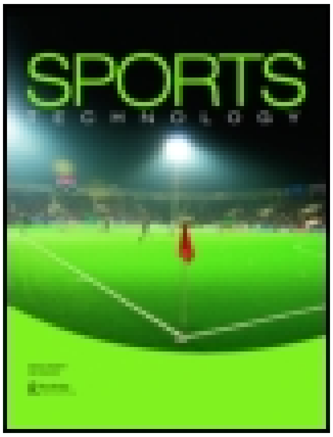

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Benefits of 3D topos for information sharing and planning in rock climbing

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RESEARCH ARTICLE

Benefits of 3D topos for information sharing and planning in rock climbing

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Abstract
In outdoor rock climbing, routes are commonly marked in *topos*, which are typically implemented as annotated photographs or hand-drawn pictures. 3D technologies, such as structure from motion (SfM), enable the creation of detailed 3D models. These technologies are now within the reach of almost everybody, and they are becoming increasingly simple to utilize. We present an interactive 3D topo of a large boulder and discuss the creation process using SfM and 3D modelling software. Furthermore, we conducted an online user study with 52 respondents investigating how 3D topos can be utilized for information sharing and planning, and how 3D topos might change rock climbing. Results show that 3D topos are seen highly useful compared to normal web topos.

Keywords: *rock climbing, bouldering, photogrammetry, SfM, 3D topo, 3D model*

Introduction

In rock climbing, routes are traditionally marked in photographs or hand-drawn pictures describing the rock. These images are commonly called topos, in which routes (also known as problems in bouldering, hereafter referred as routes) are marked with lines. Topos are often printed as books and nowadays also found in dedicated websites, which are accessed with a computer or a smart phone.

Topos serve a dual purpose: they are accessed beforehand for planning or for finding the routes while at the climbing location. Marked routes usually include a difficulty level (i.e. technical grade) and the description of a route type so that climbers know what to expect. Especially in longer routes the descriptions are essential for route planning and safety. Climbing a route with first attempt (called flash) is often desired by climbers. For the flash, the climber is free to gather any information about the route, e.g. inspect the route, ask for an advice and see others climbing. Furthermore, a first climbing attempt is also called *on-sight* when a climber has no prior information about the route. Today, videos of climbed routes are found as a useful source of information for climbers, because hard moves can directly be seen from them. For the same reason, image sequences of successful climbs have been published in printed magazines. However, although topos are the main source of information about climbing routes, they often are vaguely marked, undescriptive and coarsely drawn. This is probably due to lack of detail in small photographs and hand-drawn pictures. Extra information is also purposefully left out from printed topos, so it would not ruin the fun of problem-solving or on-sight climbing. It is still often impossible to evaluate the route beforehand and missing information includes starting holds and eliminated holds, which may even lead to uncertainty about whether the route was climbed correctly or not. Adding more details and information to topos could make the preparation and climbing easier. Nowadays creating 3D models just from a sequence of photographs is made really easy in cloud services ("Autodesk 123Catch," 2013) and 3D scanning with a mobile phone can soon become

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reality with devices such as Google's Project Tango ("Project Tango," 2014).

In this paper, we present a novel prototype of detailed 3D topo of a boulder, which includes interactive features for showing relevant climbing-related information as illustrated in Figure 1. Moreover, we report results of an online survey about the usefulness of the 3D topo for information sharing and planning in rock climbing. Finally, we give design recommendations based on the survey and discuss the future of 3D topos in climbing. The main research questions that motivated our study are:

Research question 1 (RQ1): Are 3D topos seen as useful by climbers for information sharing, planning or climbing in general?

Research question 2 (RQ2): Are 3D topos accepted by the climbing community and how would they be used?

Related work

Creation of 3D models

With current technology it is possible to create highly detailed 3D models by using only a sequence of photographs as source material (Erickson, Bauer, & Hayes, 2013). Photo-based 3D scanning, which is also known as structure from motion (SfM) (Dellaert, Seitz, Thorpe, & Thrun, 2000), is an aproach in which a 3D model is generated from photographs without

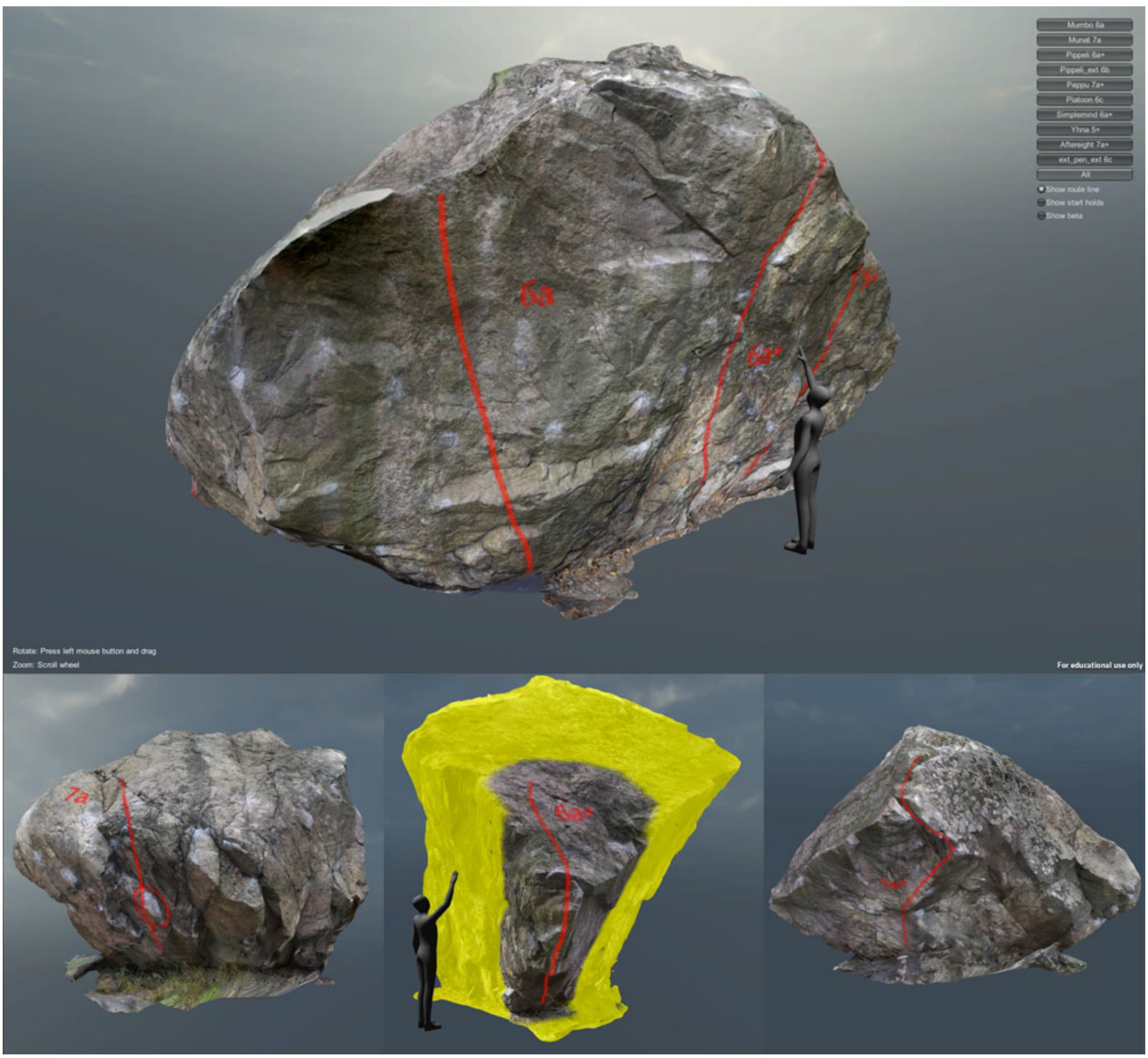

Figure 1. The 3D topo prototype. Interactive features include (1) orbiting the viewpoint around the boulder and moving closer (or further) for more detailed view, (2) a menu for selecting routes and options and (3) displaying route lines, grades, starting holds, excluded areas and climbing tips (beta feature).

the need of identification of target locations or camera positions in the photograph. Because of the simplicity and flexibility of SfM, it has been widely adopted for creating 3D models from various objects (Erickson et al., 2013) and it is used in geoscience (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012) and culture heritage sites (Bashar Alsadik, 2013). There are many commercial software, such as free-to-use Autodesk 123D Catch ("Autodesk 123Catch," 2013) and PhotoModeller ("PhotoModeller software," 2013), in which 3D model quality is comparable to laser scanning (Erickson et al., 2013). For example, with 123Catch, the creation of a 3D model is as simple as taking a sequence of photographs around the desired object, uploading the photos to a cloud service and downloading the 3D model when it is ready. However, free-to-use commercial software can have limititations, such as a limited number of images, image size or possibilities to change the parameters of the algorithms. This can impede the creation of larger objects with high detail. There are several free or open source tools such as VisualSfM (Wu, 2011), Meshlab (Cignoni et al., 2008) and CMP SfM ("CMP SfM," 2012; Jancosek & Pajdla, 2011) that offer more flexibility and also good results.

3D models in rock climbing

Previously, 3D models of mountains and walls that also interest climbers have been created. 3D models of mountains (Buchroithner, 2002; Kolecka, 2011) and even a climbing wall (Kolecka, 2012) have been created, but their impact on climbing has not been studied. Buchroithner (2002) created a low-detail 3D model of the famous Eiger north face using analogue air photographs. They suggest that the 3D model could be used by climbers to prepare themselves for the actual climb. Kolecka (2011) has studied reconstucting mountain faces with photogrammetry. Results show that the created 3D model of a mountain can have similar accuracy and level of detail compared to laser scanning. Kolecka (2012) successfully created a high- accuracy 3D model and anaglyph visualization of a climbing wall, but its potential in climbing was not assessed. However, Kolecka suggested that, in the future, created 3D models or animations could be shared online between climbers to plan their route and prepare for the real experience.

Related work also includes capturing Yosemite's famous Midnight Lightning boulder problem with Microsoft Photosynth (National Geographic, 2008; "Photosynth," 2014). It enables the viewer to navigate 360 degrees around the boulder by showing the relation of the photographs to each other and smoothly changing the viewing angle between the photographs. Another project in the Yosemite area is the high-resolution geologic map of the famous El Capitan (National Geographic, 2013). The study consists of photographs, rock samples and LiDAR laser scanning for understanding magmatic processes as well as contributing to climbing safety with rock-fall analysis. Mountains, cliffs and large boulders can be hard to photograph from close enough distance for creating full 3D models. However, quadcopters and radio-controlled planes equipped with a camera are becoming affordable. They are also easy to control and, for example, even semi-autonomous aircafts have been used to create 3D map of Matterhorn (IEEE Spectrum, 2013).

Benefits of route inspection

There is evidence that inspecting the route beforehand affects a climbing performance, thus suggesting that detailed inspection before climbing of a route might be beneficial. Sanchez, Lambert, Jones, and Llewellyn (2012) found that climbers make fewer and shorter stops during their ascent following a preview of the route, and they suggest that visually inspecting a climb prior to its ascent may be an important component of performance optimization. Pezzulo, Barca, Bocconi, and Borghi (2010) have suggested that just seeing a climbing wall or a route activates a motor simulation of climbing, which relies surprisingly on motor competence and not on perceptual salience. Boschker and Bakker (2002) showed that observing the performance of an expert climber results in faster and more fluent climbing in novice climbers. Simulated climbing also helps to recall the motor process while climbing.

3D topo prototype

We use the term 3D topo to denote an interactive 3D model of a climbing route or area, which includes relevant information for climbers. For research purposes, we created a 3D model of a large boulder in Koivusaari, Helsinki, Finland, which is a popular climbing place for local climbers. Our 3D model prototype includes a realistic scale model of the boulder, illustrated in Figure 1. The interactive features, shown in Figures 1 and 2, allow the user to view the boulder from different angles, select and examine specific climbing routes, and display relevant information for climbers. The interactive features provide only one example how information can be marked to 3D topos. We did this study and the 3D topo prototype to (1) gather information from climbers to see if 3D topos are considered useful, (2) understand how, why and where 3D topos could be used and (3) understand what would be the requirements for a usable 3D topo. Although there

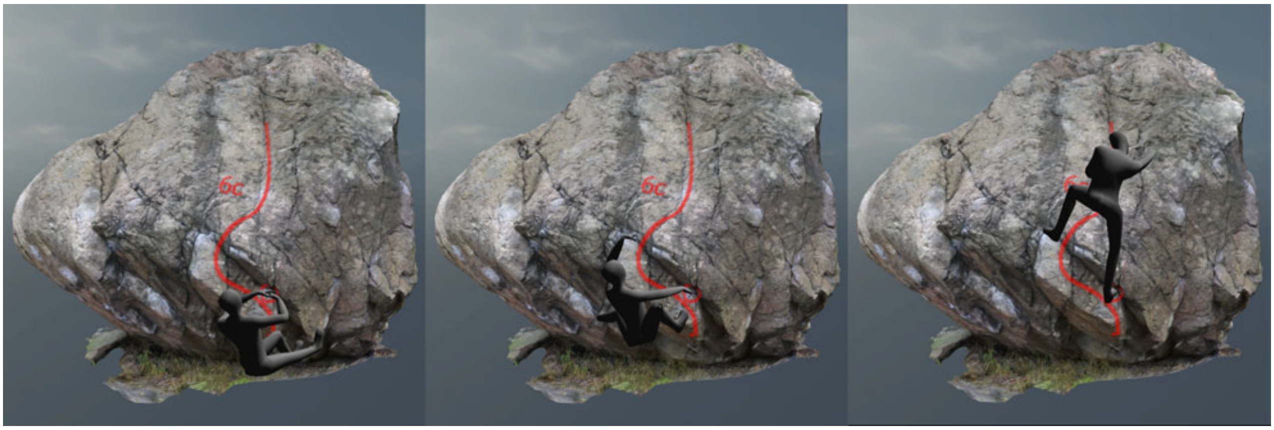

Figure 2. The beta feature in one route includes a stop motion animation of a human model showing eight positions from route start to the end. Three positions are shown in the figure.

are many ways to scan a rock for creating a 3D model, we chose to use photographs and SfM for the model creation. Ideally any climber with a camera or a smartphone could take photographs for producing 3D topos. For this 3D topo prototype, we chose a set of familiar software for us to facilitate fast creation process. With more effort the 3D model and textures could have been much more accurate and the creation process could be even automatized for easy use. However, this remains as future work and is described in the discussion. Next, we describe the creation process of the 3D topo prototype.

Creation process

The creation process of the 3D topo used in this study can be divided into five steps: (1) photographing, (2) SfM, (3) 3D model creation and texturing, (4) creating 3D topo features and (5) 3D topo finalization.

Step 1: Photographing. We took overlapping photos by circling around the boulder on standing level and about four meters high with the aid of self-standing ladders. In addition, we took photos from four relatively easily climbable trees around the boulder. However, half of the boulder is facing the sea, so we photographed the top of the boulder in close distance by walking on the top of the boulder. We found that best lighting conditions for model creation and obtaining a constant texture without large contrasts is cloudy weather with diffuse sun light. Two cameras, Canon Mark 2 and Canon G9, were used to shoot the photos and 133 photos in total were used for the 3D model creation.

Step 2: SfM. SfM is a photogrammetric technique for estimating 3D structures from 2D image sequences (Dellaert et al., 2000). In SfM the computer algorithm examines common features from a sequence of images and automatically constructs a 3D point cloud from overlapping features. We used VisualSFM software (Wu, 2011) for SfM steps, which included matching the photographs with scale-invariant feature transform (Lowe, 2004; Wu, 2007), sparse reconstruction with bundle adjustment (Wu, Agarwal, Curless, & Seitz, 2011) and dense reconstruction with multi-view stereo algorithms (Furukawa, Curless, Seitz, & Szeliski, 2010; Furukawa & Ponce, 2010). We did a sanity check for all camera positions by using the visual interface, but were unable to get the algorithm to recognize the top of the rock (top) and sides of the rock (trunk) as part of a same point cloud. Thus, the output of VisualSfM was two separate dense point clouds.

Step 3: 3D model creation. We imported the result from VisualSFM, including dense point clouds and camera positions to Meshlab software (Cignoni et al., 2008). We manually aligned the two point clouds (top and trunk) and merged them into one point cloud. Then, we performed Poisson surface reconstruction (Kazhdan, Bolitho, & Hoppe, 2006) to obtain smooth and watertight 3D model. Next, the 3D model of the boulder was simplified and cleaned from artefacts with Meshlab's filters. Finally, we applied the texture and created a UV texture map with Meshlab's filter by mesh parameterization and texturing from the photographs.

Step 4: 3D topo features. To create the interactive texture features (i.e. route lines, start holds, beta holds and excluded areas), we imported the 3D model to Autodesk Mudbox sculpting software. Each texture feature was painted on a separate transparent layer and layers were stored as textures. We used Autodesk 3ds Max to create the human figures and animation as individual 3D models.

Figure 3. Screenshots from 27 Crags' web topo page illustrating the Koivusaari boulder and routes from three directions. Source: Permission for use was granted by 27 Crags.

Step 5: 3D topo finalization. We imported all created models and textures to Unity 3D game engine ("Unity," 2014). Furthermore, we implemented the interactive features in Unity: orbiting the camera around the boulder with mouse input, driving the camera back and forward using the scroll wheel, and toggling the visibility of textures and human figures using GUI buttons. Compressed stand-alone installer for Windows and OSX and Linux was used for smaller download size (about 35 MB).

Method

Data collection

We created an online questionnaire with Webropol survey software. The questionnaire was divided into six pages with questions related to (1) sharing, (2) planning, (3) on-site use, (4) climbing sequences, (5) general (open ended) and (6) demographic. Due to the online nature of the questionnaire, the respondents were not requested to visit the Koivusaari boulder. Instead, the respondents were asked to imagine themselves in scenarios described in separate pages in the questionnaire. The topics of the questionnaire pages included:

(1) Page 1: Information sharing. "Imagine that you are at home and explaining how to climb a route to someone who has not visited the boulder."
(2) Page 2: Planning. "Imagine that you are planning your climbing before and after the climbing session and you can draw and add other information to the 3D topo or the web page topo."
(3) Page 3: On-site use. "Imagine that you are outside next to the boulder and using the 3D topo or the web page topo with a tablet or a smartphone."
(4) Page 4: Climbing sequence. "Here is a link to a video of the route named Platoon at Koivusaari. View the video and answer the questions below." The video was a beta-video at 27 Crags for the route named Platoon. The respondents were asked to compare the video to the animated sequence seen in the same route of the 3D topo and illustrated in Figure 2.
(5) Page 5: General (open ended). This page consisted of five open-ended questions for more detailed preferences about the use, features and benefits or disadvantages of the 3D topo.

(6) Page 6. Demographic. The questionnaire concluded with demographic information including age, gender and nationality. Also climbing- related information was asked, including years of climbing, weekly amount of climbing- related training and maximum technical climbing grade. We chose French grading system and provided a link to conversion table at *Wikipedia*. The questionnaire could be filled without any prior knowledge about the Koivusaari boulder. However, simple yes and no questions were asked to distinguish respondents who had climbed Koivusaari or owned a smartphone.

In pages 1–4, the respondents were asked to compare the 3D topo to the 27 Crags web topo ("Koivusaari web topo," 2014), which is widely used in Finland and summarized in Figure 3. Each page between 1 and 4 consisted of five statements related to the topic of the page, such as "If you compare 3D topo to web page topo. Climbing a route is." These statements included Likert-style responses with seven-point scale describing if a task is *Extremely harder*, *Much harder*, *Bit harder*, *Same*, *Bit easier*, *Much easier or Extremely easier* with 3D topo. In addition, pages 1–4 included one open-ended question: "What features would you like to add or what would you do differently for the 3D topo to be more useful in this scenario?"

We distributed the questionnaire via national (Finland) and international discussion forums (e.g. 8a.nu, slouppi.net) and several public *Facebook* groups related to climbing. Recruiting text read "Climbers! Try out an interactive 3D topo of a large boulder with augmented information and tell us what you think! Please download the 3D topo to your computer and access the questionnaire through this link ..." or "As part of a research project at Aalto University (Finland), we did a prototype of an interactive 3D topo of a large boulder near Helsinki. You can try out the 3D topo through this link and tell us what you think...." The html link bought the respondent directly to the online questionnaire. The first page of the questionnaire included a link for downloading the 3D topo, a short GIF-animation of the 3D topo and instructions. The respondents were asked to ignore the facts that the marked routes might not be in correct places, not all routes are marked, human characters could be positioned better, surrounding environment is not included and the model is not embedded to a website. Furthermore, the respondents were asked to forward the questionnaire to any climber they knew. The data reported in this paper were gathered in two weeks between 2 February and 25 February 2014.

Analysis

The analysis focuses on summarizing the Likert-style responses, demographic differences and the analysis of the qualitative data from open-ended questions. The open-ended responses were analysed by sorting them to relevant themes representing the questions and key concepts that were found from the responses. Comments that best describe the theme (negatively and positively) are quoted in the results.

Results

In this section, three types of results are presented. First, we give the quantitative description of the respondents. Second, we describe the results for Likert-style responses and give quantitative description about the usefulness of the 3D topo for sharing, planning and climbing in general (RQ1). Finally, the descriptive summary of the themes found from the responses is given to answer if the 3D topo was accepted by the climbing community and how would it be used (RQ2).

Profile of respondents

We received 52 full responses, which were all valid for the analysis, giving $N = 52$. The questionnaire was opened 1186 times and the 3D topo was downloaded 246 times (Windows 156, OSX 73, Linux 17). We can only speculate why the rest who opened the link did not fill questionnaire. Reasons might include that they were not climbers, only indoor climbers, laziness, unattractive topic or lack of time.

When asked about their gender, 44 responded male and 8 female. The range of age was from 18 to 54 (mean = 31.9, median = 32 and SD = 5.85). Forty-nine respondents were from Finland, one from Poland, one from Brazil and one did not define a country. Thirty-nine respondents said that they had visited the Koivusaari boulder and 13 had not. Four respondents did not own a smartphone. Figure 4 illustrates the profile of respondents in grade outdoors (French grading system), years of climbing and weekly exercise related to climbing. Choices for technical grade level were none and from 4a to 9a. Unfortunately, we forgot by mistake to have the option for 6c. This made respondents to upgrade or downgrade their grade, if they otherwise would have marked 6c.

Usefulness of the 3D topo (RQ1)

Likert-style questions were used to study the usefulness of the 3D topo compared to the normal web topo in four scenarios: (1) sharing, (2) planning, (3) on-site use and (4) climbing sequence. As seen in

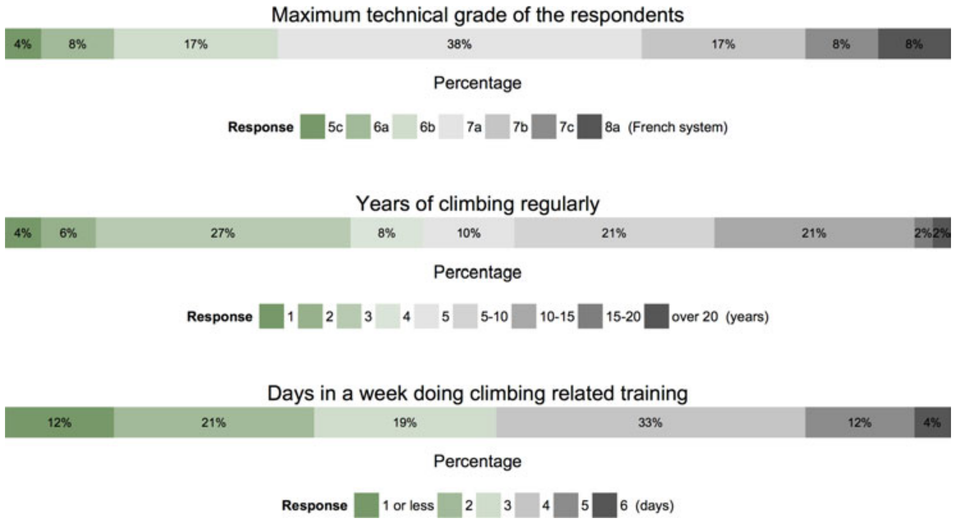

Figure 4. The rock climbing experience and weekly activity of the respondents.

Figure 5, the preference of the respondents is heavily tilted towards the side that indicates that the 3D topo significantly eases the relevant tasks in most of the scenarios.

The responses were transformed to a number ranging from 1 to 7 and representing the scale from "Extremely hard" to "Extremely easy." Furthermore, the responses to five questions for each scenario were

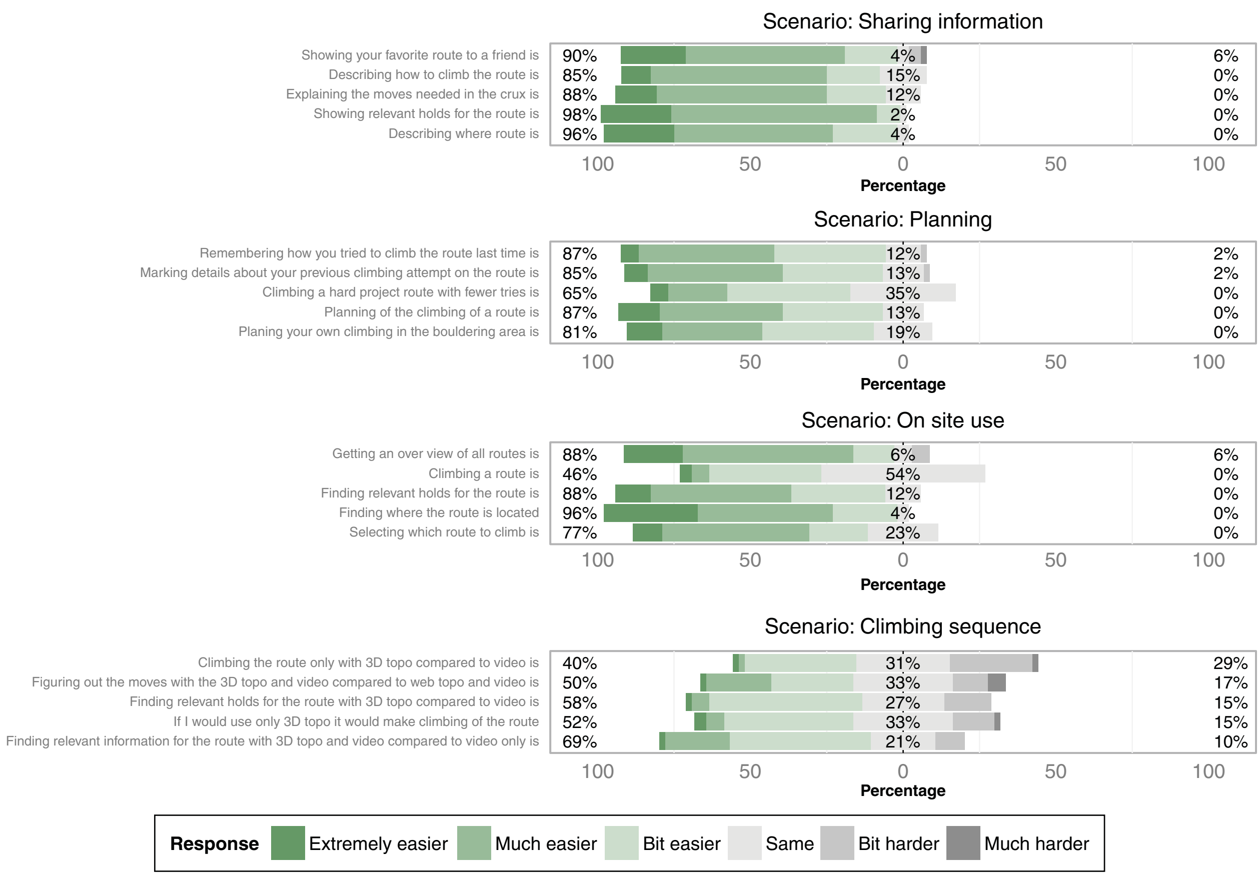

Figure 5. The distribution of responses for each questionnaire item grouped in the four scenarios: sharing, planning, on-site use and climbing sequence. In the four scenarios the 3D topo was compared to the web topo or one video. The shift of the bars to the left and the colour contrast (green) indicate better usefulness of the 3D topo. The percentages indicate the relative amount of responses: better (left), neutral (middle), worse (right).

averaged for each respondent. This gave a score for each scenario describing how one respondent sees the usefulness of the 3D topo. The scores of all respondents in share (mean = 5.83, median = 6.0, SD = 0.55), plan (mean = 5.34, median = 5.20, SD = 0.66), on-site use (mean = 5.48, median = 5.50 SD = 0.64) and climbing sequence (mean = 4.50, median = 4.60, SD = 0.72) are illustrated in Figure 6. The median and distribution are shown Figure 6 (left) and the means between different demographic groups are compared in Figure 6 (right). Before calculating the averages, the Cronbach's α was used to calculate internal validity within each scenario. The values of Cronbach's α were 0.69, 0.80, 0.77 and 0.77 for share, plan, on-site and climbing sequence, respectively.

For Figure 6 (right), we chose the demographic groups with largest differences and present the responses of climbers who can be considered beginners or advanced climbers, leaving out the intermediate climbers. The responses in the first three scenarios (share, plan and on-site) are relatively similar between the groups. In the climbing sequence scenario, a small difference between low and high technical climbing grade or number of climbing years can be seen. This suggests that in climbing sequence scenario climbers with less experience or lower technical grade, i.e. beginners, see the 3D topo slightly more useful than the advanced climbers. To find if the differences are significant, we did a Wilcoxon rank- sum test and compared independent groups. Wilcoxon rank -sum test was chosen because the data were skewed towards the upper values. The difference between groups was largest in the sequence scenario, which is reported here. Wilcoxon rank-sum tests indicated no significant difference in average score (1) between the groups with low and high technical grade, $W(n_1 = 5, \ n_2 = 17) = 75$, $p = 0.099$, (2) between groups climbing less than 5 years or more than 10 years, $W \ (n_1 = 19, n_2 = 13) = 158$, $p = 0.188$, and (3) between groups that had or had not visited Koivusaari, $W \ (n_1 = 39, n_2 = 13) = 188$, $p = 0.167$.

Use of the 3D topo (RQ2)

Next, the use, advantages and disadvantages of the 3D topo analysed from the open-ended responses are summarized within related themes. Quotes are accompanied with the maximum technical climbing grade that the respondent reported. Some respondents answered questions in Finnish and these quotes were translated by the authors to English. We found no overall pattern that would relate, for example, to maximum climbing grade, age or gender.

Overall, the 3D topo got a really positive response, and even amazement, from most of the respondents:

> Have to say that: mind blown. Compared to normal topo you can see very easily where the routes are in relation to each other. (8a)

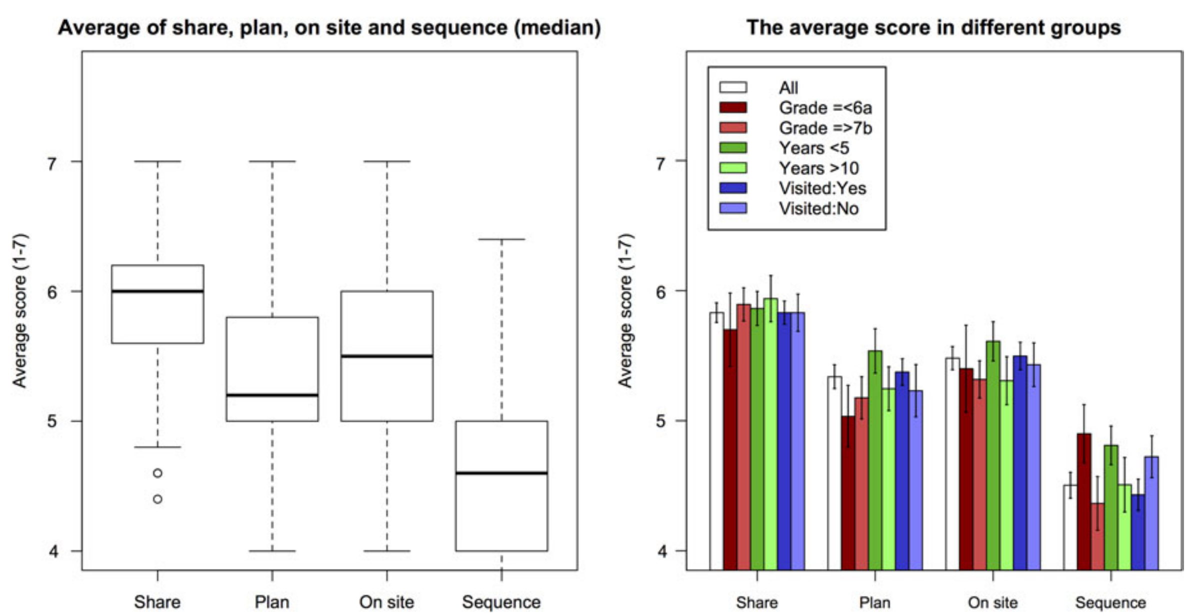

Figure 6. The box plot (left) illustrates the median and distribution of averaged scores in each scenario, where numbers ranging from 1 to 7 (higher the better) represent the scale from "Extremely hard" to "Extremely easy". The bar plot (right) illustrates the differences in means between (1) climbers with grade of 6a or lower (i.e. beginner) and climbers with grade of 7b or higher (i.e. advanced climbers), (2) climbers climbing less than 5 years or more than 10 years regularly and (3) those who had or had not visited the Koivusaari boulder. Error bars represent standard errors in the bar plot. Only the range from 4 (neutral) to 7 (extremely easy) is shown in the plots.

> Nothing really comes to my mind to improve it, I find this a great idea and work. (7b)

However, there was also some negative feedback:

> I'm not 100% sure this is right development, people should use their brains, that's one of the most interesting part of climbing. (7c)

Advantages. One of the biggest advantages of 3D topos is its ability to convey information about the profile or shape of a rock, which was explicitly mentioned by 10 respondents.

> [The best thing] ... is that you can see the route from underneath, top and side, thus you can see the SHAPE of the rock, aka. the most essential info. (6b)

> 3D topography is realized in very good way. You can recognize quite well the important shapes and blocks. In pictures, the rock always looks like obscure cheese .... (7b)

> Gives an instant overview on the angles and shapes of the route that is impossible with a paper topo. (7a)

Also the exploration and recognition of boulders and routes in a new area was seen important:

> You can see 360 degrees around the block, so it is easier to locate routes and identify blocs when unsure. The features and angles in rock are more obvious and can be seen from different angles. (7a)

> I like also that you can rotate it and therefore it makes it easier to find the route. (6b)

> I would imagine this would be absolutely priceless tool in a big bouldering areas, such as Magic Wood or Castle Hill, where there are tons and tons of routes and only the exploration takes half–3/4 of the day. (7a)

> This would be really useful for hard to reach places. (7a)

The climbers who had not visited the Koivusaari boulder explicitly also mentioned:

> It's great to actually see what the boulder is really like, as I haven't visited Koivusaari bloc at all. It gives a good idea of the size and what kind of routes it has in comparison to the grade level. (6b)

The mobile and on-site use was also considered useful:

> Using this software on a tablet or a phone is definitely the most useful feature. I don't usually browse topos that much beforehand, they are most useful when at the climbing location. (7a)

> Hopefully [I can use 3D topos] in the future with my cell phone nearby the crags. (7a)

Also the ability to view especially the upper part of a route was seen to help in flash attempts or safety:

> You can see really well the top holds. It's a big help for flash attempts that you can see the upper holds from varied angles. (7b)

> Checking the top-out is a very good feature, so you won't get big surprises at the top. (6b)

Controversies. The most negative comments were received about the 3D topo ruining the on-sight climbing and 17 respondents mentioned on-sight in some way. This divides the opinions of the respondents, because some want all the information they can find about a route and others none.

> On-sight is the most beautiful and rewarding way of climbing. Too much information ruins all on-sights, if we have only 3D topos in the future. (7c)

> Easier to plan the moves. Easier to on-sight (would it even count as an on-sight anymore? I think not. We'd need a new category). (7a)

> ... but as long as the beta feature is disabled by default and can be enabled if the user wishes to do so, I guess it's not that big of a deal. (7a)

Also the beta feature received controversial comments:

> In my opinion, the features in the beta functionality are already implemented really impressively. (7b)

> Less information, I don't want to have beta in topos! (7c)

Related to on-sight and beta, the use of animation or video received 18 comments. There were few respondents who disliked the animation and the human figure, but the animation was also seen as useful. The 3D topo combined with video was seen as the best option.

> The shape animation is extremely interesting compared to a video. I still think that the video beta has about the minimum information of the sequence of a hard project. It's crucial to know the exact body position, how to move between the positions and how to hold the hold etc. Shapes are lot better than written text but lot less than real video. (7a)

> [I would like to have]... animated beta not necessarily with a character, but basically a keyframed path that annotates holds "crimp - crimp - mantel to left", basically describing each move. (6b)

Ability to rewind/forward the moves. (8a)

There were 43 comments that can be interpreted as negative. Here they are listed in groups in order of frequency (in brackets):

(1) ruins on-sight (seven answers),
(2) hard to create: "How has patience to create them?" (six answers),
(3) human figure, e.g. "not useful," "video better," "scale wrong" (six answers),
(4) stand-alone app, e.g. "installation and downloads," "not WebGL" (five answers),
(5) poor resolution for individual holds (three answers),
(6) beta (three answers),
(7) missing the landing (two answers),
(8) technology, e.g. "Another gadget. Just go out there, have fun and climb!:)" (two answers),
(9) other, e.g. "menus," "mouse behavior," "needs electricity," "mobile use," "Colors only red, monochromatism" (nine answers).

Design. We asked the respondents how they would use the 3D topo and what features they would include or change. Nine respondents specifically asked for a more detailed texture or ability to see detailed photographs of the holds.

To get close-up photos of the holds, the 3 D model is not exactly clear with the holds. The accuracy is the same as the chalk marks on the rock in situ. (7a)

Adding a scale, ability to measure distances and steepness or using an own size human figure was asked by nine respondents. Surprisingly, eight respondents specifically noted that they would like to use the 3D topo for approaches and finding the boulders if they would be on some kind of a map.

If you could illustrate the whole bouldering area, e.g., in the top corner, it would make the navigation between boulders easier. (7b)

Add the boulders on a map. Finding the bloody rocks can be hard. (7a)

Nine respondents requested more description about landing or even tips for a crash-pad placement. Information about the orientation of the rock was mentioned by three respondents. Also marking of all relevant holds and more detailed info for specific moves, such as dynamic jumps (dynos), were requested as part of the beta by several respondents. Other requests included "Additional betas," "Free movement of the camera" and "grade opinions." The information sharing was mentioned, including, e.g., ratings, own markings and beta, first accents, (successful) climbing attempts on routes and direct links to discussion.

I would like to be able to share this information (online ...) with the climbing-mates. (7b)

It should be kept in mind that most of the individual markings should be private, but include an ability to share them, so that:

"...people won't screw up all models with full of markings and trolls" (6b).

Longer routes. Respondents were asked about advantages and disadvantages they would see for longer routes climbed with a rope.

Good look at the crux. (7a)

Show where to rest and how. (5c)

Possibly better fall hazard estimation, also easier judging of the level of overhang actually present and finally, it would give a chance to think about climbing strategy before heading off to a route. (7b)

Being able to see the route closer, being able to prepare the equipment required (how many quick draws, nuts, etc. anchor point type, etc.). (5c)

Location of the bolts could be added or traditional gear placement as beta. Clipping holds could be marked. More easy to see where the route actually goes! On along routes add GPS positioning to help on the route reading. And put the approaches to routes to help finding there. (7a)

Again the respondents' opinions varied about the usefulness of the 3D topo in longer routes. However, the negative comments mostly concentrated to ruining the on-sight as mentioned earlier.

It would make more sense [for longer routes] than for boulders. (7c)

Nobody would need this for sport or traditional climbing. (7b)

Discussion

The results above describe how the respondents view the usefulness of the 3D topo compared to the web topo or the video. Furthermore, the results show how the 3D topo is perceived especially by Finnish climbers and how they would use and improve it. Both Figures 5 and 6 show that respondents believe the 3D topo would be highly useful in sharing, planning and climbing in general. This is also backed up by the respondents' open-ended answers. The 3D topo was seen highly useful compared to the web topo especially in the three scenarios: sharing, planning and on-site use. In these scenarios, only a handful of respondents thought that the web topo was actually more useful. There was more variability of the opinions in the climbing sequence scenario, in which the 3D topo was compared to the video. Nevertheless, the 3D topo was considered on average more useful than the video also in the sequence scenario.

The quality of the 3D model in this study was sufficient for creating a meaningful questionnaire. Due to time limits and keeping the download file small, we had to make compromises, such as texture quality, numbers of texture layers and modelling the surroundings. Surroundings and ground could be added, e.g., as flat textures or panoramic photographs around the boulder. They would make the 3D topo more informative, but also convey important aspects such as aesthetic characteristics of the location.

Furthermore, we purposefully simplified the user interface and controls for orbiting around the rock and for adjusting the viewpoint. We are confident that with a bit more effort the quality of textures and the 3D model can be much better. In the 3D topo, the created texture was not optimal due to the set of used photographs, and software problems prevented us to use the best texturing tools. The texture quality can be much better by choosing different software, such as CMP SfM, or right parameters and tool for texture creation in Meshlab. However, with large 3D models the texture size causes long download times, thus downloading more detailed textures when zooming should be enabled in larger 3D topos. In addition, the 3D topo could be implemented, for example, with the WebGL technology that works with modern browsers.

As the results indicate, 3D topos are seen as useful in sharing information and marking detailed beta for the routes. However, care should be taken not to force all features to users as many respondents were concerned about the 3D topo ruining the on-sight climbing with too much information. Also in web topos, such as 27 Crags, the beta information is hidden by default and betas and videos are enabled for the ones who want to view them. The beta feature should be implemented similarly also in 3D topos and even the camera movement could be restricted to eye level in the beginning.

According to the responses, the use of 3D topo and betas in climbing is part of the bigger debate about if and how technology should be used in climbing. Technologies, such as 3D topos, are not preferred by all climbers and definitely not always useful. Topo books or paper topos are robust and do not require electricity. They are preferred by many and are really practical as long as you remember to take them with you. On the other hand, some climbers embrace the technology. They will mark their achievement to an online logbook immediately after topping a route, which is automatically shared to social media. This study has given the first insights about the use of 3D topos for climbing. Next, we discuss some scenarios, where this technology can be used and what should be investigated in the future.

Future work

This study showed that climbers believe that 3D topos are useful and would use them. However, the actual usefulness should be verified with experiments. One interesting topic is the impact of 3D topos on memory recall of route features, and recall of the motor process and climbing sequences. Example cases could be hard project routes, which can be climbed only on limited times in a year. While on-site, a climber can spend long time and put a lot of effort for remembering the climbing sequences that were successful last time.

In general, 3D topos of any route or boulder that can be photographed from various directions can be generated. Occluding object (such as trees) can cause problems. However, the pictures can also be taken from close proximity, but it is more laborious and requires more planning. In higher routes, such as big wall, photographing the whole route from the ground would not be feasible. In higher routes, the photographs could be taken with radio-controlled quad copters or planes (IEEE Spectrum, 2013). Also images extracted from video of a helmet camera used while climbing could produce useful 3D topos (Kopf, Cohen, & Szeliski, 2014). 3D topos generated in such way might not need to have accuracy down to hold level, but enough for planning and sharing information.

After the creation of 3D topos, their use can be extended from the web-based use. Adding measurement tools to a 3D topo would allow distance measurements of the holds and setting up routes (or crux moves) to climbing gyms that try to match their real-world counterparts. Additionally, the 3D profile of the rock can be used to find a best matching climbing gym wall profile. Finally, if the 3D topo is accurate enough it could be even possible to 3D print the holds to match the artificial wall as closely as possible to the real route. Also one respondent mentioned 3D printing: “3d-printing famous boulders! Maybe even actual size in few years;).”

Side products of the creation process of the 3D topo include feature descriptors that can be used in camera-based tracking with machine vision (Wagner, Reitmayr, Mulloni, Drummond, & Schmalstieg, 2010). This enables augmented reality applications (Daiber, Kosmalla, & Krüger, 2013) in which a live camera view of a smartphone (or smart glasses) can be augmented with route information in real time. This makes exploring the climbing area really intuitive as the rocks and routes in front of you can be automatically detected and augmented on the screen of your device.

Furthermore, virtual reality headset, such as Oculus Rift, could be used to bring more realism to the 3D topos. We tested our 3D topo with Oculus Rift, which allowed us to virtually move around the boulder and observe the rock naturally by turning the head or with keyboard and mouse. In our experience, the stereo view produced with the Oculus Rift further facilitates the recognition of rock shape and angles. It could be investigated how a virtual headset can be used, for example, while preparing to climb hard to reach routes.

An automatic pipeline for 3D topo creation could be implemented to facilitate wider use of 3D topos. Even now there are cloud services which create 3D models from uploaded photographs ("Autodesk 123Catch," 2013; "CMP SfM," 2012). Such a service for creating high-quality 3D topos would require taking account the special needs of modelling climbing routes and rocks. Taking the photographs in a right way is very important for the SfM to produce a usable 3D model. Therefore, climbers participating the creation of 3D topos should be informed about how to take a good set of photographs for SfM. In the near future, hand-held devices, such as Google's project Tango ("Project Tango," 2014), can be used to scan surrounding environments and adding more options for the 3D topo creation.

Conclusion

In this paper, we introduced a novel 3D topo prototype, which enables interactive exploration of a real boulder used for rock climbing. We crafted an online questionnaire for understanding the usefulness of the 3D topo in sharing, planning and climbing in general. Results show that the 3D topo is considered superior to the normal web topo of the same boulder that is currently used. The 3D model of the boulder was created from a sequence of photographs. With some more work, the creation process of 3D topos could be simplified so that all climbers could make them. Moreover, the use and research on 3D topos is not restricted only to use in the Internet, but their benefits might be extended with 3D printing of holds and augmented reality applications used in the real world.

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