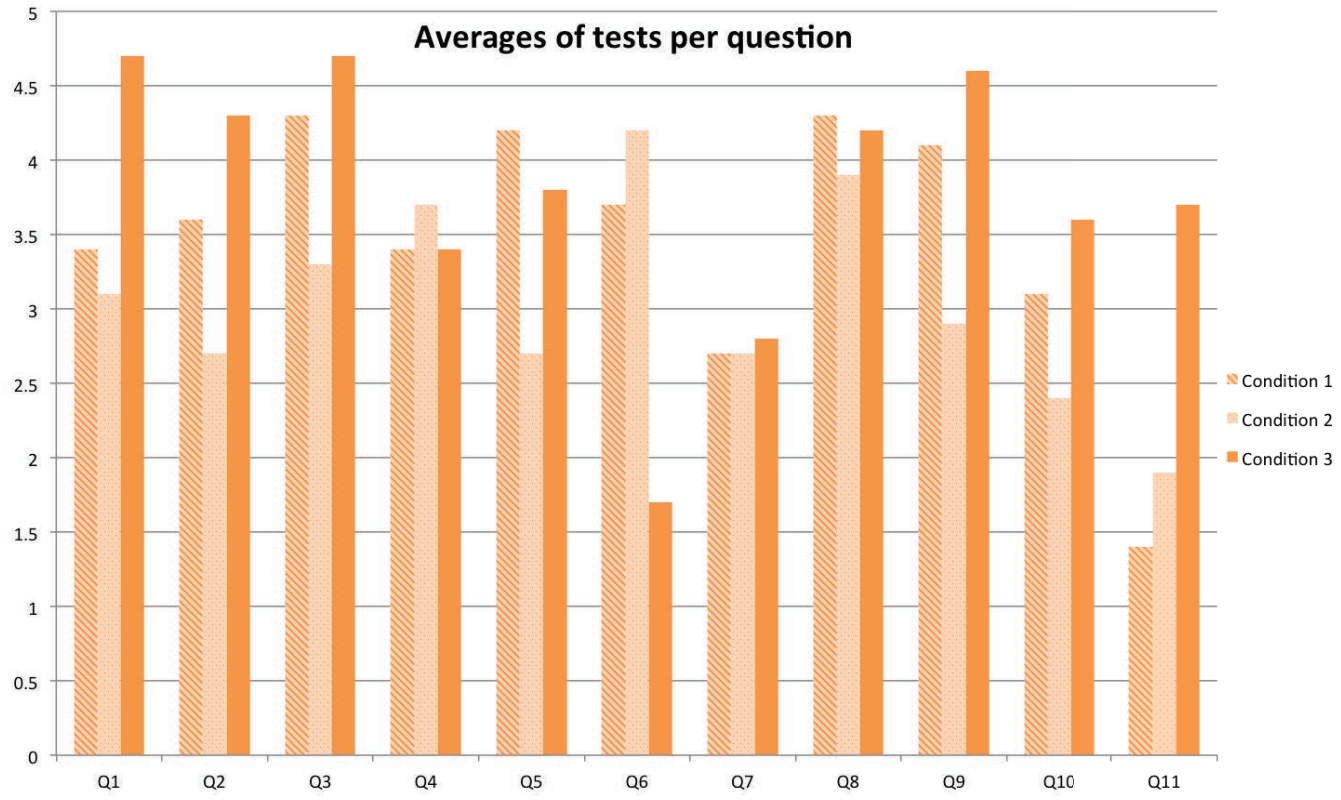
Both tests on the blocks scored equally on this question. When climbing on 'current' holds participants indicated that they felt more to have found the best way to the top, thus there is nothing left to improve.

Q5: "Climbing on the blocks/holds felt adventurous"

Both tests on the blocks were considered a lot more adventurous than climbing on normal holds.

Q6: "I made the decision on how to climb mainly during climbing"

When climbing on 'current' holds participants made the decisions mostly during climbing, while



Graph 5.1: Ranking of the statements ordered per statement

climbing with the points system, the participants had made a plan beforehand and did not decide where to put hands and feet on the spot.

Q7: "It feels like climbing outdoors"

Participants are greatly divided in this statement. On average all climbing types did not feel like climbing outside.

Q8: "I liked climbing on blocks/holds"

Participants generally liked climbing, on the 'current' holds slightly less than on the blocks.

Q9: "Climbing on the blocks/holds felt like a puzzle"

Climbing in the blocks felt a lot more like a puzzle than on 'current' holds. The points system felt most like a puzzle.

Q10: "Climbing on the blocks/holds was exciting"

Climbing on the blocks was considered more exciting than climbing on 'current' holds.

Q11: "There was a competitive atmosphere"

The competitive atmosphere increased hugely during Condition 3, but not all participants mentioned this. It was more present than during Condition 1 and 2.

Recommendations after Condition 3

Participants mentioned that it would be nice if there were more blocks, providing even more possibilities to climb to the top. Another participant suggested that a few very small (so they are not too easy to use) footholds could be added to the route. This way more opportunities to climb around the blocks are created. Some participants mentioned that, as they were aiming for the least amount of points to get to the top, they found it hard to see a 'medium tough' way up (according to their own level) with the blocks. It either felt very easy or the hardest they could climb.

Counting your own points was felt to be very hard. Most times the other climbers who were watching counted for them. A system to automatically count the points could be designed was suggested.

Some participants wrote that the blocks would be more challenging when certain planes were smoother than others. Surprisingly, this was also mentioned in the creative sessions done in the idea generation phase.

Video analysis

Due to batteries of cameras that went low and the limited amount of memory space available not all conditions of all the tests were recorded completely. This means that the results of the video analysis are interpreted with caution. Only large differences in results are used to formulate the concluding statements..

Results

In general, participants that climbed on the blocks (in both Condition 1 and 3) relocated their hands and feet a lot more than on normal holds (Table 5.1). This can be explained by the fact that there is more room for more than one hand or foot on the blocks than on normal holds. In addition, there were more normal holds available so the participants could choose to use another hold, instead of switching hand or foot.

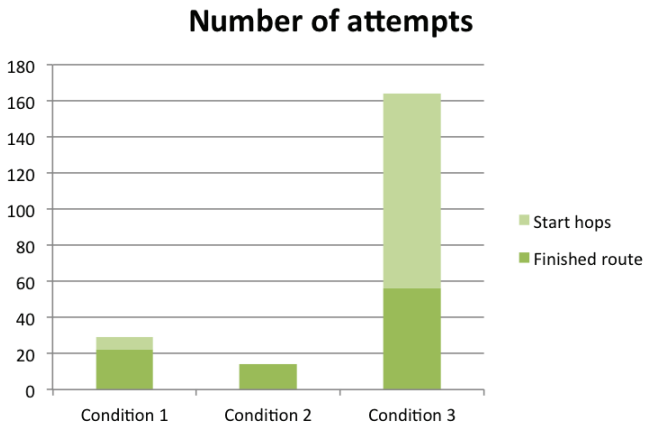
	Condition 1	Condition 2	Condition 3
Number of relocations	81	23	97

Table 5.1: Total number of relocations of hands and feet per condition.

Although climbers indicated that they made the decision of how to climb before climbing a route on blocks, they did relocate their hands and feet more than on 'current' holds. The number of relocations is therefore not a good parameter for the moment of decision-making.

In Condition 3 (climbing on blocks with the points system) the climbers attempted the first one or two steps a lot more often than in the Condition 1 and 2.

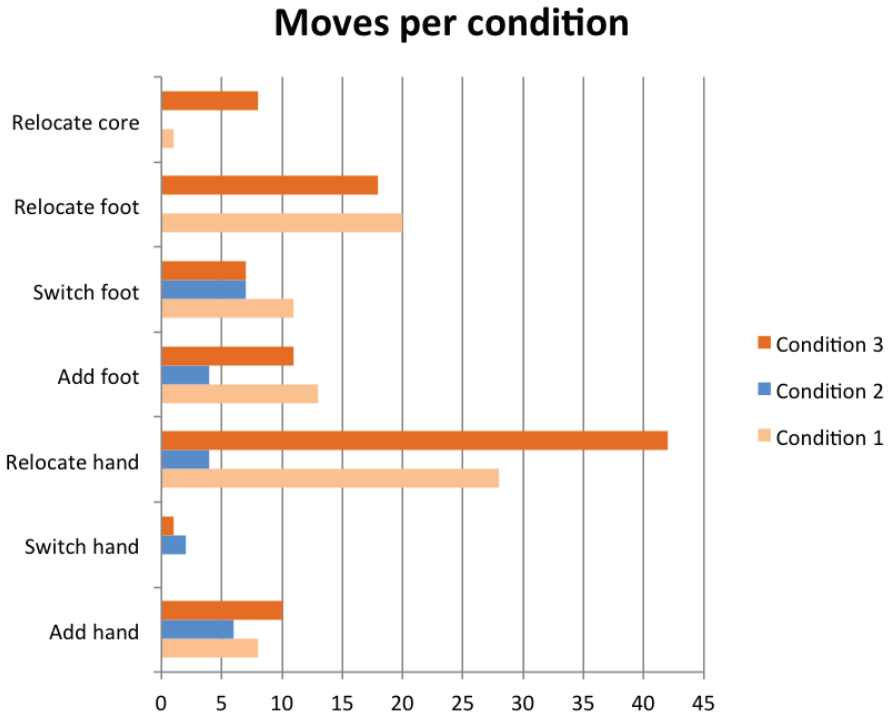
They were searching for the way to the least amount of points. That can be seen by the huge amount of 'start hops' during Condition 3. Participants tried to make the first step, if that worked they thought of the next step. This resulted in participants trying the route for 6 times before finishing it (graph 5.2)



Graph 5.2: Number of attempts for finish the route per condition. An attempt counts when both feet are off the ground.

Repositioning does indicate a climber who shifts around his limbs and weight in order to find the right position to continue climbing. This is what is called 'explorative climbing'. This is supported by the questionnaire where the participants filled in that climbing on the blocks felt more like puzzle, and were more searching for the right body position.

The seven scoring categories of repositioning limbs or core resulted in graph 5.3. During Condition 2 (climbing on normal holds) there was a lot less relocating of any body part. In general, relocating a hand was done most often and a hand switch the least often.
Relocating the core is a rare action since only three participants performed it. Those participants were the best climbers according to their level. Therefore relocating core may indicate a better climber.



Graph 5.3: Number of relocations of hands, feet and core in the three conditions per type of relocation

EVALUATION

Insights

When the participants had finished the user test, some took the time to chat informally about the test. During these conversations e few insights about the concept became clear. These insights can not be extracted from the videos or questionnaires, but are valuable nevertheless.

In a normal route with a fixed level of difficulty, the climber searches for the easiest way through the holds. In contrast with the points system the climber searches for the hardest way to finish the route. The climber sets himself a challenge and is satisfied or proud when he reaches the set goal. Although this may seem as a subtle difference, it is the element that challenges the climber during training.

The route with just five prototyped holds represented a level of difficulty varying from 4b to 6c. This means that there is a big variety of climbers that can train on just one route.
Participants like climbing in general, regardless from the type of hold they needed to use.

The fact that there was a researcher as 'referee' to count the points and sometimes motivate the participants to try the route again might have influenced the outcomes of the test.

In general, climbing on Blocks with the points system was a success in terms of challenging the climbers and bringing them more fun in climbing.

CONCLUSIONS

Hypotheses

Hypothesis 1: Big blocks evoke more explorative behaviour than climbing on current smaller holds.
True. Participants mentioned that the blocks (either with or without points system) were fun, a puzzle, led them to explore more possibilities, they looked at the blocks differently than at holds figuring out multiple ways to climb the route. Some mentioned they found it more creative and they tried out a number of movements.

Hypothesis 2: Climbers climbing with the points system will challenge themselves by setting a goal in points.
Partly true. Climbers did not set themselves a goal in points but aimed for getting the lowest score possible in general. They did puzzle to get the blocks on the sides that had the lowest number.

PART SIX

In the last part conclusions are drawn on the possible implementation of the blocks, and recommendations are formulated. To close the story a vision on the future of indoor climbing is given.

FUTURE VISION

IMPLEMENTATION

A company that would be interested to produce the blocks would be a company that either builds climbing walls, holds or modules. A producer of climbing holds (such as Cheeta, Makak, Volx, AIX, HRT, Axis or Expression) adds the blocks to its product portfolio, as the Blocks will be used as holds. A company that builds climbing walls or modules (such as HRT, AIX, Art Line, Volx, Vertigo and Walltopia) may also add the Blocks to its portfolio, as it is likely they have the experience and machinery to produce the Blocks because they so similar to the production of wall and modules. Yet the difference must be noted that the Blocks are a type of hold and not a type of module.

Sets

In the design, the Blocks come in sets. A set of five blocks (as done in the user test) is enough to build a boulder. The climbing gym buys a set of blocks. The set comes with the long bolts to screw the blocks onto the climbing wall. A set of numbered discs is also added to the package. These numbers are the scoring of the edges from 1 to 5. The route setter screws the discs on the edges when the blocks are on the wall. The edges have a fixed range of difficulty, according to the angle between the planes and the crimper distance, but the difficulty of the edge also depends on its place in the route. This is why the numbered discs need to be placed once the route is finished.

Shape

The shapes of the blocks are constructed in a 3D CAD software. Many software programmes are able to fulfil this task. The shape should be determined and a template of the shape's different planes should be extracted from the programme. In addition, all angles between the planes should be calculated. A designer makes this construction plan once, and the producer builds the blocks.

Production

In this project five shapes were built, but there were only three unique shapes in the prototype, because it was more time efficient to double some blocks instead of building five unique blocks. This is the same in production.

The production of the Blocks is quite similar to the production of Modules. The prototype was made of 18 mm triplex, but when the edges are sawed and glued with greater precision, the adhesive bond will be much stronger. So in production, thinner plates can be used. Thinner plates also save weight, which is beneficial for the route setter that needs to carry these blocks up the wall for route setting. In addition to the glued edges, inserts to support the plane with the holes should be made.

Putting the planes together into one Block is quite a puzzle and will always need to be done manually. In production, it makes sense to produce a series of the same block at the time. The setting of the machinery only needs to be done once in order to saw and sand multiple blocks

Polyurethane construction glue was used to glue the Blocks, it has a drying time of 24 hours. This means that production of one block will take at least two days before completion.

The surface structure of the blocks can be copied from the modules and climbing wall planes. It is a two-component paint mixed with sand. When this is hardened the sand is 'glued' into the paint that creates the rough surface finish. This paint takes 8 hours to dry (Bogerman & ter Steege, 2015)

Prize estimation

Modules that are available on the market now range from 40 to 80 euros according to their size, ranging from 42 to 74 cm over the longest edge. (Klimgrepen.com, 2015). The Blocks in the design are estimated at a price of 49,70 euros for an unqiue block, so the designer costs and setting of the machines are included. One block in a batch is estimated to cost 39,90 euros. A set of five blocks with bolts, numbered plates and screws is estimated at 225,00 euros.

The calculation of the prize estimation is added in Appendix K.

Lightweight alternative

The biggest disadvantage of making big blocks is that is hard to handle them. At first, they need to be shipped to the climbing gym. Once in the gym, the route setter needs to take the block up the wall to screw them on. Besides from the size, weight is a problem when moving around big blocks. The chosen plywood might not be the lightest in its category. The prototype blocks vary from 2 to 4 kilos according to their size. The biggest, 55 cm over the longest edge, weighed four kilos. Lighter alternatives in plywood are more expensive and less strong.

FUTURE RESEARCH

Long-term effect

During the user test, only a short-term effect was tested. To the participants, climbing on the blocks made them feel curious. This is not a surprising outcome because most climbers are used to climb on plastic holds instead of big wooden blocks. They also indicated that climbing was more explorative than on normal holds. The question is, if these blocks keep evoking that explorative behaviour in climbers if they climb the routes with blocks over a couple of weeks. It could be that after a few weeks the climbers has 'figured out' the route, and the challenge will be just as big as on normal holds.
This is something that could be tested in a long-term study. By putting a route with blocks in an indoor climbing gym for some months and examine the behaviour of the climbers after these months.

Route climbing

In this project the blocks were tested in a boulder route. In theory more explorative climbing could also apply to route climbing. A downside of the blocks for route climbing is the line of the rope, because the blocks are big and the rope might get stuck behind a block. This could lead to dangerous situation because the climber is belayed from a strange position and friction between the rope and the block could cause damage to the rope. In addition, counting the points climbed in a longer route is more difficult because the climber might forget to count continuously during ascent.

Surface structure

Varying the surface structure of the blocks was mentioned in both the creative session and the user test. A smoother surface is harder and scarier to stand on. It will help the climber to be able to practise more 'scary' steps in the gym.

Combining concepts

As mentioned in the evaluation of the concepts, combing the (tested) Athletic Accountant concept with The Chimney concept could lead to an interesting variation, offering practising chimney climbing to climbing gyms.

FUTURE VISION

Challenging oneself

As a designer I do believe that the big blocks with the points system does challenge the climber in a different way than normal routes do. During the user test, participants were searching for least amount of points, making it as hard as possible for themselves. Whilst in normal routes, the climbers are looking to find the easiest possible line through the route. I do believe that this subtle difference will make the climber more aware of this body position and therefore become a better skilled climber.

FUTURE VISION

Future of the climbing sport

Indoor climbing is still growing in popularity as a sport. Bouldering, lead climbing and speed climbing are disciplines that might be included in the Olympic games of 2020 in Japan (Climbing, 2015). Estimations are that this will make the sport even more popular. There will be a need for more climbing gyms. When there are more people coming, climbing gyms need to offer more different types of training. The blocks are a possible extra ‘offer’ for a climbing gym.

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APPENDICES

APPENDIX A

BASIC CLIMBING TECHNIQUES AND MOVES

Styles in climbing / types of movements

The table describes different types of movements for different types of wall or rock.

Style	Description	Indoor or outdoor	Touch points* During move	Wall angle	Muscle power	Way of belaying?
Crack	Body mostly to one side, putting hands and feet inside the crack to climb.	Outdoor	3	90	Medium	Normal
Chimney	Body inside chimney. Use back and shoulders too to push yourself up	Outdoor	3	90	Medium	Normal
Plate	Wall with very little and small holds. Climber stands on (dynamic) friction and has his hands flat on the wall.	Outdoor	3	+ 90	Little	Little loose
Overhanging	Climber his body position is leaning towards horizontal. Much greater stress on arms than legs.	Indoor / outdoor	2-3	45-80	Much	Normal
Balance focused	Holds are bigger than in Plate walls. Small handholds and climber needs to cleverly shift its weight to reach the next hold.	Indoor / outdoor	2	-	Little	Little loose
Use of momentum	The next hold can't be reached by static movement, so the climber needs a small hop or jump to get to the hold.	Indoor / outdoor	2	-	Medium / much	Loose
Dyno	The next hold is very far to reach and the climber has to jump out of the wall onto the next hold(s).	Indoor / outdoor	0	±90	Much	Very loose

* Classically, a climber holds three points and moves the fourth touch point.

Plate climbing

Climbing movements and holdings

In an climbing route different types of techniques are combined before finishing the route. Below a list of techniques are described.

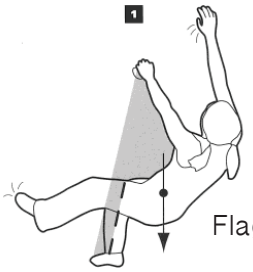
Movements / techniques

- Frontal. This may be called 'normal' climbing. The climber has his belly and face towards the wall.

Frontal

- Opblokken. (translation?) This is basically a pull-up. The climber pulls himself up until his hand touches his shoulder. This is done when a hold is too far to reach by just standing.

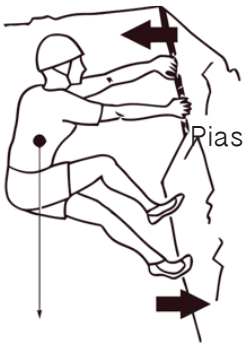
- Flagging. This is a basic technique used to save energy. It is used to reach a hold that is too far to just reach. When flagging the climber uses the diagonal of his body. Hanging on your left arm, while pushing off with your right leg. The left leg can be set on the wall for stability but is not used to stand on. This way, the right arm is free for grasping the next hold.



Flagging

APPENDIX A

- Piassen. This is a technique that is used when there are no footholds and the handholds are faced to the side. The climber hangs in the handholds and puts his feet high up against the wall (almost at the same height as the hands).



Piassen

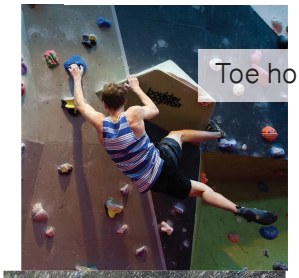
- Side pull. Normally when you grab a handhold, the palm of your hand is pointing towards you, and your fingers are further away. When side pulling you rotate your hand the other way, so that your fingers are closer to you that your hand palm. Also see Gaston holding.

- Dynamic friction. When a foothold is very small and even slippery, it helps to quickly stand on it and climb on. The theory is that dynamic friction is stronger than static friction. It is a bit 'scary' step.

Heel hook

Holdings:

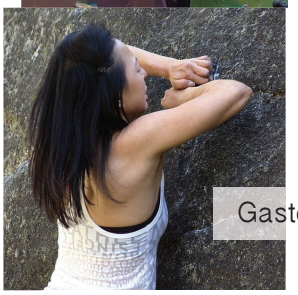
- Heel hook. Hook your heel behind a hold and pull yourself towards your foot. This is a move used to position yourself, because it impossible to stand on the foot that is heel-hooked.



Toe hook

- Toe hook. Hook your toes behind a hold and pull yourself towards your foot. It is very hard to hang from your toes as the shin has very small muscles. It is mainly used to position yourself.

- Foot on friction. When there is no dent or bump to place your foot on, static friction can be used to make the step. Because you put pressure on the foot onto the (flat) wall, you are able to stand and make a move towards the next hold.



Gaston

- Gaston. Here you have both hands in a side pull but in the opposite direction. Fingers from both hands point towards you and both hand palms are pointing outwards.

- Undercling. Normally you hold a hold by folding your fingers over the top of the hold. By an undercling, the dent of the hold is at the bottom, so you fold your fingers under the hold. This works best if your waist is at somewhat the same height as the hold.

Pinch

- Pinch grip. Some holds are so small that you can't fold your fingers nicely around them. Then you have to bent your phalanges in the 'wrong' direction to create some grip.

Two finger

- Mono-finger. Some holds have a hole in it, small enough for just one finger.

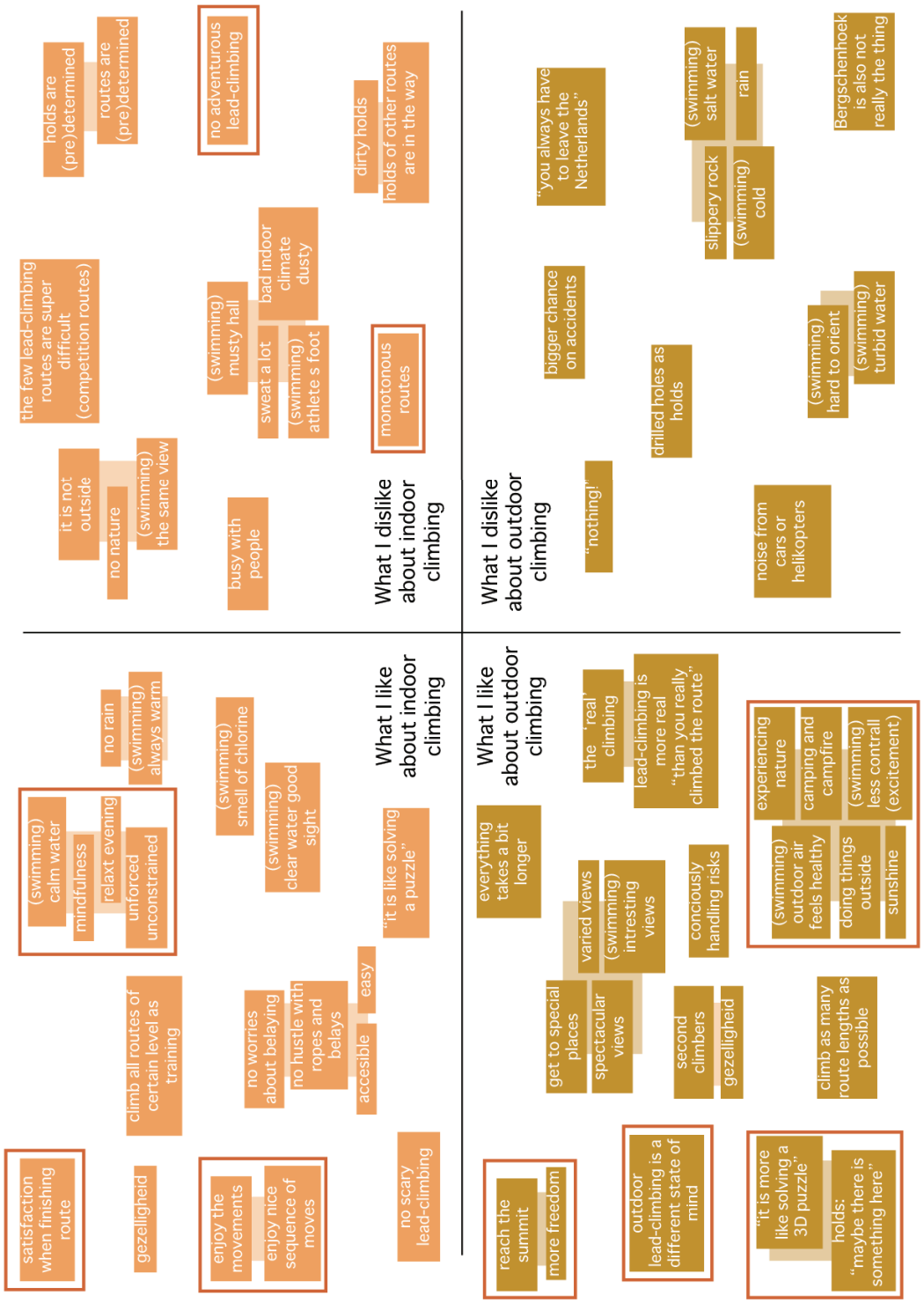
- Two-finger. Some holds have a hold in it that is small enough for just two fingers.

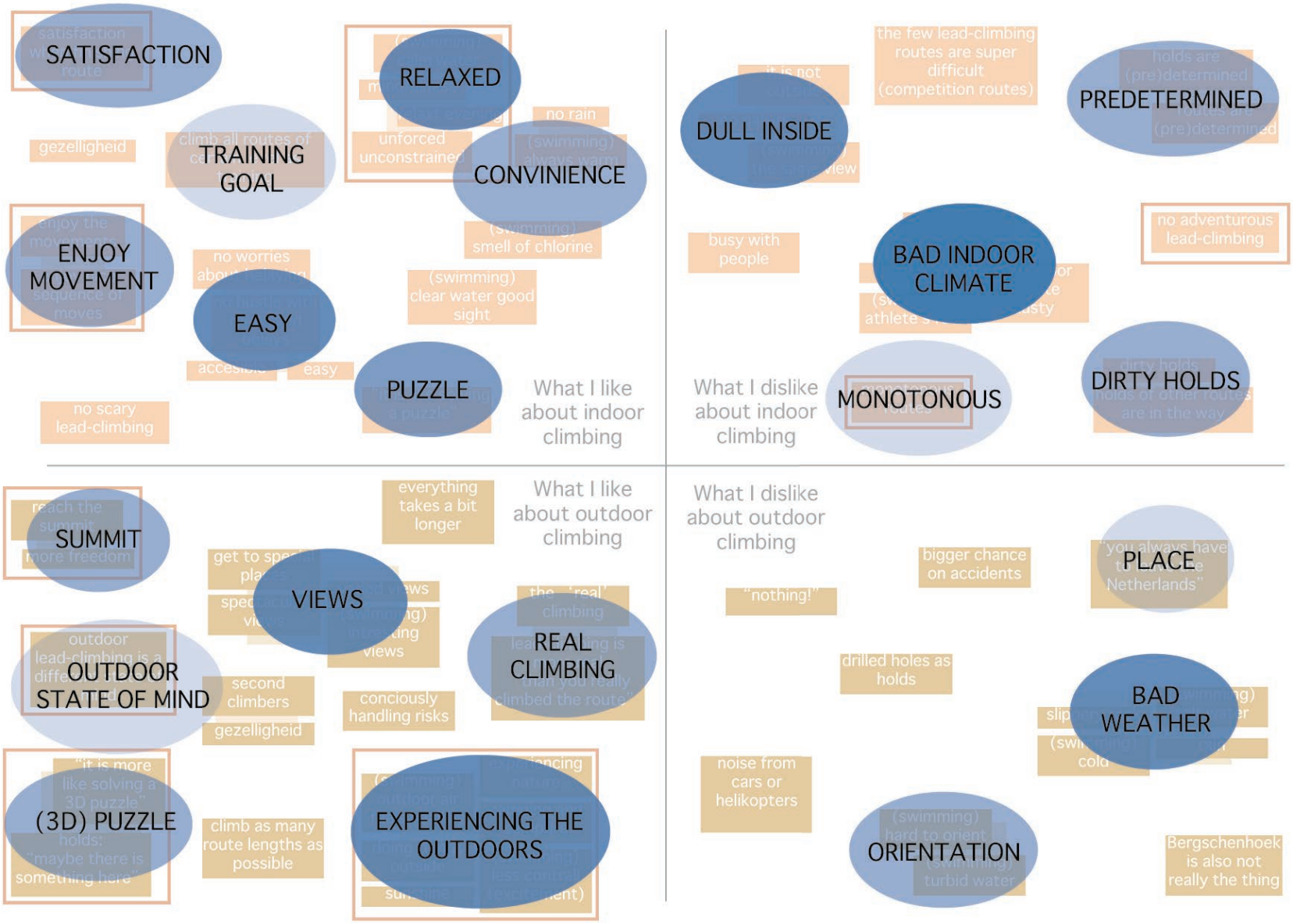
APPENDIX B

INTERVIEW QUOTES MATRIX

From the ten structured interviews that were done with climbers and one swimmer a matrix was made. In here, the quotes and statements the participants had made about “what I like about indoor“, “what I dislike about indoor“, “what I like about outdoor“ and “what I dislike about outdoor“ -climbing are placed. The remarks that concern ‘experiences’ are circled in red.

These quotes can be clustered in to statements words. The more participants mentioned a cluster, the darker shade of blue it got. The clustered is shown in the second matrix on the next page.




SATISFACTION
RELAXED
TRAINING GOAL
CONVINIENCE
gezelligheid
no rain
unforced unconstrained
(swimming) smell of chlorine
ENJOY MOVEMENT
no worries
EASY
(swimming) clear water good sight
accesible
easy
PUZZLE
no scary lead-climbing
What I like about indoor climbing
DULL INSIDE
the few lead-climbing routes are super difficult (competition routes)
PREDETERMINED
busy with people
BAD INDOOR CLIMATE
no adventurous lead-climbing
MONOTONOUS
DIRTY HOLDS
What I dislike about indoor climbing
SUMMIT
reach the summit
more freedom
everything takes a bit longer
What I like about outdoor climbing
VIEWS
get to special places
views
REAL CLIMBING
the "real" climbing
OUTDOOR STATE OF MIND
outdoor lead-climbing is a
second climbers
gezelligheid
conciously handling risks
(3D) PUZZLE
"it is more like solving a 3D puzzle"
holds:
"maybe there is something here"
climb as many route lengths as possible
EXPERIENCING THE OUTDOORS
What I dislike about outdoor climbing
"nothing!"
bigger chance on accidents
PLACE
drilled holes as holds
BAD WEATHER
noise from cars or helikopters
ORIENTATION
(swimming) hard to orient
(swimming) turbid water
Bergschenhoek is also not really the thing

APPENDIX C

OBSERVATIONS INDOOR CLIMBING

30/04/2015

How do people train?

- Buddy
- Individual
- Exercises
- Time
- Number of attempts per route
- What happens when route fails
- How do climbers pre-read
- How many climbers pre-read
- Puzzle?

Buddy: Indoor halls climbers automatically have a buddy to secure the rope of the other buddy climbing.
1) This is usually a friend or somebody you trust. This buddy encourages from the ground and sometimes gives tips to localize the next hold or suggests a move. This usually stops when the climber has passed 4 to 5 meters because then it becomes too far to see and to hear from the ground besides, the securer gets a sour neck from looking upward.
2) When you are climbing with three, the person securing has time for some conversation with the second whilst the third is climbing the route. Other securers on the ground may also start conversations, but that are less common.

Individual: As mentioned before, after 4 to 5 meters of climbing these is no more opportunity for (mental) support from the ground. Only short commands and encouragements may be given. From this moment on, the climber is “alone” in the route. There is no communication between by passers in other routes, climbers are focussed on their own route.

Exercises: The hall provides some tools for strength exercises. They are used by some climbers.

Time: Climbers spend around 2 hours in the hall. Climbing routes one buddy after the other, which gives the belaying climber the opportunity to rest before switching roles again. A buddy that only secures is never seen.

Number of attempts per route: The route is begun and climbed to the top. When a rest is needed or the climber falls out, the securer holds the rope fixed until the climber is ready to continue the route. A route is generally tried once, but several tries within that route (on a difficult move for example) are done. When a move is very hard and the climber still doesn’t make it the 6th time, he mostly calls to let him down to the ground.

Pre-reading: 1) Climbers pre-read the route from the ground until round 3 meters (4-6) moves. Above that height it’s too hard to see the holds well and to predict the moves.
2) When 3 meters are passed, the climber solves the route on the spot.
3) When a move is not directly understood, the climber lets go and the securer fixes him on that height. This gives the climber the opportunity to pre-read the next moves and may try again.
4) This way the route is “trained” in smaller chunks, hoping to fluently climb the whole route one day.

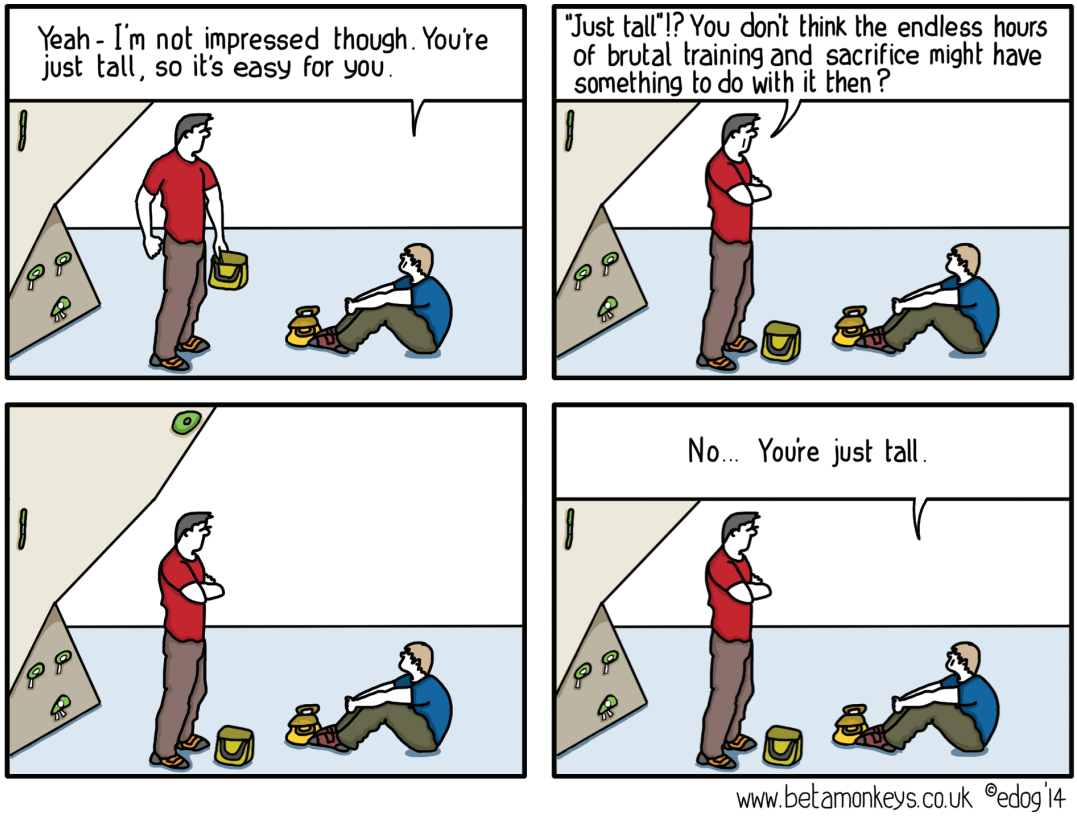
Social interaction: One or two buddy pairs are a group of

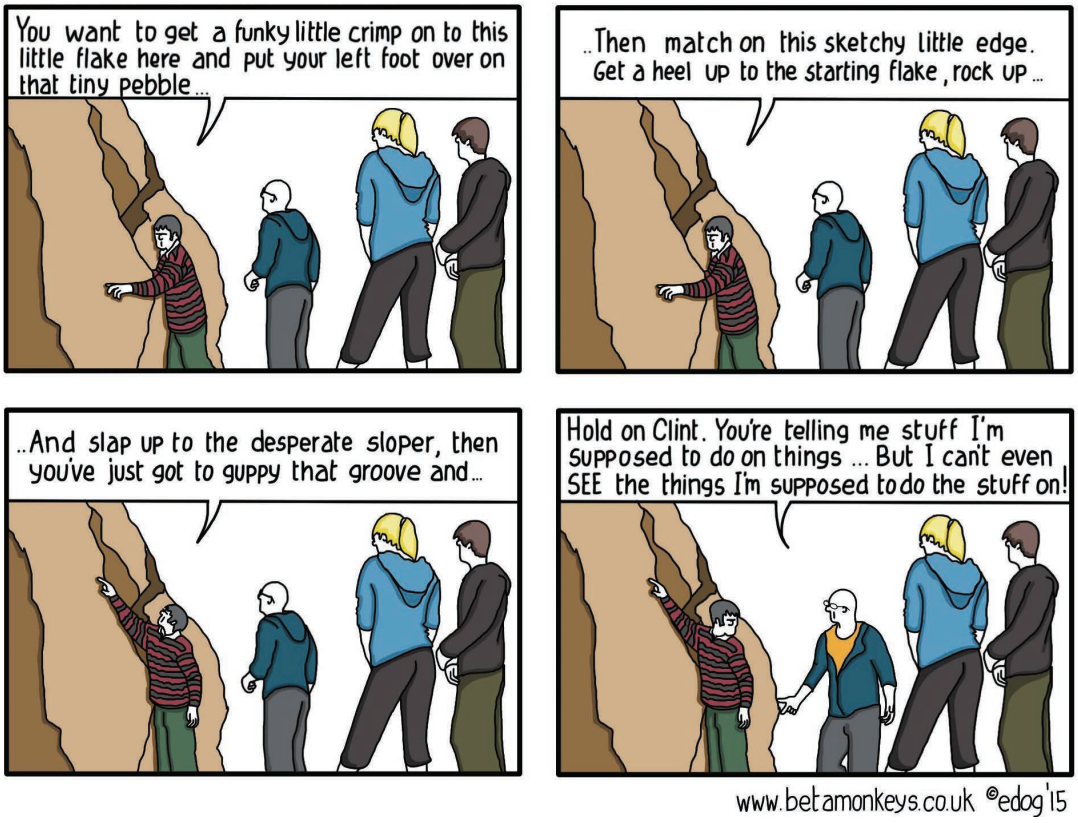
Warming up: Climb two to three routes below level, in a peaceful pace.

APPENDIX D

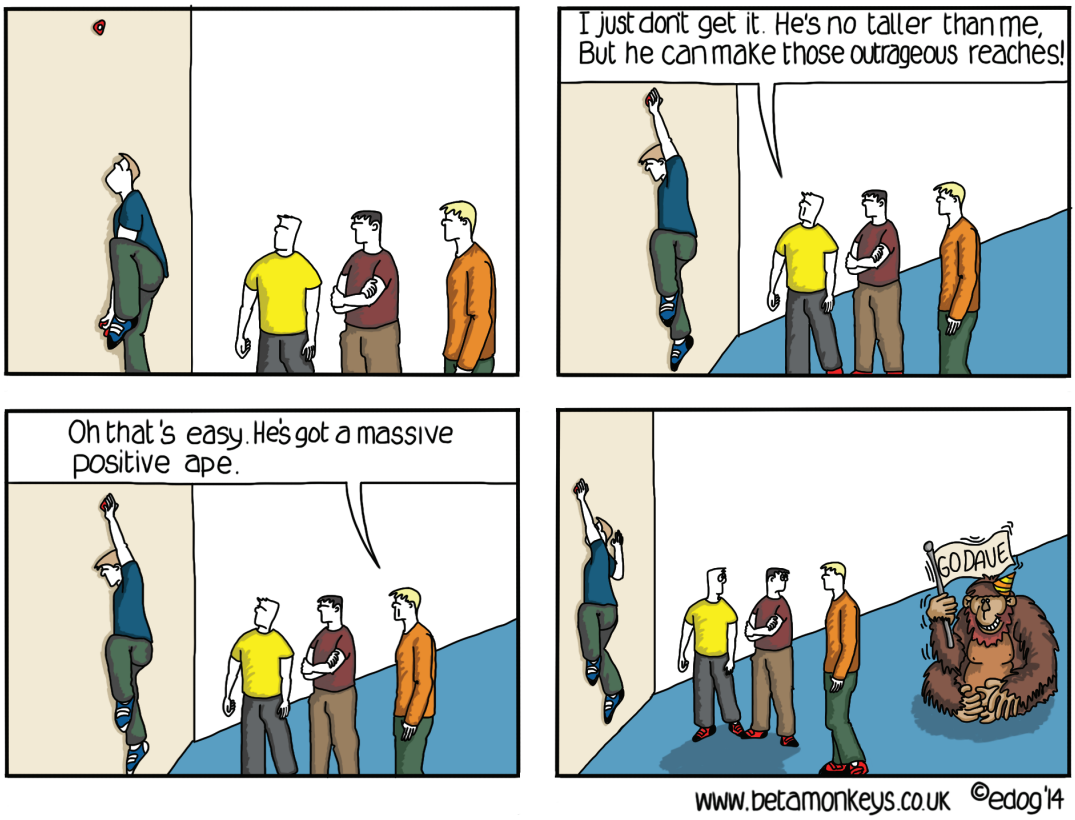
BETA MONKEYS COMICS

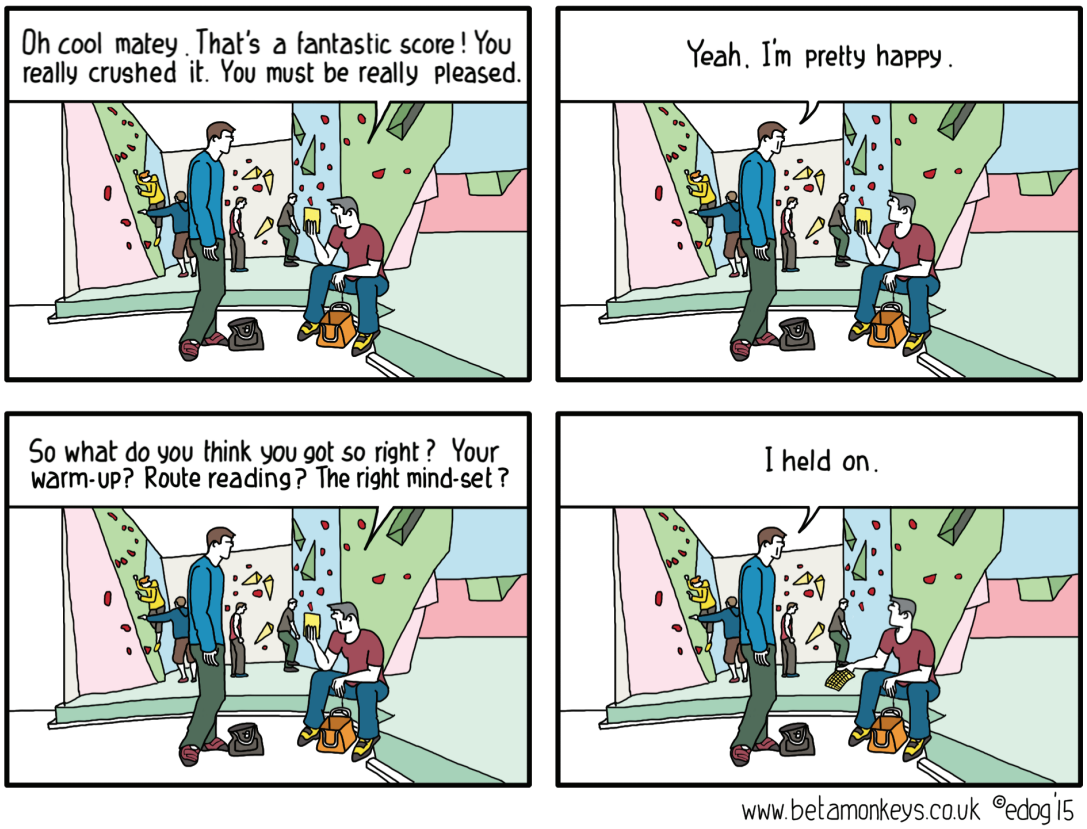
The climbing culture in bouldering and route climbing gyms is nicely captured in the series of comics by Beta monkeys.





APPENDIX D


I just don't get it. He's no taller than me, But he can make those outrageous reaches!
Oh that's easy. He's got a massive positive ape.
GO DAVE
www.betamonkeys.co.uk ©edog'14


Oh cool matey. That's a fantastic score! You really crushed it. You must be really pleased.
Yeah. I'm pretty happy.
So what do you think you got so right? Your warm-up? Route reading? The right mind-set?
I held on.
www.betamonkeys.co.uk ©edog'15

APPENDIX D

THE BETAMONKEYS' GUIDE TO... CLIMBING TERMINOLOGY

APPARENTLY: I've not actually done it yet but this guy who said he had told me...

POP: Small committed dynamic move.

LITTLE POP: Terrifying leap of faith.

CRIMP: A hand hold so small that it casts no shadow, whatever the time of day.

SKETCHY CRIMP: Imagine the smallest hold you can - then halve it.

SMEAR: there's nothing there so those fancy boots you bought, trust them!

DELICATE: Whatever you do, don't breathe.

JAM: This is what your finger will be turned into if you get it wrong.

PEBBLE: the grain of sand sized hold that sticks out from an otherwise glass wall.

NICE: beautifully polished to dramatically reflect sunlight and have zero friction.

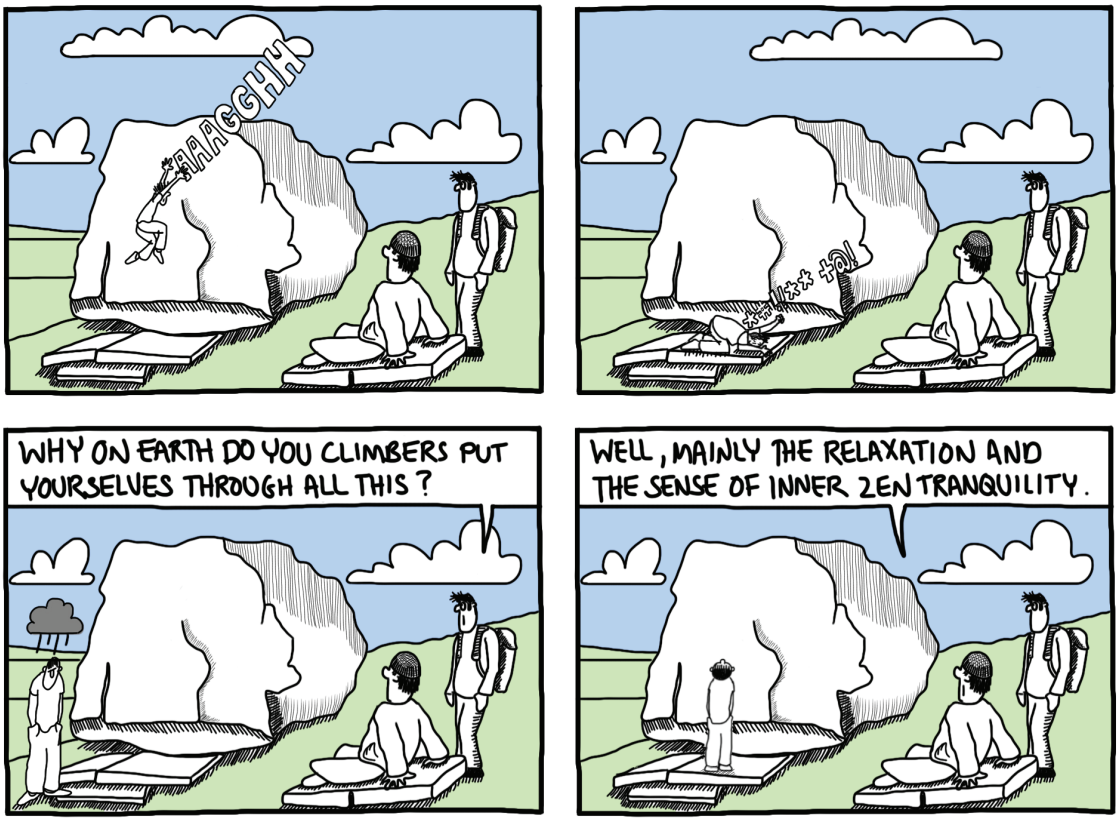
MATCH: It's the only hold.

JUG: A good hand hold.

JUGGY: Not a good hand hold.

FLAKE: you know what that crumbly chocolate does? Well, this is like that.

TOP OUT: drag yourself, walrus like, to relative safety.

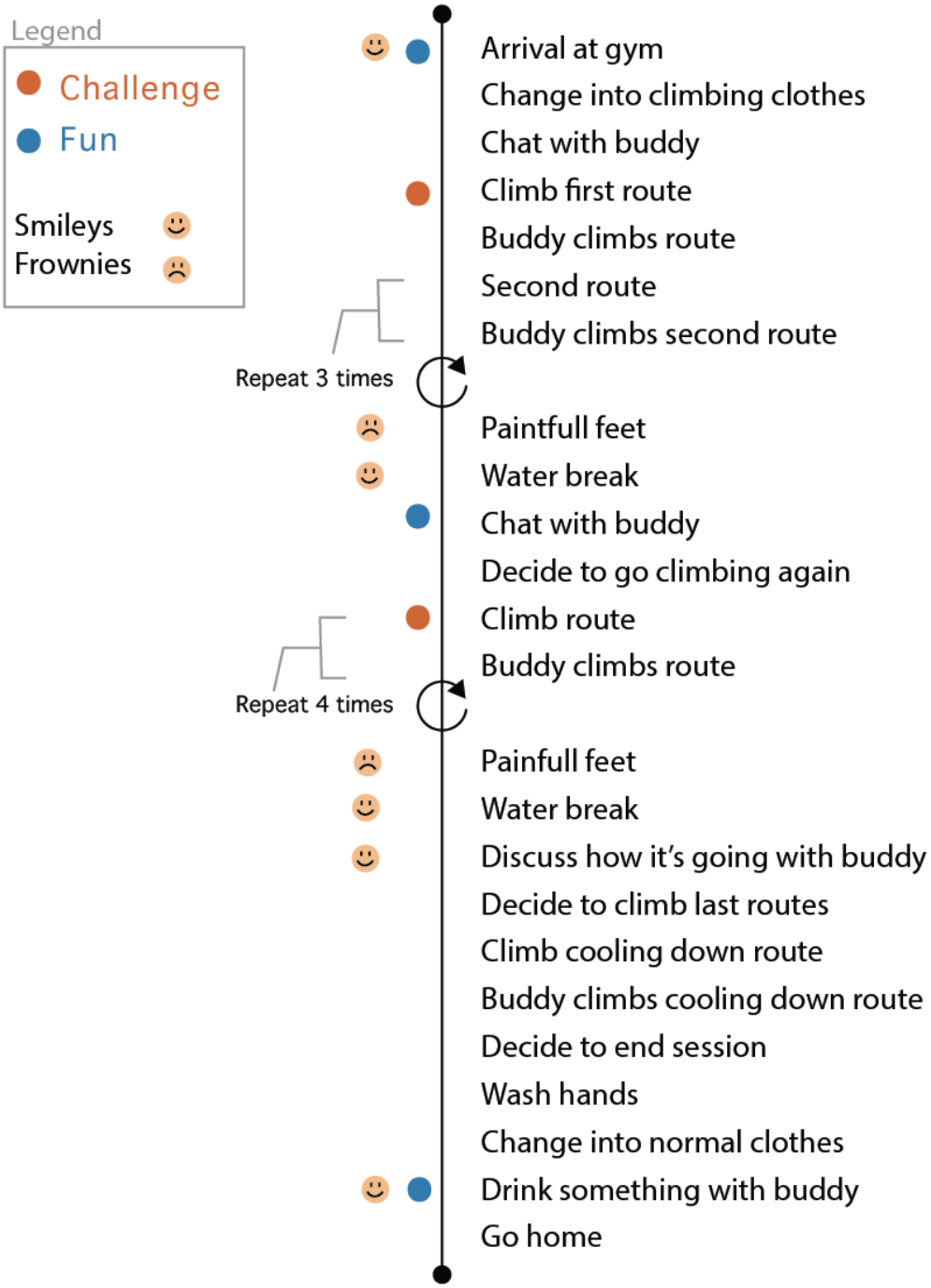


APPENDIX E

CUSTOMER JOURNEYS

I. Climbing session

Chronological overview of the events that occur during a climbing session. This journey was written by the designer and her climbing buddy during one of their own climbing sessions. This journey was checked by some of the participants of the interviews with climbers to compare indoor and outdoor climbing, also mentioned in Appendix B.

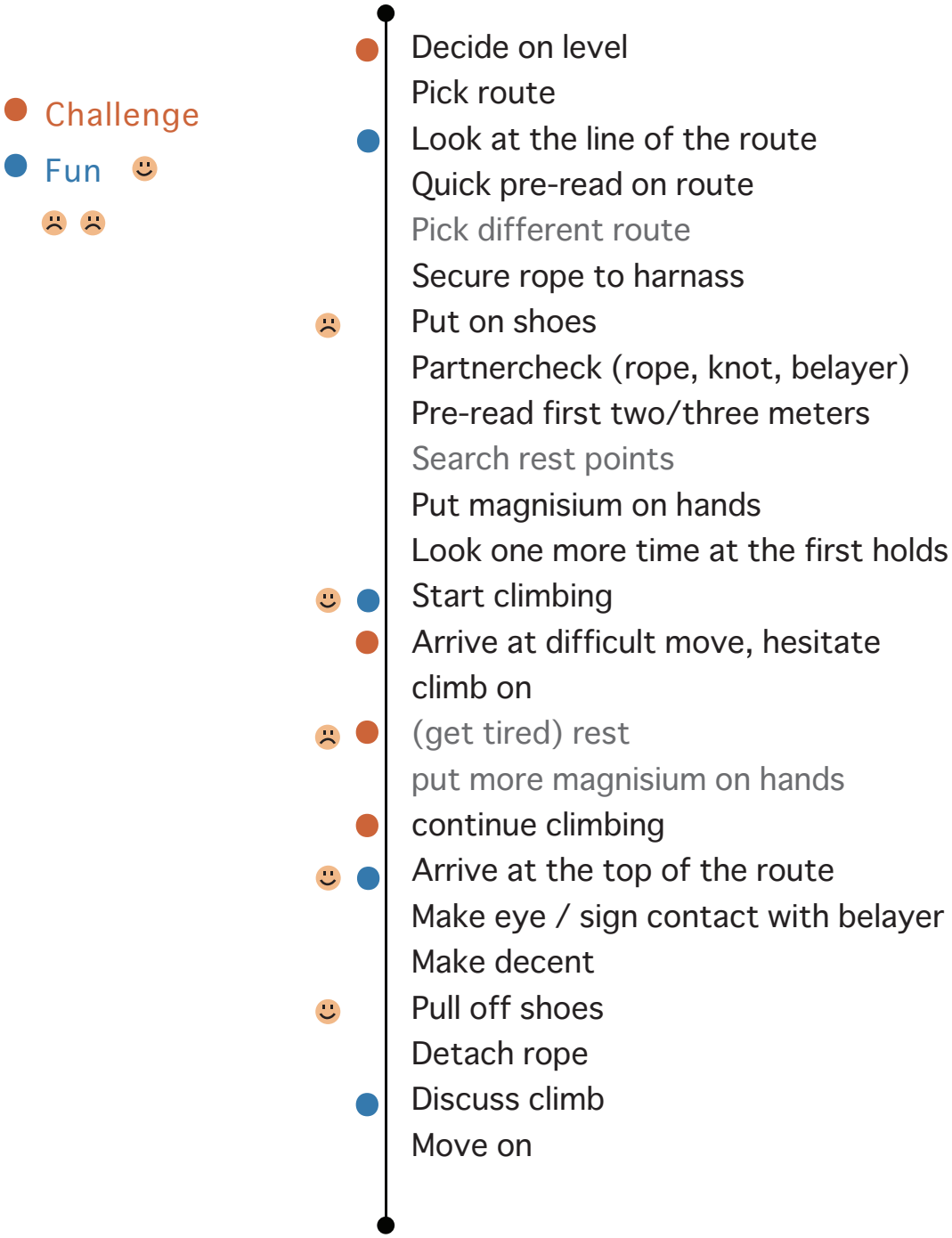


APPENDIX E

CUSTOMER JOURNEYS

II. Climbing a route

Chronological overview of the events that occur during a climbing session. This journey was written by the designer and her climbing buddy during one of their own climbing sessions. This journey was checked by some of the participants of the interviews with climbers to compare indoor and outdoor climbing, also mentioned in Appendix B.

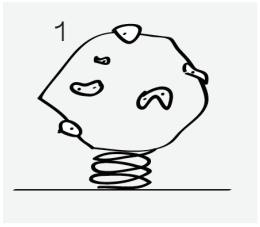


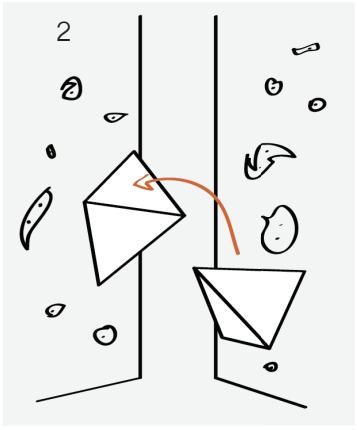
APPENDIX F

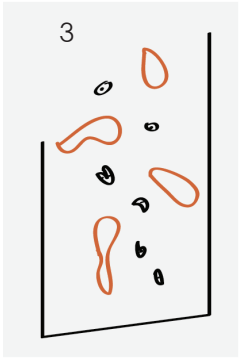
GAME WORLD AND ITS PLAYS

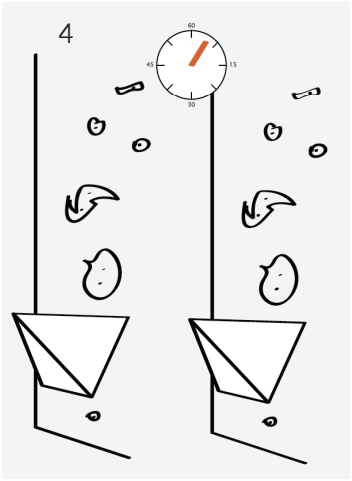
The game world is presented as a children's playground.
Children play in an unstructured manner, running from one climbing rack to another. They might stop climbing one rack before getting to the top because another game caught their attention. This unstructured characteristic is what demonstrates explorative behaviour that is wanted when climbers learn climbing, unfortunately is not beneficial when a climber is aiming for an efficient training.

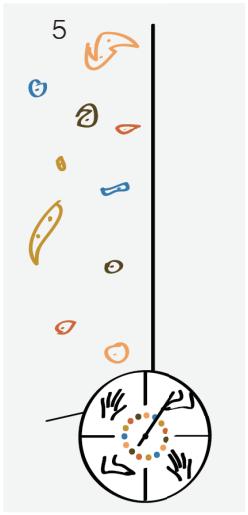
There are climbing-related games available in the playground, a twister wall, an obstacle-run like climb, a race, a game with a dice, wobbly climbing racks and jumping from one wall to the other

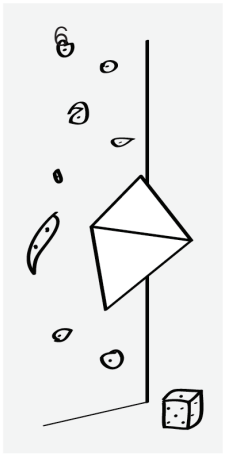












The dream world children's playground has the following six elements.

Route	Why?
1. Get on top of wobbly objects	Feeling of reaching some sort of summit evokes joy (matrix)
2. Jump form one block on the wall to a block on another wall	New type of movement that you probably do not master yet but should be a challenge within reach
3. No touch objects in the route	Obstacle climb and parcours like element. Challenge
Social	
4. Two identical routes next to each other to copy of race another climber	Copying another climbers moves is like a synchronic dancing routine Racing another climber pushes your limits and raises adrenaline.
5. Twister with hands, feet and the colors of the holds	Uncontrolled direction yet fun to solve the puzzle of keeping yourself on the wall as long as possible.
6. Roll a dice, that are the amount of steps you are allowed to take to finish the route.	Uncontrolled task boundary in which you have to solve the puzzle.

APPENDIX G

PARKING LOT IDEAS

In the main body of this report a smaller version of this image is shown. Here you are able to read the ideas sheets. Some of these ideas are used in the game world or as concepts.

APPENDIX H

CREATIVE SESSION

I. Session procedure

Goal for me: To get inspirational ideas of how to implement fun and challenging (game) elements in the module climbing holds.

30 students
1 hour
@ Scouting at Delftse Hout

What	Time	Notes
Energizer*	10 min	"Gordian knot"
Make groups	4 min	Everybody with the same colour post-it forms a group
Fill in & brainwrite H2's	7 x2,5 = 18 min	
Rotate		Repeat 7 times
Take all H2's of another group	2 min	
Rank ideas with stickers	5+5 = 10 min	5 min read other H2's Mark with stickers for fun and challenging
In duos (or trios) shape 1 concept	6 min	
Write concept on template	4 min	

Group formation:
Me: stick post'its on everybody in four colours. Per group one post it has an L on it. L is the leader. Group leader gathers the H2 sheets and gives to the next group. At the end of the session the leader gives the H2 sheets and templates to me.

*Energizer !!! Gordian knot. Grab somebody's hand. Everybody grabs a hand at random, and quite a tangle (should!) appear. Participants have to untangle until this are in a circle.

II. Materials

H2's
Group A
1. How to climb when you only have one leg?
2. How to climb when you only have one arm?
3. How to climb like a child?
4. How to climb on the ceiling?
5. How to climb as if you are very, very lazy?
6. How to climb when you are blindfolded?
7. How to climb when the wall is very slippery?
8. How would a mouse climb a route?

Group B
1. How to do a twister game on the climbing wall?
2. How to make a path?
3. What else could you use a climbing wall for?
4. How to implement a fear factor on the climbing wall?
5. How to make a game out of climbing?
6. How to make a dance out of climbing?
7. How to reward a climber at the top?
8. How climb as if there is no gravity?

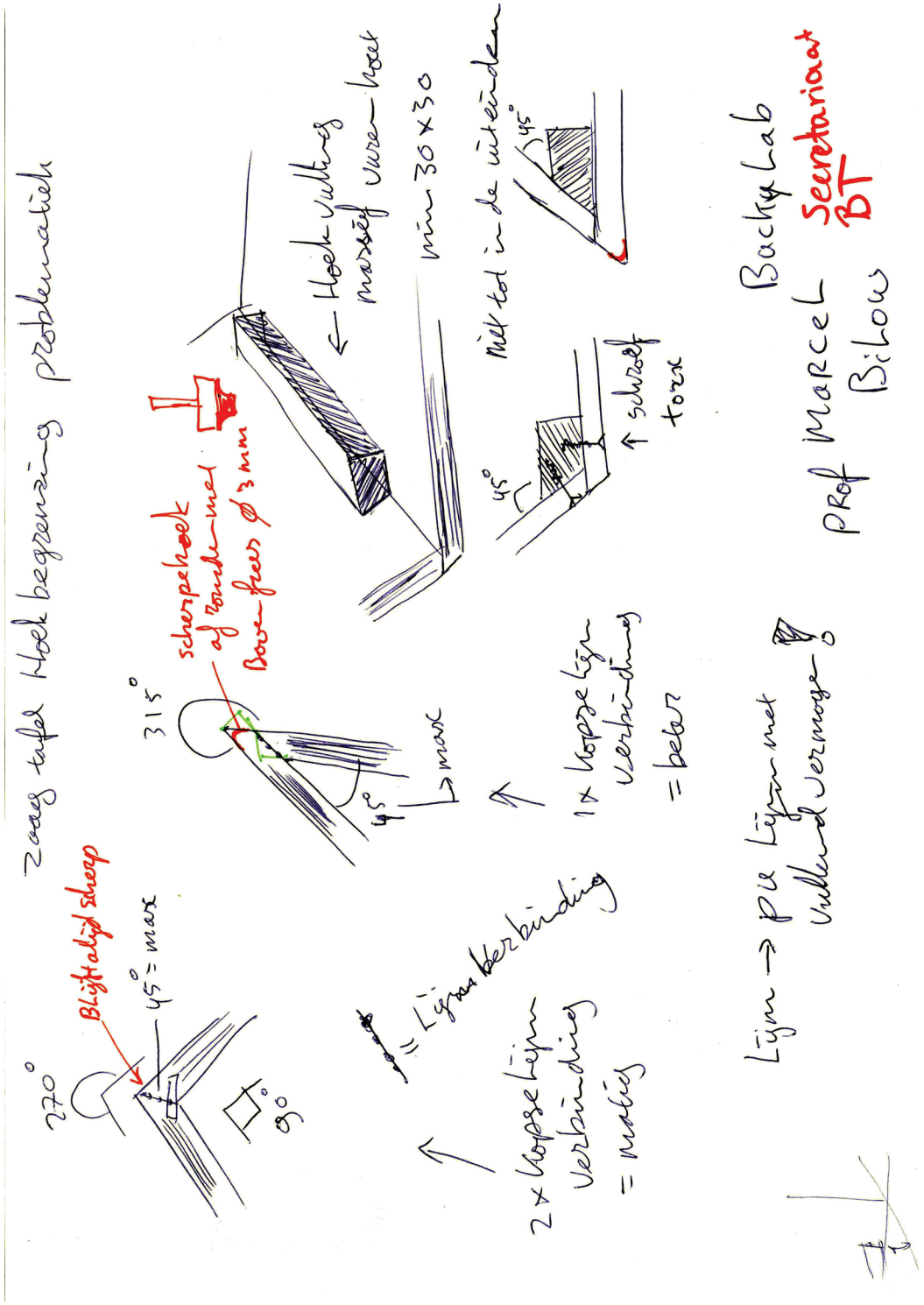
Things needed
- A3 with H2's (four sets, group A and B)
- A3 concept template (print 20 pieces)
- Mark stickers (two colours)
- Prototype
- Alarm for rotation
- Beer and wine
- Watch
- Post-its, four colours, one with L

APPENDIX I

BUILDING PROTOTYPE

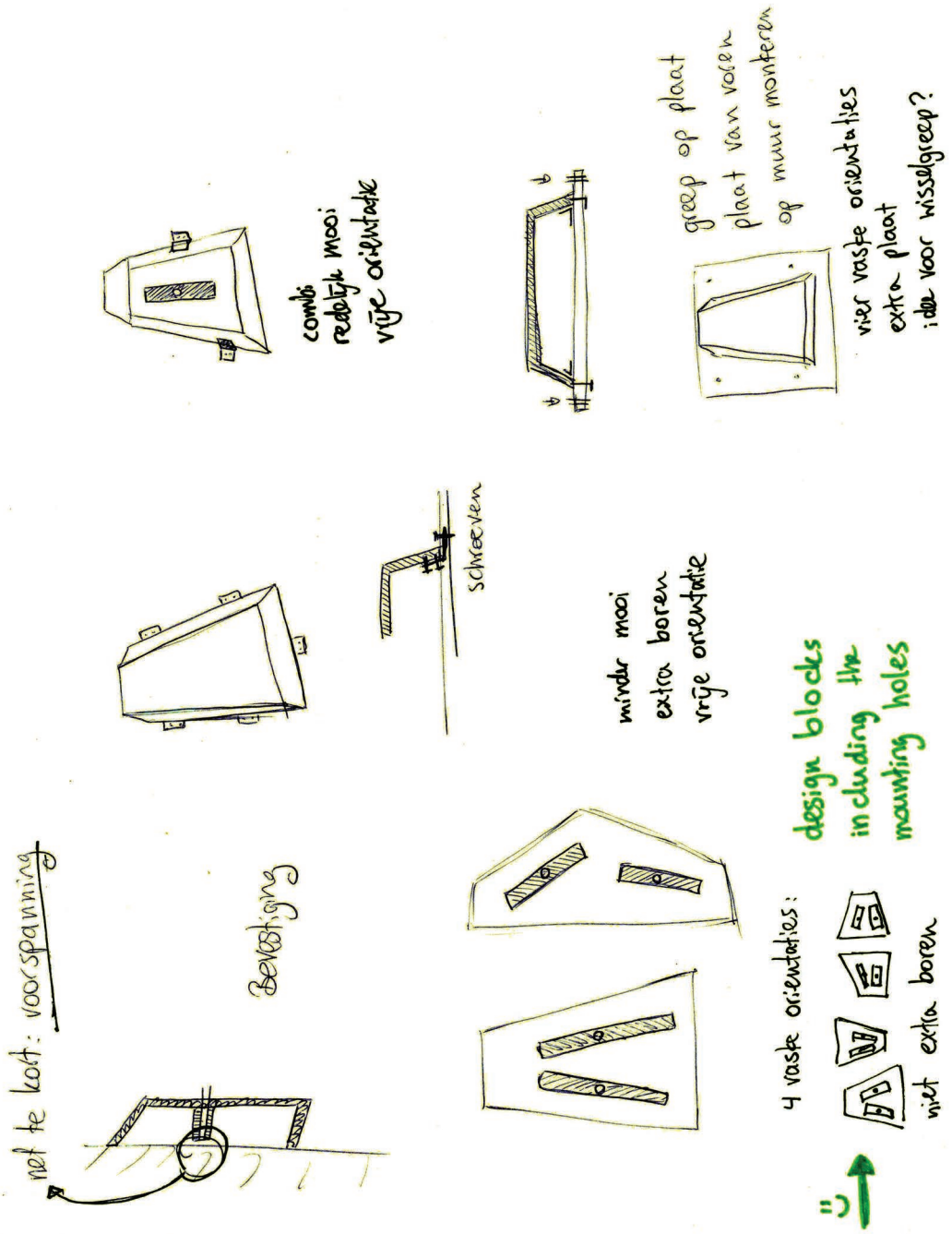
I. Structure problem drawings

Drawing of possible solutions for constructing strong edges in the blocks.



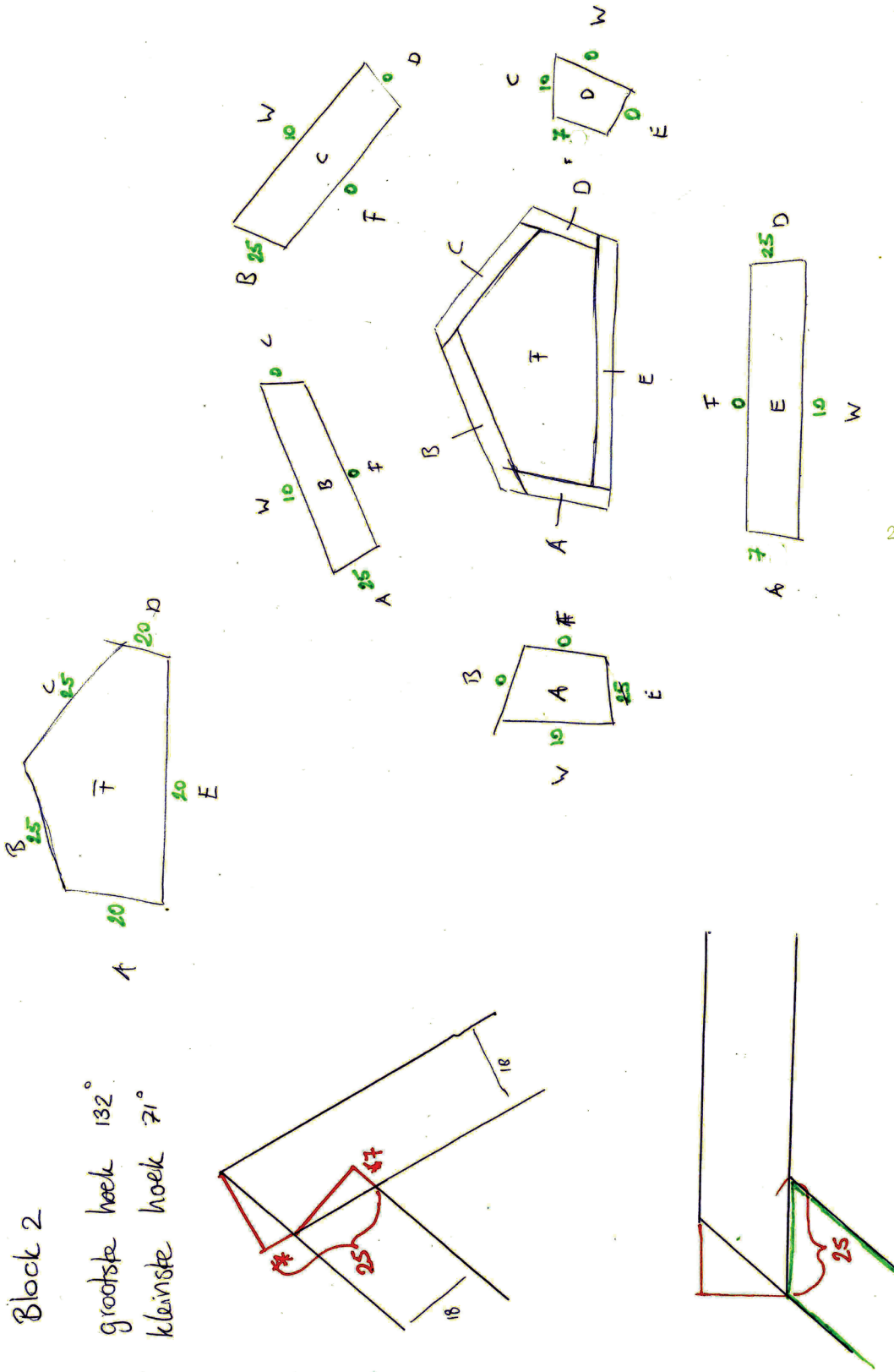
II. Wall attachment

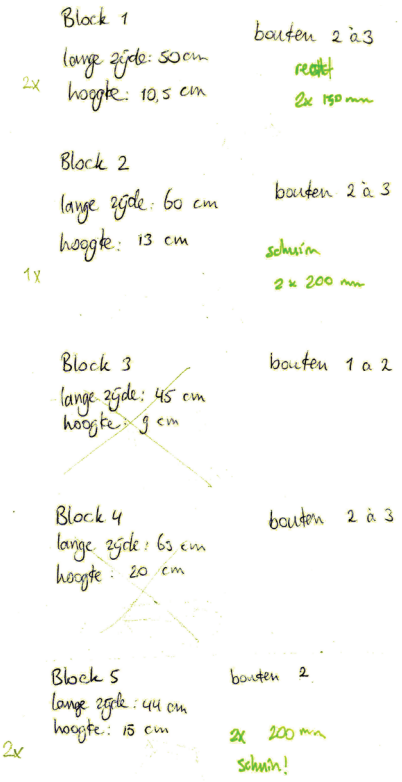
Short brainstorm on how to attach the Blocks to the wall.



III. Construction drawing

Drawing of construction of one of the Blocks made for the user test.





Construction plan per block. The number and length of the bolts.

APPENDIX I

IV. Tests surface structure

In order to give the Blocks their rough surface structure, some tests were done to cheaply get to this structure for the prototype.
In the first round tests were done with wood glue and “beits”, a type of laquer. In the wet glue and “beits“ sugar and salt were spread. When the glue and “beits“ were dry, the salt and sugar was washed off so that the glue would have the rough surface structure. Unfortunately, the wood glue was not water resistant, so after washing is was smooth again. The “beits“ is, unlike laquer or paint a coating that is sucked into the wood, so the salt and sugar didn’t create bumps.

A second test was done with laquer and sugar and salt. The dried lacquer was water resistant, but stays a bit soft when the salt and sugar were washed off. The best sample up till now is one with lacquer where the sugar isn’t washed off yet.

In the user study participants are climbing in the blocks and might sweat eventually. When the surface coating is made with sugar, that will become a sticky mess when it mixes with sweat.
At last a test with wet lacquer and sand was done. This worked wonderfully in the prototype.

APPENDIX J

PARTICIPANTS FORMS

Sheet 1 - Informed consent

Forms are written in Dutch because all particpants as well as the designer have Dutch as the mother tongue.

Deelnemers formulier

Welkom! Leuk dat je mee wil doen aan mijn test.

Leeftijd:
Klimniveau:

Film
Tijdens het klimmen zal er gefilmd worden. Dit filmmateriaal word gebruikt bij het analyseren van jou gedrag tijdens het klimmen en kan gebruikt worden in een filmpje over deze test. Deze film zal eenmaal op mijn afstudeerpresentatie (17 november 2015, Delft) aan de zaal getoond zal worden. Al het overige videomateriaal wordt daarna vernietigd. Mocht de film ergens anders getoond worden, zal ik jou eerst daarvan op de hoogte stellen.

Eigen risico
Als er tijdens de test verwondingen opgelopen worden door het klimmen op het prototype, dan is dat jou verantwoordelijkheid en is de onderzoeker niet aansprakelijk.

Ik wil meedoen aan de test

Paraaf:

Dankjewel!
Vera

Sheet 2 - Questionnaire after Condition 1

- Hoe vond je het klimmen op deze blokken?
- Klimt het anders dan de grepen waar je normaal op klimt? Ja/nee
- Kun je uitleggen waarom?
- Denk je dat je iets anders traint dan als je op normale grepen klimt?
- Kun je uit deze 12 emotie kaarten er 3 kiezen die het beste weergeven hoe je je voelde tijdens het klimmen?
- Beschrijf per kaart waarom je dat voelde (schema is op de volgende bladzijde)

Geef van de volgende stellingen aan of je het er mee eens of oneens bent.

1: mee oneens 5: helemaal mee eens

1 2 3 4 5

1. Ik vond het uitdagend klimmen
2. De grote blokken zorgden voor een uitdaging tijdens het klimmen
3. Ik was aan het zoeken naar de beste lichaamspositie om verder te komen
4. Ik heb ontdekt hoe ik het beste bovenaan kan komen
5. Ik vond klimmen op de blokken avontuurlijk
6. Ik nam de beslissingen over hoe ik ging klimmen vooral tijdens het klimmen
7. Het lijkt op buiten klimmen
8. Ik vond het leuk
9. Klimmen op deze blokken voelde als een puzzel
10. Ik vond klimmen op deze blokken spannend
11. Er was een competitieve sfeer

APPENDIX J

Sheet 3 - Questionnaire after Condition 2

- Hoe vond je het klimmen op deze grepen?
- Kun je uit deze 12 emotie kaarten er 3 kiezen die het beste weergeven hoe je je voelde tijden het klimmen?
- Beschrijf per kaart waarom je dit dacht (schema is op de volgende bladzijde)

Geef van de volgende stellingen aan of je het er mee eens of oneens bent.

1: mee oneens 5: helemaal mee eens

1 2 3 4 5

1. Ik vond het uitdagend klimmen
2. De grepen zorgden voor een uitdaging tijdens het klimmen
3. Ik was aan het zoeken naar de beste lichaamspositie om verder te komen
4. Ik heb ontdekt hoe ik het beste bovenaan kan komen
5. Ik vond klimmen op grepen avontuurlijk
6. Ik nam de beslissingen over hoe ik ging klimmen vooral tijdens het klimmen
7. Het lijkt op buiten klimmen
8. Ik vond het leuk
9. Klimmen op de grepen voelde als een puzzel
10. Ik vond klimmen op deze blokken spannend
11. Er was een competitieve sfeer

Sheet 4 - Short description points system

Zoals je kunt zien is deze route niet gemarkeerd met een cijfer of kleur om het niveau aan te geven. Hier is het niveau bepaald per vlak van een blok. 5 is het makkelijkst en 1 is het moeilijkst. Als je de nummers op de blokken bij elkaar optelt bepaal jij het niveau van je geklommen route. Probeer het eens!

Sheet 5 - Questionnaire after Condition 3

- Hoe vond je het klimmen op deze blokken?
- Hoeveel punten heb je minimaal geklommen?
- Heb je jezelf een punten doel gezet voordat je ging klimmen? Ja/nee
- Veranderde dat iets aan hoe je de route klom?
- Kun je uit deze 12 emotie kaarten er 3 kiezen die het beste weergeven hoe je je voelde tijden het klimmen?
- Beschrijf per kaart waarom je dit dacht (schema is op de volgende bladzijde)
- Kun je verbeter punten noemen voor het ontwerp met dit puntensysteem?

Geef van de volgende stellingen aan of je het er mee eens of oneens bent.

1: mee oneens 5: helemaal mee eens

1 2 3 4 5

1. Ik vond het uitdagend klimmen
2. De grote blokken zorgden voor een uitdaging tijdens het klimmen
3. Ik was aan het zoeken naar de beste lichaamspositie om verder te komen
4. Ik heb ontdekt hoe ik het beste bovenaan kan komen
5. Ik vond klimmen op de blokken avontuurlijk
6. Ik nam de beslissingen over hoe ik ging klimmen vooral tijdens het klimmen
7. Het lijkt op buiten klimmen

APPENDIX J

8. Ik vond het leuk
9. Klimmen op deze blokken voelde als een puzzel
10. Ik vond klimmen op deze blokken spannend
11. Er was een competitieve sfeer

PRIZE ESTIMATION

	Prize estimation	PER BLOCK	m2	hours	prize (euros)	drying time (hours)	Notes					
Design	CAD software			0								
	Designer hours			0,2								
Material	Triplex 18 mm		0,42		8,4		20 e per m2					
	Paint		?									
	Glue		?									
Production	Setting machines			0,5								
	Kerfs			0,1								
	Cornering			0								
		Milling		1								
		Insert slat sawing		0,3								
		Insert slat gluing		0,1		24	Plates and slats can dry simultaniously					
	Glue plates			0,2		24						
	Sand edges and leaked glue			0,25				man hours	14	E p/h		
	Paint			0,2		8		production hous				
	Pre drill holes for bolts			0,05				2,75				
	Pre-drill countersink for number discs			0,05				drying time				
								32				
					49,7	per unique block						
					39,9	for the same block						
total prduciton				34,75								
Set	5 Blocks				199,5							
	10 Bolts				15							
	30 Discs with numbers				8							
	20 Screws				2,5		these are estimations of prizes in commercial DIY stores, with estimanted industry discount					
	Total				225							
Packaging					0							
Batch size					??							

Sources:
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Granta,. (2002). Cambridge Engineering Selector (Version EduPack). Granta.

APPENDIX K