Informing Futures of Computer Vision and Augmented Reality Centred Tools for Hillwalking and Mountaineering

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This paper responds to the increasing prevalence of Augmented Reality (AR) and Computer Vision (CV) tools broadly, considering hillwalking and mountaineering as a context. Possible futures where these technologies become prevalent in this context are speculated upon using materials developed in a participatory-design methodology, with the aim of describing favourable futures through developing heuristics and refined design concepts. A survey, iterative development process and user workshop resulted in sixteen heuristics, as well as six distinct proposed tools and a singular portfolio describing generalisations between the designs. Together, these reflected principles for, and embodied, proposed favourable futures for these technologies within hillwalking and mountaineering from a Human-Computer Interaction (HCI) perspective.

CCS CONCEPTS • **Human-centred computing** → Human-Computer interaction (HCI) → Interaction paradigms → Mixed / augmented reality • **Human-centred computing** → Interaction design → Interaction design process and methods → Participatory design

Additional Keywords and Phrases: Computer Vision, Hiking, Hillwalking, Mountaineering, Research Through Design, Speculative Design

1 INTRODUCTION

1.1 Topic and Context

AR and CV are intrinsically linked. AR refers to real-time integration of digital information into users' environments [34], whereas CV is an artificial intelligence (AI) field that uses machine learning to derive meaningful information from visual inputs [59]. Conceptually, these are linked by *markerless* AR [2]; in contrast with *markers* (recognised patterns), markerless AR utilises CV techniques like edge-detection [63] and object detection [22] to determine and position digital elements. Although research began as early as 1957 [24], ubiquitous adoption of these technologies has materialised in the past decade through modern smartphone applications, like Google lens [64].

Mountaineering broadly describes ascending mountains, but is often associated with alpine pursuits involving use of technical gear like ropes. Hillwalking, then, specifies less technical endeavours, with the scope of UK upland including veritable examples of both these activities [65]. This upland context[1] offers unique considerations compared to flat environments: there is often a focus on achievement [66]; technology is more interwoven [67]; skills must be learnt [68]; and communication is of more importance, including with emergency services [69]. These differences cannot be obscured when designing tools.

[1] Henceforth referred to via shorthand simply as "Walking" and "Walkers", encompassing hillwalking and mountaineering, not walking as an action or non-mountain contexts.

The natural link between AR/CV and walking is in acquiring useful information. AR allows for dynamic information acquisition, where traditionally this involves deliberate attention towards a process like map-reading. This could support immersion in nature and focus on walking. Abstraction is reduced by depicting data in the real-world through an overlay, allowing for digestible information that is harder to misinterpret, supporting correct decisions. CV inherently provides useful information, since in a mountain-environment many decisions are reliant on articles with visual cues like features and terrain.

1.2 Motivation

HCI researchers [6] and mountaineers [12] alike have warned of proliferation of digital technology in outdoor activities, citing concerns about obtrusive designs obscuring the value of human-nature interactions and overreliance on non-traditional tools respectively.

Nonetheless, mobile applications supporting tracking and navigation have become pervasive. With many near-identical tools, it is necessary to explore how underrepresented technologies like CV and AR could broaden the scope of interaction, preceding solutions that positively impact stakeholders and address these concerns - ensuring "favourable futures".

Current tools may have impacted recent rising accidents [53], particularly in the now most-rescued 18-24 age group, who have the highest smartphone usage [61]. Experts accuse social media, wherein photogenic "honeypot" locations attract underprepared walkers, and overreliance on navigation applications over traditional methods [53]. This motivated investigation into participants perceptions of social features and reliance on tech, toward a future with reduced accidents while accepting contemporary ubiquity of digital tools.

Additionally, researchers have suggested technology contributes to a disconnect between humans and nature [13], prompting substantiation of this through research, and tools to instead support nature experiences, if true.

AR and CV are well-researched, though with studies predominantly in safety-critical areas like healthcare [17] and autonomous vehicles [26], leaving exploration within walking comparatively slim. This study seeks a basis for technical exploration of this intersection, ensuring guiding principles and proposed tools are available to refer to.

Recently, CV and AR have seen significant advancements. Fusion of large language models (LLM) with image modality allows for tools determining unprecedented contextual information from images, outperforming traditional CV on non-real-time object detection and description [48]. Furthermore, the 2024 Apple Vision Pro [60] represents a significant foray into AR by a "Big Five" [28] tech company. Thus, it is a pertinent time for this study, preceding a potential increase in the body-of-work of AR and CV tools, to be used as reference for works focused on walking, and itself being able to speculate in light of recent developments and their effect on possible futures.

Recent developments that already overlap CV/AR and walking are largely in robotics, namely where CV robots [70] are increasingly able to traverse less structured environments, revealing a need to consider how these can be appropriately used in this context.

Altogether, ideological concerns of technology in nature and recent technical developments in CV and AR motivated this study, to reveal how responsible and effective progress can be ensured in coupling of these domains, where unprecedented progress may be forthcoming.

1.3 Research Questions

From topic, context, and motivating factors these research questions were devised, referencing "favourable futures" from the cone of possibilities in speculative design [16]:

1. What are favourable futures of CV and AR solutions for hillwalking and mountaineering?
2. What heuristics can be deduced via user research and design to guide subsequent work in realising these futures?

3. What might specific tools that embody these favourable futures look like?

1.4 Research Contribution

Research contributions of this study are threefold.

1. The theoretical contribution of “heuristics” (borrowing the interface design term to mean a rule-of-thumb with evaluative power [38]) for subsequent researchers, designers and developers working with AR and CV for walking. These highlight consolidated inferences from analysis of user research and the design process itself formatted as principles for designing or evaluating favourable future tools.
2. An artefact contribution in the form of Gaver and Bowers’ annotated portfolio [20], which presents a user-refined collection of designs annotated with generalisations between the works as elicited from the design process, highlighting “fruitful locations and configurations to develop”. This contribution is grounded in the value of design itself as research [19], while maintaining rigour.
3. Individual compositions for each tool as artefacts, intended as embodiments of favourable futures. These include all developed materials, and text denoting their specific considerations, informing future areas to expand upon.

2 BACKGROUND AND RELATED WORK

Given the aim of investigating futures, further background research was required to identify the *current* state of AR and CV within walking, to inform direction of user research, and identify what to address or maintain in these futures. This included regarding contemporary literature, and state-of-the-art systems.

Broadly, tools for walking were found to either *support* conducting activities or *enhance* activities with non-essential features for recreation, support being further stratified into navigation, safety, and accessibility. (appendix A.3). Additionally, a timeline was established, splitting the hillwalking/mountaineering process into preparation, activity, and reflection, inspired by similar divisions like “plan, hike, achievements” [27]. These structures were useful, informing questions for user research, and guiding proposed tools to reflect the breadth of possible futures.

Within walking, CV and AR research and solutions are limited, and examples of each intersection of timeline and structure are often sparse, representing areas of particular value for research. For example, CV nor AR were typically used for support *or* enhancement during reflection, prompting tools exploring this.

Ultimately, it was surmised that CV is underrepresented in outdoor, unstructured environments like the British uplands, and AR is typically not used in safety-critical settings by the public, encouraging a study design that uses speculative design to question these conventions.

This limited background scope marks an underexplored space within HCI. Those works within this space lack various elements; they focus on the present not speculative futures, or if not lack research-based approach like *ARHike* [43]. Additionally, there are not specific “descriptive and predictive” [55] theoretical principles for future works.

Additionally, incorporating elements of research-through-design [19] meant background works were often regarded not for their theoretical findings, but as “a variety of concrete examples” of artefacts [20].

2.1 Literature

Beginning with *safety*, broader literature of digital tech for walking largely focusses either on search-and-rescue or bolstering preparation through improved data. These fit two strata in the timeline, excluding *reflective* safety. An example of the former within CV research is guiding UAVs for search-and-rescue using Yolov5 software to identify casualties [8]. This here inspired consideration of the relationship between robotics and walking emergencies.

AR in literature can present safety-implicated data in improved formats, such as snow visibility simulation [47], prompting consideration of AR to visualise conditions broadly, aiding preparation for safety. Furthermore, artefacts in these two studies provided design inspiration.

Literature on wilderness *navigation* often focuses on pathfinding, and CV is widely utilised for allowing robots to navigate these environments [23]. This illuminates possibilities of CV pathfinding aiding human users, and reinforces robotics as a means of exploring the *support* category of tools. AR for outdoor navigation predates google maps, where initial researchers sought to utilise newfound ubiquity of cameras in smartphones [36]. Still, smartphones within walking are contentious, one recent paper instead proposing a separate device of a "smart" walking stick that projects directions. From this, it was deemed worth considering how current kit can integrate AR for unobtrusiveness. LLM's reading maps [56] concerns instead *preparation* of navigation, though influence was minimal as this research seeks to preserve human autonomy.

Accessibility of walking is difficult to address due to the implication of physicality and sightedness. Concerning the latter is *Climb-o-vision* [44], which uses CV to register climbing holds, communicating these as electro-tactile pulses on the user's tongue so visually impaired users can understand where holds are. Still, terrain is a more prevalent issue in walking than climbing holds for disabled individuals, hence consideration of how CV could similarly address this by identifying unevenness and slope etc.

Using AR to *enhance* walking is well-studied in comparison with support. Researchers are often concerned with increasing tourism, such as in two studies which display 3D models at points of interest, providing an interactive recreational experience [27, 49]. Whether increased tourism is favourable or not is unclear, as there are negative consequences like footpath erosion [71] and litter [58]. Thus, here tools encouraging novelty at the *activity* stage were not prioritised, to preserve walking for those concerned with the activity itself. *ARTopos* [54] enhances the *preparation* stage, revealing possibilities of collaborative and educational features to this end. Enhancement via CV research was less considered, despite popular state-of-the-art uses, perhaps reflecting this being more difficult to frame as research without links to broader topics like tourism as in AR. Indeed, this work presents the link between CV and curating walking photography for enhancement, investigating this through a proposed future tool.

Overall, it was surmised literature on CV and AR tools largely involves ingenious technical propositions, rather than theoretical considerations about the nature of these within walking. Extant artefacts provided useful inspiration, while this lack of theoretical contributions makes clear a need for guidance in futures of such technologies.

2.2 State-of-the-Art Systems

Systems utilising CV and AR are seldom in a walking context. Conversely, solutions for support and enhancement exist but rarely utilise CV and AR. Regardless, pervasive solutions for walking function as "Swiss army knives" [62] which provide safety, navigation, accessibility and enhancement features using industry standard methods. For example, *Strava* [50], *OSMaps* [41], and *Alltrails* [5] utilise GPS and topographic maps for navigation, communication features for safety, enhancement through recording and sharing, and accessibility by curating routes to lower barrier-to-entry. These applications don't rely on experimental functionalities like CV and AR, revealing a need to consider how speculating on these technologies could progress the standard of today toward favourable futures. For example, walking experience-sharing features are revealed in this paper to synthesise well with CV and AR.

Some less adopted tools do utilise CV and AR; take the *PeakLens* app [42], which combines GPS with CV to augment views from a smartphone camera with identification of peaks. Users criticise its reliability, but the concept of identification for enhancement, where CV reliability will likely progress in the future, was deemed useful to evaluate.

Altogether, the state-of-the-art for walking is largely unimpacted by CV and AR but insights can be drawn nonetheless, guiding enhancement of proven features from pervasive applications with these technologies to address pain-points as investigated through user research.

2.3 Background Insights, Implications and Impact

Combined, contemporary literature and systems revealed the aforementioned structure, referenced in the subsequent questionnaire to assess respective importance of navigation and enhancement etc., and timeline - referenced to learn how respondents use technology differently across these stages.

This was equally important during development, wherein prototypes deployed were ensured to cover various intersections of these divisions, guaranteeing a holistic consideration of possible futures from users when utilising these as stimuli in the workshop, subsequently informing heuristics.

Structurally, concepts from this review also impacted the workshop, thus informed by both extant research and novel research.

From a research-through-design perspective artefacts in these works provided direct design inspiration for prototyped future tools here, for example *Smart Maps* being a variation of *ARTopos* which further explored collaborative and safety features.

Furthermore, pervasive areas were *purposely* avoided to ensure possible futures tools are challenging, e.g. each design having distinct characteristics rather than being a "Swiss army knife" like *OSMaps* etc.

Ultimately, reviewing the background highlighted the *current* picture of CV and AR for walking, in order to act on revealed concerns through speculative developments that instead reflect *futures.*

3 METHODOLOGY

Following the background review, a methodology was devised incorporating elements of research-through-design [57], speculative design [16], and participatory design [35]. This involved an initial survey, then using insights gained, alongside the background review, to depict tools that embody possible futures. These provided stimulus in a variation on a co-design workshop, to elicit data from informing heuristics and refining designs. Designs as stimuli are a one of two implementations of research-through-design in this study [72], the other described in chapters 3.2 and 4.2.

3.1 Survey

A questionnaire was envisioned to achieve mixed-methods [21] insights into walkers' experiences, particularly with technology, informing subsequent design. This was to be semi-structured, e.g. utilising Likert Scales [29] , and open-ended questions that incorporated elements of participatory design, prompting respondents to envision futures as though they were designers. This grounded the design process in HCI theory to ensure user-centred tools, rather than just conjuring prototypes from respondents' pain points [73]. A pilot [25] was employed to refine the questionnaire, increasing clarity and lowering drop-off rate, for maximum useful responses.

3.1.1 Pilot

Various forms software were compared for this questionnaire and *Formester* [1] was chosen based on its appealing UI, ability to embed JavaScript code (for illustration responses), and automated analysis of structured questions.

Questions were largely informed by the background review, for example asking for users' perception on obtrusiveness of tech in nature [6]

Structurally, the questionnaire had 5 stages:

1. Demographics and walking background, to query relationship with responses.

2. Respondent's experiences and important aspects of walking.
3. Experiences with digital technologies in this context.
4. Experiences with CV and AR broadly.
5. Participatory design of future tools.

This structure intended to follow the standard of ordering questions "easy, difficult, interesting" [15], presuming participatory elements as engaging to respondents. Good questionnaire practice [45] was followed throughout, like avoiding leading questions. Furthermore, the pilot had an additional section where respondents noted unclear or difficult questions and other feedback to refine the questionnaire.

Convenience sampling was utilised to recruit for the pilot, wherein two participants who were already familiar with the proposed study were recruited over text. This allowed benefits like rapid turnaround for feedback, and using a small sample meant leaving a larger remaining pool of participants, without burdening them with completing two near-identical questionnaires.

The pilot was particularly valuable in gauging users interests and attention, and reformatting misunderstood questions. Often respondents typed nonsense or "don't know" to the last participatory questions, and didn't utilise JavaScript "sketchpads" here. Amongst changes throughout, like reducing technical language for comprehension, this prompted restructuring this section for brevity, maintaining interest, and assisting user in envisioning future designs without leading them. For example, replacing fully open-ended questions with gap filling ones.

3.1.2 Questionnaire

A superior sampling method was selected for the questionnaire proper, to reduce bias and aid generalisability. To ensure validity of participatory design, artefacts must result from consultation with intended users [10], by selecting a suitable target population – UK walkers.

This multi-stage sampling did initially use convenience sampling to identify easily digitally reachable groups within the population, like Facebook group "I am bagging the Munros" [74], ensuring success of disseminating the questionnaire through social media. Volunteer sampling was then employed, which ensured willing participants to minimise drop-off, and guaranteed sufficient responses for validity, given data requisite for methods like stratified sampling was not necessarily available. A non-probabilistic method was suitable here since representation within walkers was less important than acquiring sufficient data for valid insights.

The questionnaire proper used the pilot's structure, but with refined questions and significant information to ensure informed consent, like how data will be used and stored. The questionnaire was open for fifteen days, garnering twenty-one responses, enough to derive valuable insights.

All data was stored in an excel spreadsheet. Closed questions were analysed by the software itself; for example, automatically averaging respondents' rankings as exemplified under *Questionnaire findings,* reducing need for bespoke statistical analysis. Analysis of open-ended questions required thematic analysis largely using an inductive framework [9], chosen as a standard methodology for finding meaning from qualitative data, as this meaning was to inform inferences for initial design of prototypes. *Nvivo* [31] was used to assign 465 codes *in vivo* [32] representing specific meanings (appended with context of the question) to quotes from each open-ended response, utilising both semantic and latent coding [9]. These codes were then considered and compared to identify patterns representing emergent themes. Additionally, "navigation, safety, accessibility and enhancement" were used as codes in a deductive method [14], to find quotes on experience with and implementation of this structure. The timeline instead was referenced explicitly in the questionnaire. Themes were reviewed to ensure coherence, distinction between them, and accurate representation of quotes [4], revealing a finalised set of fourteen themes. Additionally, certain questions were subject to content analysis, wherein each mention of an article in response to a "List (blank)" question was counted to quantify importance of that article across the respondent population.

Each theme, quantitative finding, and quantified article were also given an explanation and an implication. The explanation expands upon the theme's title, then the implication gives direct guidance on design of prototyped tools for this study, and informs the heuristics later specified alongside workshop results. These are exemplified in chapter 4.1.

3.2 Design

Designs' role in this study are both as stimuli within the workshop to encourage understanding and speculative discussion, ultimately informing heuristics as an outcome, and as standalone refined artefacts. The value of these artefacts is inherent to their design, as in a research-through-design methodology, while maintaining rigor through the annotated portfolio.

A variation of the double-diamond approach was here used [11]. Using a typical design framework permits a value of research-through-design: insights from this are inherently outcomes. The *discover* phase encompasses background and user research undertaken, whereas the *define* phase includes detailing implications from analysis of this work as explained above, and exactly how to instantiate implications as proposed tools and materials.

Two principles underpinning specification of designs were the support/enhancement and timeline structures elicited from the background review. Designs were to represent "plausible futures" in the cone of possibilities [16], given "possible futures" had already been narrowed through conducted research to those that fulfil user-centred principles. So, to speculate across the breadth of these plausible futures, designs were specified that covered each stratum in these structures, for example *Navglasses* (Fig. 4) fulfilling "safety" and "navigation" at the "activity" stage or *Hiking Gallery* (appendix A.1.1) covering "enhancement" at the "reflection" stage.

Ensuring a breadth of distinct tools by this standard was an initial constraint on designs, next being considering how these designs in their infancy conformed to survey implications or could draw from their participatory insights. Six distinct, user-centred designs were subsequently established.

Next the *develop* phase began, using sketching to initially visualise these designs. This was valuable as a reflective process, since progressing from an abstract idea to visual implementation of specifics meant many considerations had to be clarified. For example, initial conception of *RescueBot (Fig. 1)*, wherein considerations like camera placement or tailoring details for mountain terrain were easier to address through concrete visualisation. This exemplifies research-through-design, where insights revealed from design processes were locally valuable, but also generalisable to broader works. Notably, the sketching process also required further background investigation to assess comparable artefacts to each design and draw from these. For instance, borrowing from contemporary exoskeletons [75] to illustrate *Exotrail.*

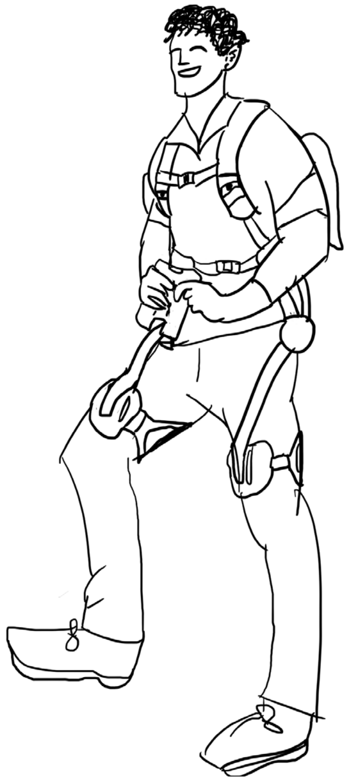

Figure 1: *Exotrail* initial sketch

Once rough layouts were achieved, a higher fidelity [46] depiction was required. This depiction continued the reflective process, as detailed in Table 6, and achieved a sufficiently high-fidelity deliverable to communicate the concept in the workshop with aiding materials, and stand alone as an artefact once refined.

These were developed using various tools and techniques. Initially, AI such as *Vizcom* [76] were sought to quickly generate high-fidelity 3D models from prompts, however, a limitation of these tools was discovered when communicating ideas which already had specifics drawn from user research or discovered during sketching. Since they could not understand particularities of concepts proposed, Photoshop [3] and Figma [18] were instead used as the primary software, as manual development allowed for preserving these important details. Photoshop was used to combine images and edit appearance to produce close approximations of sketched physical renders, whereas Figma was used to depict interfaces through text, icons, and preset smartphone assets.

Besides these depictions, communicating concepts effectively required supporting materials, particularly to envision *experience* of these tools, a necessity given the inability to produce functional prototypes for speculative futures. These resembled typical IXD methods like storytelling (a possible persona and scenario) and used text to explain the tool and annotate specific elements. This explanation sought to provide four clarifications: *what* the tool is, what the primary *use-case* is, what are comparable *current solutions*, and *how* the tool is used. This served to maximise clarity by addressing typical questions. Similarly, the annotations explained features, particularly where not clear simply from a visual depiction, to describe how the tool was specified to its context and purpose. Portraying depictions of use, scenarios and personas instead were images, with Photoshop used to edit AI generated [51] visual portrayals of bespoke scenarios (Fig. 4) to include the relevant tool. For example, generating "an old ex-mountaineer fondly looking at an iPad", and editing this to be her using *Hiking Gallery*.

Evaluation of these, i.e. the *deliver* phase of the double-diamond process, was conducted in the workshop.

3.3 Workshop

3.3.1 Details

Intention behind further research was firstly a variation on co-design where users contributed ideas on refinement of tools, and secondly speculation on plausible futures these designs represent to determine which may be favourable. As mentioned, this draws from the cone of possibilities and here stimuli act to "open up possibilities that can be discussed, debated, and used to collectively define a preferable future for a given group of people" – walkers. In this sense, they are "design fiction" [16].

A workshop was chosen for this as it could convene multiple respondents allowing communication, integrating participatory design is standard, and for convenient presentation of requisite visual designs and materials. Furthermore, using sticky notes and voting are typical inclusions allowing annotation for refinement and comparison respectively.

The workshop was devised as digital and asynchronous, allowing for participants in different locations to respond, given the sampling method, and asynchrony allowing respondents flexibility, especially given using software simultaneously with others can confuse respondents. Typically, in-person workshops would allow participants to physically interact with objects or digital prototypes, but this was not required here. Reasoning for not further developing prototypes to allow interaction was twofold: one, this time investment could only be counteracted by developing fewer designs, reducing the breadth of futures represented. Two, the speculative nature of designs meant approximating their function is difficult with current technologies. Indeed, supplementary materials provided mitigate this by clarifying how these interactions *would* work.

To create this workshop, Miro [33] was used, and the format built from scratch to fulfil intentions above.
The workshop began with onboarding, directing users how to use Miro to avoid confusion, limiting drop-offs. Each user was here assigned a colour, so they could be distinguished without identifying themselves, preserving anonymity.

Participants were firstly instructed to regard and "understand" materials before proceeding, ensuring users' responses were accurate and considered. Then, they were to use sticky notes to place initial thoughts near respective tools. This intended to elicit any glaring issues and avoid participants later tailoring responses to their initial impressions rather than fully considering questions.

The next question instructed users to compare designs through sorting them by categories like usefulness, usability and impact, and provide reasoning. Allowing comparison was a benefit of having multiple stimulus designs, garnering a relative, quantifiable, picture of their feasibility.

Subsequently, respondents chose from numerous scenarios like "winter mountaineering" or "a solo trip" to consider their impact on each tool. Here, designs were evaluated further than their typical use-case, a speculative approach [16]. Indeed, this revealed novel utilities for these in future, informing refinements.

Respondents next considered impacts and ethics through the "responsible research and innovation" cards by TASH [52], choosing four of sixteen cards from elements "Anticipate, Reflect, Engage, and Act" to discuss with regard to their chosen design, like "unintended consequences". This aided in speculating on favourable futures, since here impact of designs on stakeholders is as important as usage.

To this point, questions served to draw criticisms of designs, which were utilised in question six, "Co-refine", where participants decided what they would change, and why, for each. This was a significant element of the participatory design process, where users directly informed refinement as well as the designs originally, ensuring proposed tools were user-centred. Contrary to frequently in co-design, participants were informed they may illustrate but not instructed to, given lack of adoption of this in the questionnaire.

Lastly, users contributed their proposed principles for the future of AR and CV tools for walking, meaning the participatory element was not limited to designs, but also heuristics themselves - informed by responses throughout with extra weight given to this direct contribution. This was split into “futures to be avoided, pursued, and considered.”

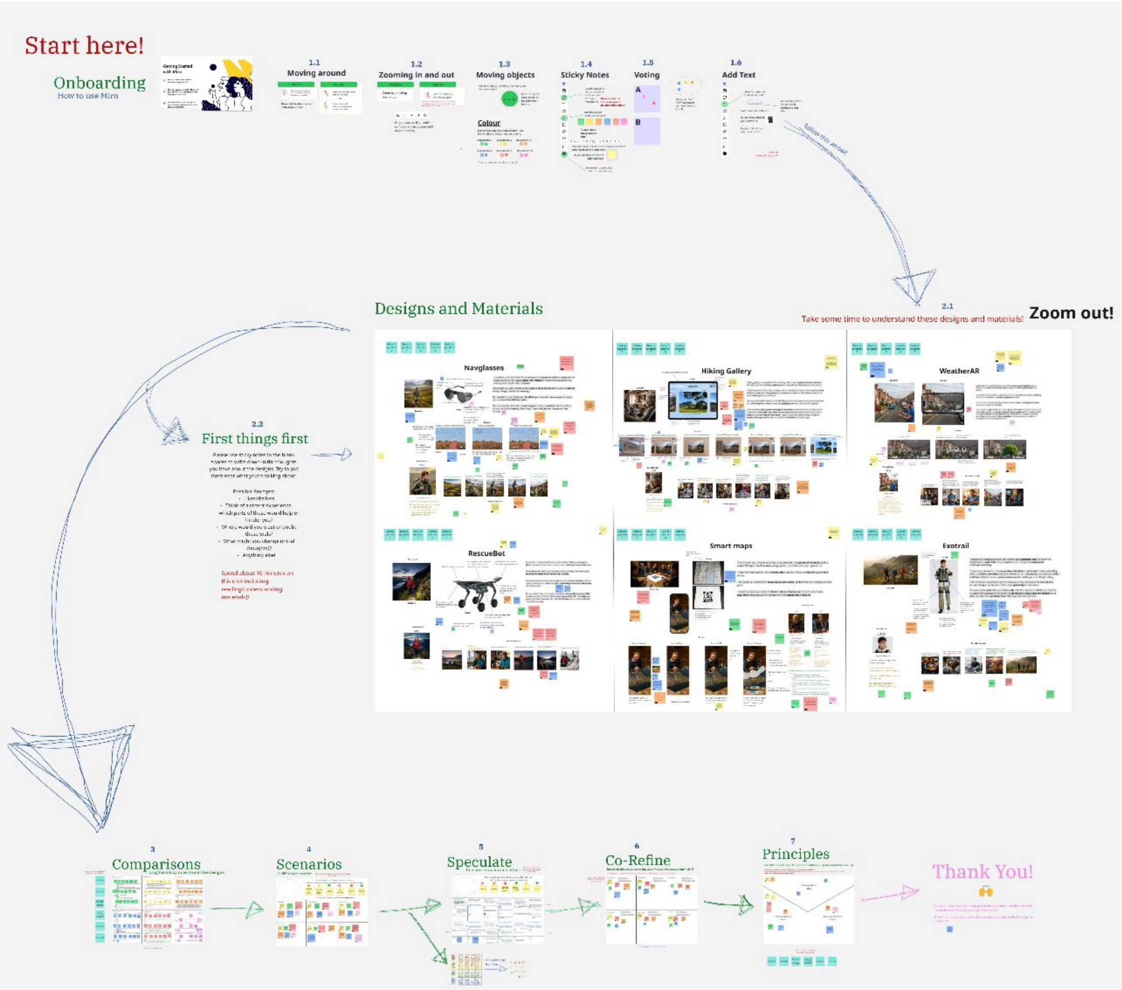

Figure 2: Completed workshop

3.3.2 Recruitment

Recruiting for the workshop was to be done using stratified sampling. To expedite this the target population was solely those who responded to the questionnaire confirming availability for further research. From these, participants would be grouped on demographic and self-reported ability data then randomly selected from each stratum. This would be a probabilistic method to ensure validity of insights since respondents would better represent walkers as a holistic population. However, respondents were contacted via email to confirm their availability prior, only 6 were available. This was the minimum number to achieve complete design insights given the workshop’s structure, meaning stratified sampling could not be utilised, and instead this represented volunteer sampling, a flaw of the study.

These six read a participant information sheet then signed a consent form confirming understanding of how their data would be used etc. At 00:00 On the 19th of August they were contacted via email with the link to the workshop, respondent number (informing colour), and researcher contact details. The workshop closed on the 21st with six complete responses.

3.3.3 Analysis

Analysing workshop data used affinity diagramming [30]. While typically used for completely unstructured data like ideation, value lies here in grouping sticky notes into broader ideas, which informed heuristics. This process was researcher-driven rather than a group activity since it would be difficult to make sense of data without HCI and contextual knowledge. Affinity diagramming commenced with reviewing sticky notes, copying meaningful ones into groups from emerging patterns. Groups were titled once they had a single member, then reflexively appended, ensuring possible members were not omitted due to unclear groupings. Additionally, relevant themes from the survey became predetermined groups to see where findings were corroborated.

Once clusters were established, as sticky notes had all been considered, they were ordered on priority. This was determined by quantity of sticky notes in a category, variation of note colour (indicating beliefs held by many respondents), and suitability to form prescriptive heuristics. Eventually, sixteen heuristics were derived from this process, with titles based on groupings and details from curated sticky notes within these. A secondary analysis was grouping sticky notes with participatory design insights by tool, to refine based on these. This refinement reflects iteration of *develop* and *deliver* phases of the double-diamond framework, where the final delivery was the outcomes detailed below.

4 FINDINGS AND EVALUATION

The findings of this study are reflected in the annotated portfolio, six individual design compositions, and heuristics. These result from this structure which transformed data to findings relevant to research questions:

Raw questionnaire data -> quotes -> codes -> themes -> explanation -> implication -> initial designs + materials -> raw workshop data -> clustered workshop data -> priority-ordered identified meaning + refinements for designs -> ***heuristics*** *(titles, explanation and details) +* ***refined designs*** *(including* ***annotated portfolio****).*

Above, arrows represent research processes that transformed and produced data like the workshop itself or affinity diagramming, demonstrating how these findings are justifiable through a rigorous methodology.

Preceding data above are findings in themselves and are also exemplified below with regard to informing contributions.

4.1 Questionnaire findings

Table 1: Themes from thematic analysis

Theme	Example codes
Activity as contributing to long-term project	Completing Munro-bagging book
Anticipating emergencies	Reducing risk of accidents would be useful
AR for live direction	Real-time nav guidance in future
Cater to group members over self when leading	Tone down severity for group
Exact location and when tech fails to provide this	GPS pings to faraway location
Favouring minimalism in kit and tech	Walking boils down to putting one foot in front of the other
Identification for recreation	Overlay photo captions would be helpful
Leading responsibilities as following rules rather than individual discretion	Leading with organisation = limits to consider
Preparation ensures mental wellbeing	Prep = feeling at ease when walking
Sharing experiences and their inspiration to others	Use of Strava, Read walk reports
Superhuman real-time knowledge	Recognising stability of handholds would be useful
Tech improving confidence	Reliability important in mountain environment,

Theme	Example codes
Tools to supplement not replace	Future digital tools as aid not take over, Maintain possibility of failing and risk.
Protection from the elements paramount	Make sure prepared for weather, recognising shelter would be useful

Additionally, content analysis took place as described under chapter 3.1.2:

Table 2: count of coded articles from question “Which equipment, tools and "kit" are most important to you, and why?” (truncated)

Code	Count
Physical map	16
Waterproof jacket	14
Boots	12
Waterproof trousers	11
Compass	11
…	…
Bug Protection	1

Table 3: Count of coded articles from question “Please list any mobile or smartwatch applications you have used in your activities:” (truncated)

Code	Count
OSMaps	14
Strava	13
Walkhighlands	5
…	…
Komoot	1

Omitted from the above table are many codes appearing only once, likely due to lack of broad consideration rather than actual lack of use, such as “Google photos”.

Lastly, statistical analysis of quantitative data also revealed useful findings. Firstly, there was intention to query comparisons between attributes like demographics and ability with results, but no useful correlations were found. More useful were automated analyses done by the forms software, like the below examples:

Table 4: “Please rank your priorities for a future AR/CV Solution” responses average positions (truncated).

Priority	Ranking
Aid with safety	1
Aid with navigation	2
Built into existing equipment	3
Useful for emergency teams	4
Unobtrusive design	5
…	…
Covert design	15

Table 5: “Please rank these aspects of hillwalking/mountaineering in order of their importance to you” responses average positions (truncated)

Priority	Ranking
Experiencing nature	1
Seeing new places	2
Health and fitness / exercise	3
Socialising with companions	4
Stress Relief	5
…	…
“Earning” pleasant food and/or drinks	15

All tables above result from processes described in chapter 3, representing user insights informing the design process, and heuristics reflexively. Surplus to these, raw data included quotes from respondents (omitted as they resemble the codes, given the in vivo [32] methodology). Explanations and inferences were expanded from each theme and quantitative finding.

An example of explanation and inference for a theme is “Superhuman real-time knowledge” which was explained as “Respondents often desire tech to provide them with knowledge that would be impossible for them to acquire in real-time without assistance, such as ‘vision through fog’ or ‘knowing incoming weather’”, to inform the inference “Use of contextual knowledge, sensors and CV combined to provide knowledge that vision alone cannot provide, and humans cannot establish without tech.” This informed design, for example including hydration sensing in *navglasses* (Fig. 4).

Data from Table 2 was explained as “The 5 most popular items include traditional navigation, protection from the elements, and boots for stability in mountain terrain”. The inference from this being “Consider design maintaining traditional navigation as a failsafe, ensure protection from the elements through planning and waterproofing, and consider terrain and stability”. Here this informed design like CV’s use in *Exotrail (Appendix 1.5)* to interpret terrain and ensure stability for accessibility.

The five top priorities from tables 4 and 5 did not require further explanation but were simply inferred as the most important principles for future designs. For example, “Built into existing equipment” was utilised in *Navglasses* and *Smart Maps* (Appendix 1.4) and was corroborated in the workshop.

4.2 Findings-through-design

Given usage of a research-through-design methodology, some findings were simply insights from the design process i.e. the double-diamond methodology.

Findings from double-diamond stages *discover*, *define* and *deliver* are reflected in the background review, questionnaire and workshop respectively; here will illustrate how the *develop* stage (initially and during refinement), revealed findings divorced from references or participants, unlike a traditional research process. Indeed, one might argue these represent gaps in specificity of research, and how these were addressed while maintaining rigour.

Table 6: Example research-through-design findings at the develop stage (Fig. 3 for tools)

Tool	Juncture	Meaning
Navglasses	Deciding appearance and form.	Justifying a physical appearance and form revealed the proposed principle of drawing aspects from bespoke kit for walking, as these aspects are already suited to the upland context. I.e. appearance and form of vintage alpine sunglasses [40].
Rescuebot	Deciding specifics of functionality.	Conversely, deciding specifics of functionality here involved borrowing a basis from broader solutions, then tailoring aspects to the context. I.e. modifying an existing robot [70] by adding a torch.
Exotrail	Contemplating issue of obscured cameras.	It became clear that sometimes the camera may be obscured no matter where it is attached on the tool (given it must keep the ground in view) e.g. by swinging arms or gait. The solution was to use multiple cameras, with the added benefit depth perception possibilities. This can be generalised to wearable CV systems for walking.

Naturally, the above findings, amongst others, are reflected in both artefact contributions.

4.3 Workshop findings

The principal findings of the workshop were titled clusters of sticky notes, revealing patterns to inform heuristics. Examples are detailed below:

Table 7: Selected affinity diagramming clusters and quotes

Cluster	Example Note	Heuristic(s) informed
Trust and reliability	"What happens if the navglasses get it wrong?"	Trust through reliability and optics, The danger of over-reliance and tempering overconfidence
Can/will everyone use these tools?	"... Helping young and old and providing access to the outdoors to as many people as possible"	CV and AR most helpful for experts and beginners, Anticipating and supporting emergencies
Manual (and customisation) > automation	"Unnecessary automation" (principle "to be avoided in future")	Reduce automation and increase customisation, Not replacing humans
Good to reduce effort	"being able to visualise would be so much easier"	Supplementation to reduce effort
Replacing experts	"might negatively affect paid guides if people choose the glasses over them"	Not replacing humans

Further to this, relevant themes from the survey were corroborated by a similar process. For instance, theme "Sharing experiences and their inspiration to others" with such sticky notes as "... having a way to transfer routes to people, friends, family or emergency services both recreationally and in emergencies". These too informed the heuristics.

Lastly, sticky notes indicating refinements were grouped with relevant tools. For instance, "Could the QR code be designed as an addition to a two-sided map. Maybe in the corner..." referred to *Smart Maps*. This was used to organise the refinement process, incorporating participatory design.

4.4 Annotated Portfolio

An annotated portfolio, detailed under "research contributions", is a typical artefact contribution when using a research-through-design methodology. In this study an additional theoretical delivery is provided by the heuristics, however value of the annotated portfolio remains as a presentation of designs and generalities, allowing it to act as a standalone portrayal that reflects the character of this paper holistically without necessitating further reading.

Here, the portfolio includes six refined designs, grounded in participatory methods and embodying a speculative "favourable future". It presents only the designs, screens, and their real-world depiction without supporting materials, as intent here is focusing on designs themselves as valuable.

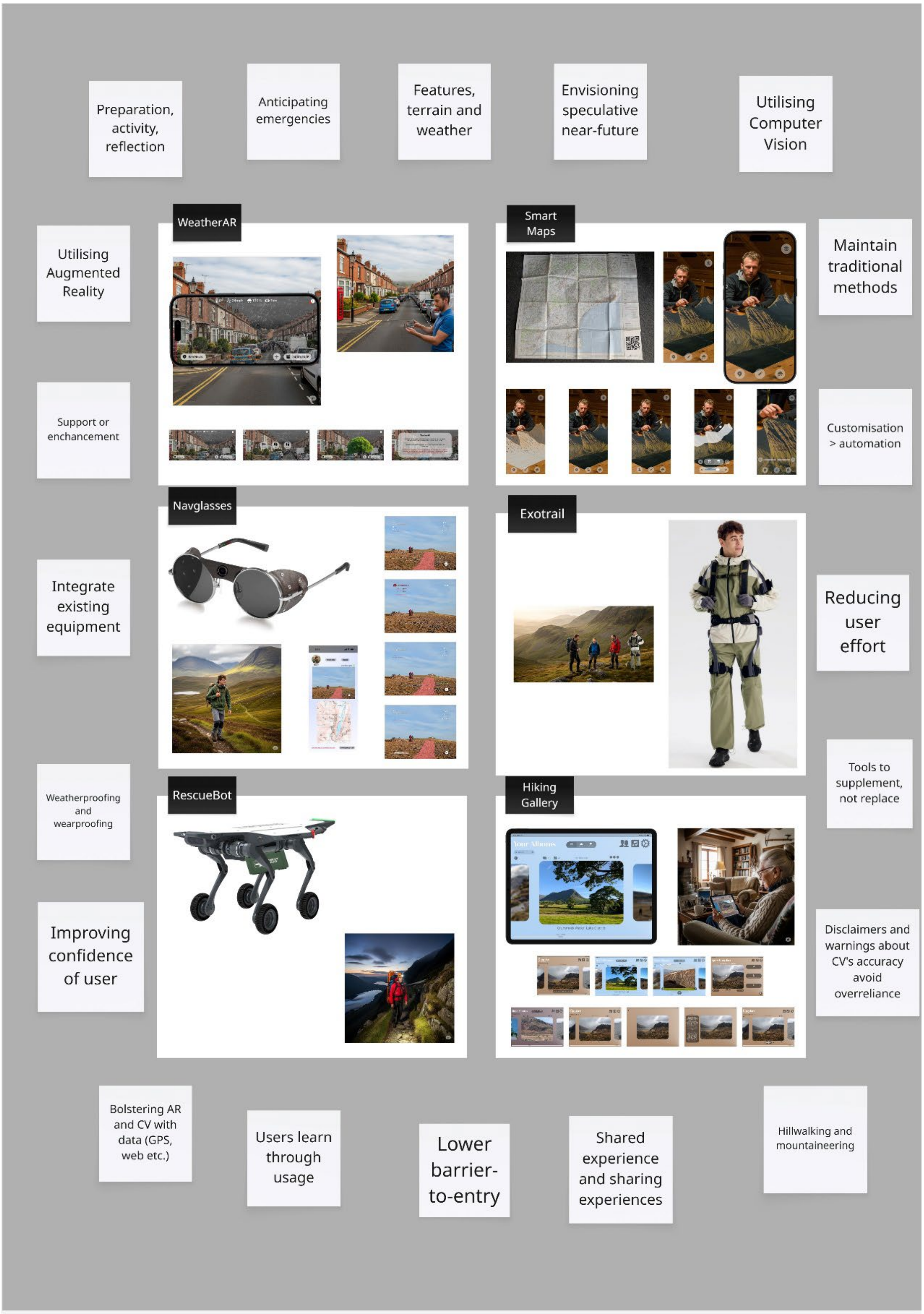

Figure 3: Annotated portfolio.

The above generalities between designs were drawn throughout research, from as early as identifying walking as a context and speculative CV and AR tools as a topic – "Utilising augmented reality", to the background review – "preparation, activity, reflection", to initial user research – "Tools to supplement, not replace", to those derived from heuristics – "Reduce automation and increase customisation".
In combination with visual presentation of the culmination and totality of design, a holistic view of the work is achieved.

Table 8: Clarifying proposed future tools

Tool	Description
WeatherAR	Smartphone AR weather visualiser for preparation and safety
Smart Maps	Marker-based AR map visualiser for preparation and navigation/safety/enhancement
Navglasses	AR/CV navigation/safety wearable during activity
Exotrail	CV informs exoskeleton for accessibility during activity
RescueBot	CV informs robotics navigation and casualty-detection during activity
Hiking Gallery	CV photo curation and annotation for enhancement during reflection

4.5 Compositions

As well as this, individual compositions were developed for each tool, representing them as a detailed standalone artefact, including supporting materials utilised in the workshop like hi-fidelity storyboards, and areas and inferences from the design process particular to that prototype (not generalities) of possible interest for future work. Furthermore, these compositions serve as concrete examples of tools for favourable future design.

Figure 4: *Navglasses* composition.

With regard to conciseness of the paper, particularities of this composition will here be described where others can be found in appendix A.1. These particularities reflect the general methodology for producing these compositions.

Firstly, note this is a refined version of the original design utilised in the workshop; an evaluation process in itself. For instance, tracking was not in the original design, but three sticky notes clustered around *navglasses* from different respondents stated this was a necessary "safety feature". Heuristics were also used to evaluate and refine tools, like "Trust through reliability and optics" being reflected in warnings not to rely solely on the device. Naturally, implicated screens, and changes to the storyboard and portrayal were also a result of this refinement, such as a new screen being depicted as a mobile app for tracking the glasses.

Besides this refinement, initial conception of the design and materials was derived from background and user research, detailed above. For example, the visual prototype itself shows a camera embedded into an existing piece of equipment, building from respondents' third priority for a "future AR/CV solution" – "Built into existing equipment". Annotations label these decisions and clarify those that are not well represented visually, for instance identifying "sensors that track heart rate etc." which was partly derived from theme "superhuman real-time knowledge" in that users cannot know this desired information without technology. The real-world depiction above serves to communicate this where it may not be immediately clear, such as if observers think the tool requires users to constantly handle their phone – this is shown not to be the case. Bullet-pointed explanation is crucial to the intelligibility of the composition, specifying primary functionality as an AR navigation device. This draws from theme "AR for live direction". Screens below this show different circumstances of use to illuminate the totality of the tool's functionality. For instance, the user can disable the overlay entirely, reflecting theme "favouring minimalism in kit and tech". Nonetheless, emergencies still showing is also depicted, giving equal weight to theme "anticipating emergencies".

The accompanying visual storyboarding is also informed by these research processes. This intends to communicate the tool as a dynamic future experience rather than a snapshot, and illustrate pain points for current users. For example, "Harry" is an embodiment of a subsect of users from the questionnaire who favoured solo walking but did not have good navigation skills. They often felt unsafe without reliance on a digital solution (like *OSmaps*) which is reflected in Harry's close call with getting lost. The favourable future embodied here is *navglasses* averting disaster by guiding him back to the path, versus traditional methods. Additionally, findings like building into existing kit (sunglasses to block sun) and maintaining traditional methods (turning overlay off for map-and-compass navigation) are depicted here.

Overall, these compositions represent the breadth of how research was utilised in developing proposed tools, and relevance of different features to this.

4.6 Heuristics

Sixteen heuristics are presented, to provide a theoretical basis for future works on CV and AR tools for walking. If followed, or used for evaluation, these heuristics purport to aid in producing favourable futures as discovered.

To develop these, affinity diagramming findings of novel clusters and corroborated survey themes were used as a basis. Details were then populated through regarding design insights and quotes from user research. An evaluation process for heuristics was conceived to ensure they were useful and relevant. This process was based on their being research contribution [39] – a valuable heuristic must be:

1. Derived from user insight ("novel")
2. Not self-evident, given their position as a research contribution ("uncertain")
3. Particular to context and topic of CV and AR tools for walking (at least when detailed) ("creative")

Heuristics are as follows:

Reduce automation and increase customisation

The danger of over-reliance and tempering overconfidence
Trust through reliability and optics.
Supplementation to reduce effort
Weatherproofing and activity-proofing
Anticipate and support emergencies
CV and AR most helpful for experts and beginners.
Managing accessibility and cost
Not replacing humans
Design for leading and following
AR should preserve real-world detail
AR must not be self-evident
Sharing features paramount
Identification for Recreation
Build into existing equipment
Consider military implications

Table 9: Full examples of three heuristics. Remaining in appendix A.2.

Title	Explanation	Details
1. Reduce automation and increase customisation	Fully automated AR and CV is not well received compared to integrated toggles and user-control. Users want to maintain their autonomy and recruit CV and AR as tools rather than being guided. This includes the user controlling aspects of the tool rather than concrete function.	AR overlay should be dynamic e.g. entirely togglable at any given moment, excepting emergencies. Tools should not remove enjoyment of the activity by overbearing aid. CV identification should be overridable by user control.
2. AR should preserve real-world detail	AR overlays can obscure real-world detail that is useful for comprehension and safety.	These details should be preserved where possible. For example, by using transparency to maintain vision of real-world underneath digital articles, or by ensuring items in digital overlay communicate underlying detail through their design. e.g. AR navigation shouldn't obscure terrain.
3. Anticipate and support emergencies	Users are constantly anticipating emergencies occurring and consider tools supporting prevention and success in emergency scenarios to be a priority.	Reassure users by allowing them to avoid emergencies where possible, e.g. through live warnings and supporting planning. Design to support emergency scenarios, particularly through ensuring communication. Design to support emergency services by considering bespoke applications of CV and AR for their usage, that may not have value for the public. CV can be used to automate communication with emergency services where user is unable to manually.

Title	Explanation	Details
		AR can provide warnings that are highly conspicuous while allowing user to maintain attention on the real-world.

As mentioned, heuristics were evaluated. Here, being derived from user insight was inherently achieved through the research process. With reference those in Table 1, the first heuristic reworded a cluster from the affinity diagram "manual (and customisation) > automation" as in table 7. Similarly, the second was a grouping with quotes like "it could be overlaid against an OS map so it can be 2d and 3d at the same time to keep the connection between the two mediums". The third initially emerged in thematic analysis as theme *anticipating emergencies* as detailed in table 1 e.g. This was built upon in the workshop with respondents considering *how* tools support emergency situations rather than avoiding them, informing details of this heuristic.

These heuristics are not self-evident, for example number one is in contrast with typical practices in research, wherein automation is often a *goal* of CV [7]. Number two is also not typically considered in many settings, for example appending standalone digital objects to the real world [49] compared to *Smart Maps,* wherein details of the physical map like topography were preserved, aiding in clarifying digital representation. The third is self-evident though emergencies are a continual talking-point within walking, as details provide novel implementations like referencing CV for emergency detection.

These heuristics are also specific to context and topic, partly through specifying them to such in the details. For instance, the first one broadly states automation should be reduced by togglable AR overlays but excepts emergencies which are a walking consideration. The second specifies AR navigation shouldn't obscure terrain, which is a walking consideration since obscured uneven or steep terrain increases injury risk. The third focusses on communication with emergency services, which is a particular solo walking issue since in non-wilderness scenarios others can contact them for the casualty.

All heuristics are subject to this structure and evaluation criteria, allowing for a finalised list of valid principles, marking a valuable outcome.

5 DISCUSSION AND CONCLUSIONS

Naturally, these three findings have possible specific utility for future works, but also in revisiting past works.

Firstly, it is possible value could be held for those working within CV, AR, hillwalking, and mountaineering as separately rather than the intersection. For instance, some heuristics such as "weatherproofing and activity-proofing", while having meaning specific to this study's context, could have their titles used as inspiration for developing digital walking tools with different technologies. For example, a designer may consider tools using networks in this context, and weatherproofing may have a different meaning here, such as ensuring storms don't interfere with radio communications.

As well as utility for future work, it could be useful to revisit past research with these heuristics, to evaluate whether artefacts align with these principles. If not, this could represent potential for reconsideration and possibly publishing this evaluation as a paper.

The compositions would impact developers, who may soon wish to use cutting-edge technologies to realise these as functional products, which could positively impact walking as a sphere, and foray into novel ways of utilising CV and AR. Alternatively, numerous aspects of these designs and portrayed inferences could be taken separately and processed, such as integrating features into a current solution, or further exploring an area of interest. Notably, these designs intentionally have minimal overlap for easier analysis in the workshop and consideration of distinct futures, but in practice the background review and research show users often prefer "Swiss army knives" which integrate numerous features into one tool. This could be explored through design of a hypothetical tool with myriad CV and AR functionalities amalgamated.

According to Gaver and Bower, the annotated portfolio reveals generalities representing "fruitful locations and configurations to develop". Considering "configurations", by modulating one of these annotations, the whole picture of design could change. for example, if they shared generality "increasing user effort" not "reducing user effort" the portfolio could consist of CV and AR tools for health and fitness in walking instead. This can be used to further speculate on possible futures by revealing a new domain of tools. Conversely, designs themselves could be modulated, revealing new generalities. For instance, by adapting the designs for usage in another context while maintaining their character, new useful generalities could be revealed rapidly.

Ultimately, the consequence of this work is intended to be revealing favourable futures and thus informing realisation of these through following heuristics, implementing designs, or investigating premises noted. This represents a theoretical contribution and two distinct artefact contributions.

The project can be said to have achieved this, as favourable futures of CV and AR tools for walking were rigorously revealed through the structure transforming data to contributions. As intended, user-centred methods were used (participatory design), speculative design was incorporated through regarding the future with a responsible design slant, and this was underpinned by research-through-design conceptually, utilising designs as stimuli, drawing inferences from the design process, and presenting them as contributions with inherent value.

That said, the project is not without its flaws. Sampling methods utilised were weak in terms of generalisability, so with a more diverse sample heuristics deduced may have been different. This harms repeatability of the study and thus weakens its position within broader HCI literature. Furthermore, it may have been more precise to simply consider one or the other of AR and CV, and indeed for hillwalking and mountaineering. This is because AR and CV do not necessarily overlap in all cases, and indeed hillwalking and mountaineering may have different considerations that could have been addressed more particularly by disregarding the other. As such, some heuristics may be more suited to a CV device for mountaineering, whereas another may suit AR devices for hillwalking, reducing their applicability in the broad sense as initially proposed. Moreover, it's true many more hillwalkers than mountaineers contributed to user research due to the nature of accessibility of these activities within the UK and groups contacted. Therefore, mountaineering-exclusive concerns like climbing perhaps were less considered within the workshop etc, biasing heuristics and designs further.

Nonetheless, there is significant potential for further work to develop from this. For example, evaluating the heuristics' validity in practice. This could be done in many ways, for example as Nielsen did [37], comparing heuristics to real usability problems from a variety of projects to determine explanatory coverage.

Furthermore, it should be noted perception and comprehension of "possible futures" will change depending on what is imagined as one day being possible, which of course depends on current technology e.g. in this study perhaps wearable robotics would not have been considered had exoskeleton technology not recently drawn public attention. Here, this means it could be worth revisiting a similar methodology in ten years, where researchers would have a new outlook on futures based on shifting standards and technologies in the meantime, allowing for designs and heuristics that can explore a new breadth of possibilities, perhaps more accurately capturing plausible futures to guide.

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REFERENCES

[1] Acorn Globus. 2024. Formester. Retrieved from https://formester.com/

[2] Admin. 2022. What is Markerless AR and Examples. *Kiber*. Retrieved June 27, 2025 from https://kiber.tech/what-is-markerless-ar-examples/

[3] Adobe. 2025. Photoshop. Retrieved from https://www.adobe.com/uk/products/photoshop.html

[4] Sirwan Khalid Ahmed, Ribwar Arsalan Mohammed, Abdulqadir J. Nashwan, Radhwan Hussein Ibrahim, Araz Qadir Abdalla, Barzan Mohammed M. Ameen, and Renas Mohammed Khdhir. 2025. Using thematic analysis in qualitative research. *Journal of Medicine, Surgery, and Public Health* 6, (August 2025), 100198. https://doi.org/10.1016/j.glmedi.2025.100198

[5] AllTrails, LLC. 2014. AllTrails: Hike, Cycle & Run. Retrieved June 22, 2025 from https://play.google.com/store/apps/details?id=com.alltrails.alltrails&hl=en_GB

[6] Zann Anderson and Michael Jones. 2020. Rethinking the Role of a Mobile Computing in Recreational Hiking. In *HCI Outdoors: Theory, Design, Methods and Applications*, D. Scott McCrickard, Michael Jones and Timothy L. Stelter (eds.). Springer International Publishing, Cham, 291–305. https://doi.org/10.1007/978-3-030-45289-6_16

[7] Mohammad Aqel, Mohammad Hamiruce Marhaban, M Iqbal Saripan, and Napsiah Ismail. 2016. Review of visual odometry: types, approaches, challenges, and applications. *SpringerPlus* 5, (December 2016). https://doi.org/10.1186/s40064-016-3573-7

[8] Namat Bachir and Qurban Memon. 2022. Investigating YOLOv5 for Search and Rescue Operations Involving UAVs: Investigating YOLO5. In *Proceedings of the 5th International Conference on Control and Computer Vision* (*ICCCV '22*), November 09, 2022. Association for Computing Machinery, New York, NY, USA, 200–204. https://doi.org/10.1145/3561613.3561644

[9] Richard Boyatzis. 1998. Transforming Qualitative Information: Thematic Analysis and Code Development. (January 1998).

[10] T. Bratteteig, Keld Bødker, Yvonne Dittrich, P.H. Mogensen, and Jesper Simonsen. 2012. Organising principles and general guidelines for Participatory Design projects. *Routledge Handbook of Participatory Design* (January 2012), 117.

[11] British Design Council. 2005. Eleven lessons: A study of the design process. Retrieved September 1, 2025 from https://www.designcouncil.org.uk/fileadmin/uploads/dc/Documents/ElevenLessons_Design_Council%2520%25282%2529.pdf

[12] Miranda Bryant. 2022. Hill walkers in UK urged not to rely on smartphones. *The Guardian*. Retrieved June 27, 2025 from https://www.theguardian.com/uk-news/2022/dec/27/walkers-upland-britain-told-not-rely-on-smartphones-rescuers-compass-maps

[13] Richard Coyne. 2014. Nature vs. smartphones | IX Magazine Issue XXI.5 September + October 2014. *ACM Interactions*. Retrieved July 3, 2025 from https://interactions.acm.org/archive/view/september-october-2014/nature-vs.-smartphones

[14] Benjamin F. Crabtree. 1999. *Doing Qualitative Research*. SAGE.

[15] Don Dillman, Jolene Smyth, and Leah Christian. 2024. *Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method*. https://doi.org/10.1002/9781394260645

[16] Anthony Dunne. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming*. MIT Press, Cambridge.

[17] Martin Eckert, Julia S Volmerg, and Christoph M Friedrich. 2019. Augmented Reality in Medicine: Systematic and Bibliographic Review. *JMIR Mhealth Uhealth* 7, 4 (April 2019), e10967. https://doi.org/10.2196/10967

[18] Figma, Inc. 2016. Figma: the Collaborative Interface Design Tool. Retrieved from https://www.figma.com/login

[19] Christopher Frayling. 1993. *Research in art and design*. Royal College of Art, London.

[20] Bill Gaver and John Bowers. 2012. Annotated portfolios. *interactions* 19, 4 (July 2012), 40–49. https://doi.org/10.1145/2212877.2212889

[21] Tegan George. 2022. Mixed Methods Research | Definition, Guide, & Examples. *Scribbr*. Retrieved September 1, 2025 from https://www.scribbr.co.uk/research-methods/mixed-methods/

[22] Yalda Ghasemi, Heejin Jeong, Sung Ho Choi, Kyeong-Beom Park, and Jae Yeol Lee. 2022. Deep learning-based object detection in augmented reality: A systematic review. *Computers in Industry* 139, (August 2022), 103661. https://doi.org/10.1016/j.compind.2022.103661

[23] Tianrui Guan, Divya Kothandaraman, Rohan Chandra, Adarsh Jagan Sathyamoorthy, Kasun Weerakoon, and Dinesh Manocha. 2022. GANav: Efficient Terrain Segmentation for Robot Navigation in Unstructured Outdoor Environments. https://doi.org/10.48550/arXiv.2103.04233

[24] Morton L. Heilig. 1960. Stereoscopic-television apparatus for individual use. Retrieved June 27, 2025 from https://patents.google.com/patent/US2955156A/en

[25] Junyong In. 2017. Introduction of a pilot study. *Korean J Anesthesiol* 70, 6 (December 2017), 601–605. https://doi.org/10.4097/kjae.2017.70.6.601

[26] Bimsara Kanchana, Rojith Peiris, Damitha Perera, Dulani Jayasinghe, and Dharshana Kasthurirathna. 2021. Computer Vision for Autonomous Driving. In *2021 3rd International Conference on Advancements in Computing (ICAC)*, December 2021. 175–180. https://doi.org/10.1109/ICAC54203.2021.9671099

[27] Panayiotis Koutsabasis, Andreas Nikolarakis, Eriana Panopoulou, Stevy Georgiadi, Constantinos Mavrogonatos, and Martin Engi. 2023. Mobile User Experience to Learn About Geology While Hiking: The Syros GeoPaths app. In *Proceedings of the 2nd International Conference of the ACM Greek SIGCHI Chapter* (*CHIGREECE '23*), September 27, 2023. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3609987.3609999

[28] Nicolas Lekkas. 2025. GAFAM: The Big Five Tech Companies Facts (FAAMG). *GrowthRocks*. Retrieved September 1, 2025 from https://growthrocks.com/blog/big-five-tech-companies-acquisitions/

[29] R. Likert. 1932. A technique for the measurement of attitudes. *Archives of Psychology* 22 140, (1932), 55–55.

[30] Andrés Lucero. 2015. *Using Affinity Diagrams to Evaluate Interactive Prototypes*. https://doi.org/10.1007/978-3-319-22668-2_19

[31] Lumivero. 2025. Nvivo. Retrieved from https://lumivero.com/products/nvivo/

[32] Jimmie Manning. 2017. In Vivo Coding. https://doi.org/10.1002/9781118901731.iecrm0270

[33] Miro. 2011. Miro: The Innovation Workspace.

[34] Molly Hayes and Amanda Downie. 2024. What is Augmented Reality? | IBM. Retrieved June 27, 2025 from https://www.ibm.com/think/topics/augmented-reality

[35] Michael J. Muller and Sarah Kuhn. 1993. Participatory design. *Commun. ACM* 36, 6 (June 1993), 24–28. https://doi.org/10.1145/153571.255960

[36] Wolfgang Narzt, Gustav Pomberger, Alois Ferscha, Dieter Kolb, Reiner Müller, Jan Wieghardt, Horst Hörtner, and Christopher Lindinger. 2006. Augmented reality navigation systems. *Univ Access Inf Soc* 4, 3 (March 2006), 177–187. https://doi.org/10.1007/s10209-005-0017-5

[37] Jakob Nielsen. 1994. Enhancing the explanatory power of usability heuristics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (*CHI '94*), April 24, 1994. Association for Computing Machinery, New York, NY, USA, 152–158. https://doi.org/10.1145/191666.191729

[38] Jakob Nielsen and Rolf Molich. 1990. Heuristic evaluation of user interfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems Empowering people - CHI '90*, 1990. ACM Press, Seattle, Washington, United States, 249–256. https://doi.org/10.1145/97243.97281

[39] OECD. 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development*. OECD. https://doi.org/10.1787/9789264239012-en

[40] Northern Lights Optic. NL 6. *Northern Lights Optic*. Retrieved September 1, 2025 from https://www.northernlightsoptic.com/products/nl6

[41] Ordnance Survey Ltd. 2015. OS Maps: Walk, Hike, Run, Bike. Retrieved June 22, 2025 from https://play.google.com/store/apps/details?id=uk.co.ordnancesurvey.osmaps&hl=en_GB

[42] PeakLens. 2017. PeakLens. Retrieved July 3, 2025 from https://play.google.com/store/apps/details?id=com.peaklens.ar&hl=en_GB

[43] Plamena Atanasova, Barbara Bugalska, and Alan Dilleen. 2022. ARHike: A speculatively designed advanced navigation and location system. Retrieved June 26, 2025 from https://pdl.iadt.ie/wp-content/uploads/sites/5/2022/10/CA2-Speculative-Design-Project-Presentation_TeamNeptune.pdf

[44] Mike Richardson, Karin Petrini, and Michael Proulx. 2022. Climb-o-Vision: A Computer Vision Driven Sensory Substitution Device for Rock Climbing. In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (*CHI EA '22*), April 28, 2022. Association for Computing Machinery, New York, NY, USA, 1–7. https://doi.org/10.1145/3491101.3519680

[45] Colin Robson. 2002. Real World Research : A Resource for Social Scientists and Practitioner-Researchers / C. Robson. (January 2002).

[46] Jim Rudd, Ken Stern, and Scott Isensee. 1996. Low vs. high-fidelity prototyping debate. *interactions* 3, 1 (January 1996), 76–85. https://doi.org/10.1145/223500.223514

[47] Sanjay Saifi and Raaj Ramsankaran. 2024. Augmented-reality-based snow visibility simulation for disaster preparedness in the Western Himalayas. In *Proceedings of IAHS*, November 18, 2024. Copernicus GmbH, 73–77. https://doi.org/10.5194/piahs-387-73-2024

[48] Mateus Scarpelli and Plinio Aquino Junior. 2024. *The Synergy Between Artificial Intelligence and Environmental Perception through GPT Vision and YOLO v8*.

[49] Rute Silva, Rui Jesus, and Pedro Jorge. 2023. Development and Evaluation of a Mobile Application with Augmented Reality for Guiding Visitors on Hiking Trails. *Multimodal Technologies and Interaction* 7, 6 (June 2023), 58. https://doi.org/10.3390/mti7060058

[50] Strava Inc. 2011. Strava. Retrieved June 30, 2025 from https://play.google.com/store/apps/details?id=com.strava&hl=en_GB&pli=1

[51] Gemini Team. 2025. Gemini: A Family of Highly Capable Multimodal Models. https://doi.org/10.48550/arXiv.2312.11805

[52] UKRI Trustworthy Autonomous Systems Hub. 2023. RRI Prompts and Practice Cards. Retrieved July 4, 2025 from https://tas.ac.uk/responsible-research-innovation/rri-prompts-and-practice-cards/

[53] Robyn Vinter and Libby Brooks. 2025. Social media and map apps blamed for record rise in mountain rescue callouts. *The Guardian*. Retrieved June 28, 2025 from https://www.theguardian.com/world/2025/apr/16/record-high-british-mountain-rescue-callouts-social-media-map-apps

[54] Frederik Wiehr, Florian Daiber, Felix Kosmalla, and Antonio Krüger. 2017. ARTopos: augmented reality terrain map visualization for collaborative route planning. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers*, September 11, 2017. ACM, Maui Hawaii, 1047–1050. https://doi.org/10.1145/3123024.3124446

[55] Jacob O. Wobbrock and Julie A. Kientz. 2016. Research contributions in human-computer interaction. *interactions* 23, 3 (April 2016), 38–44. https://doi.org/10.1145/2907069

[56] Jinwen Xu and Ran Tao. 2024. Map Reading and Analysis with GPT-4V(ision). *ISPRS International Journal of Geo-Information* 13, 4 (April 2024), 127. https://doi.org/10.3390/ijgi13040127

[57] John Zimmerman and Jodi Forlizzi. 2014. Research Through Design in HCI. In *Ways of Knowing in HCI*, Judith S. Olson and Wendy A. Kellogg (eds.). Springer, New York, NY, 167–189. https://doi.org/10.1007/978-1-4939-0378-8_8

[58] 2014. Impacts of tourism. *Lake District National Park*. Retrieved July 3, 2025 from https://www.lakedistrict.gov.uk/learning/factstourism/impactsoftourism

[59] 2021. What is Computer Vision? | IBM. Retrieved June 27, 2025 from https://www.ibm.com/think/topics/computer-vision

[60] 2024. Apple Vision Pro. Retrieved June 28, 2025 from https://www.apple.com/apple-vision-pro/

[61] 2024. Revealing Average Screen Time Statistics for 2025. *Backlinko*. Retrieved June 28, 2025 from https://backlinko.com/screen-time-statistics

[62] 2024. Swiss Army knife. *Wiktionary, the free dictionary*. Retrieved September 1, 2025 from https://en.wiktionary.org/w/index.php?title=Swiss_Army_knife&oldid=83013180

[63] OpenCV: Canny Edge Detection. Retrieved June 27, 2025 from https://docs.opencv.org/4.x/da/d22/tutorial_py_canny.html

[64] Google Lens - Search What You See. *Google Lens*. Retrieved June 27, 2025 from https://lens.google/

[65] UKC Logbook - "Tower Ridge." Retrieved September 1, 2025 from https://www.ukclimbing.com/logbook/crags/ben_nevis-16877/tower_ridge-567

[66] A guide to Munro-bagging. *National Trust for Scotland*. Retrieved July 3, 2025 from https://www.nts.org.uk/visit/things-to-do/a-guide-to-munro-bagging

[67] Reliance on Technology Among Climbers on Mount Rainier. https://doi.org/10.1016/j.wem.2015.06.010

[68] Hill Walking Learn - The British Mountaineering Council. Retrieved September 1, 2025 from https://www.thebmc.co.uk/en/hillwalking-learn

[69] Calling for help | Mountaineering Scotland. Retrieved September 1, 2025 from https://www.mountaineering.scot/safety-and-skills/essential-skills/mountain-rescue/calling-for-help

[70] DEEP Robotics - Pioneering Innovation & Applicatio. Retrieved September 1, 2025 from https://www.deeprobotics.cn/en/index/lynx.html

[71] 14 reasons why we can't ignore footpath erosion - The British Mountaineering Council. Retrieved July 3, 2025 from https://www.thebmc.co.uk/en/14-reasons-path-erosion

[72] *Research through Design*. Retrieved September 1, 2025 from https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/research-through-design

[73] Three Levels of Pain Points in Customer Experience. *Nielsen Norman Group*. Retrieved September 1, 2025 from https://www.nngroup.com/articles/pain-points/

[74] I am bagging the Munros | Facebook. Retrieved September 1, 2025 from https://www.facebook.com/groups/2222435804/?locale=en_GB

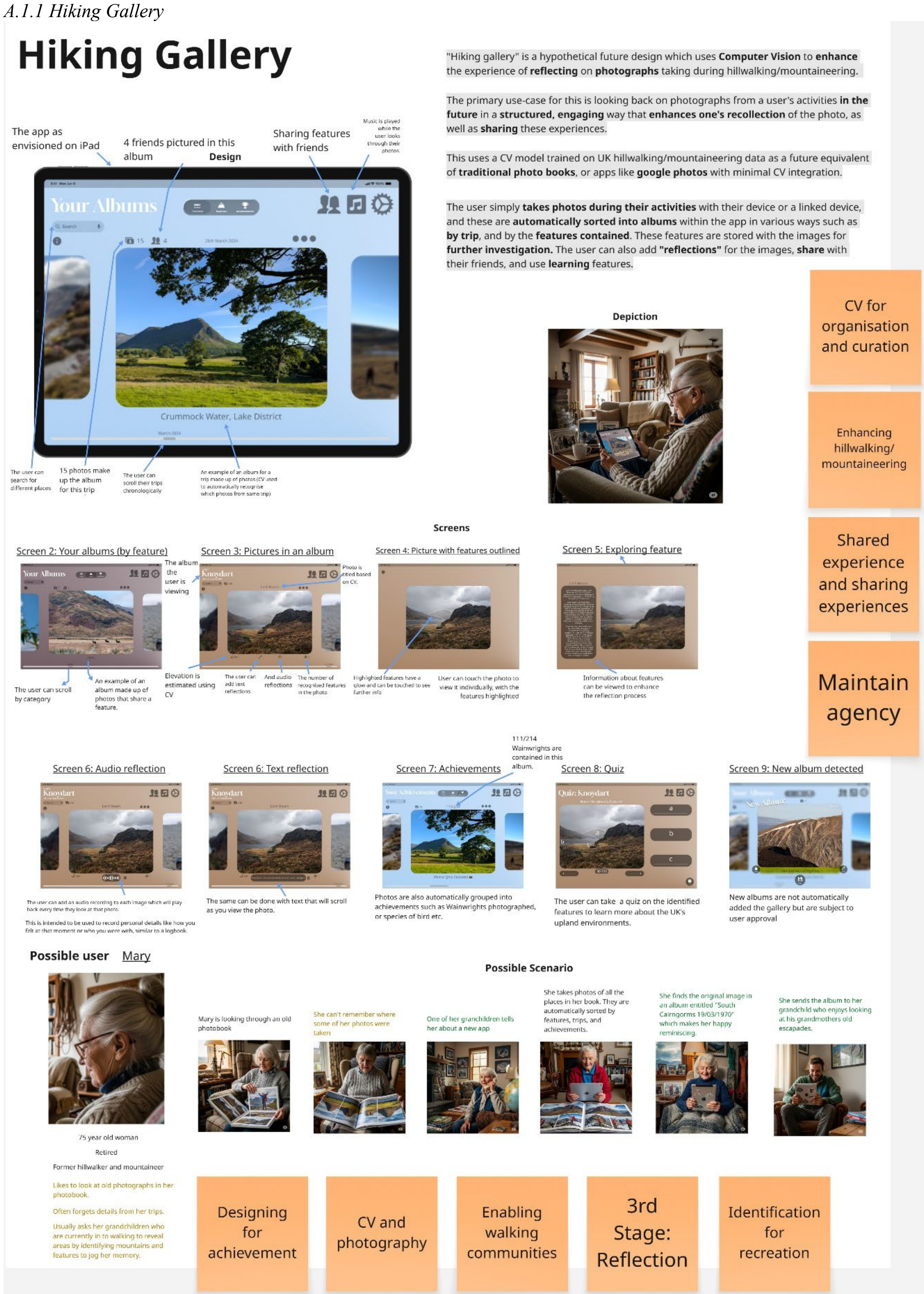
[75] Hypershell: World's First Outdoor Exoskeleton for Hiking & Daily Use. *Hypershell UK*. Retrieved September 1, 2025 from https://uk.hypershell.tech/

[76] Vizcom. Retrieved September 1, 2025 from https://www.vizcom.ai/

A APPENDICES

A.1 Compositions

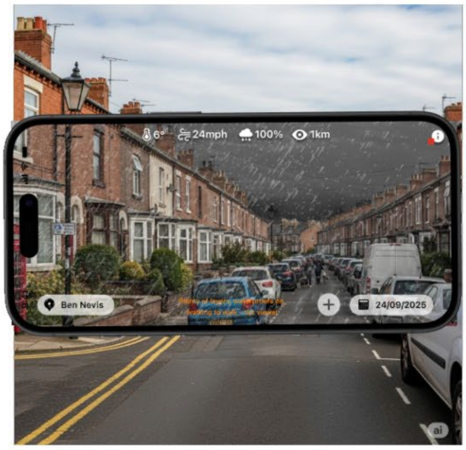
A.1.1 Hiking Gallery



A.1.2 WeatherAR

WeatherAR

Design



"WeatherAR" is a hypothetical future tool which uses **Augmented Reality** to view an overlay of a **different location's weather** on a given date **over the real world** in the camera.

The primary use-case for this is **planning** trips that are **safe and enjoyable**, by **visualising** the possible **conditions** in an **easily comprehensible** format.

This is a future counterpart to simply checking **weather apps**, or **asking fellow walkers** what given conditions may feel like.

The user finds an **open space** and uses the **app on their phone** to view the real-world with this **weather overlay** once **location and date have been selected.** They can also visualise how **various elements would appear in those conditions** by placing them in the real-world. They can then make an **informed decision** such as proceeding, cancelling, or altering plans and/or changing preparation.

Possible User

Phil

Inexperienced walker

Wants to take family out on walks

Concerned with losing children, or them being unhappy in bad weather.

Can't understand the forecast as he doesn't understand what wind speed might feel like, or what visibility could look like

40 year old man

Father of 3

Depiction

Temperature, wind speed, precipitation and visibility

Info

User can change the target location.

Forecast portrayed as direct advice

This button allows the user to add visualisers.

User can change the target date.

User can add a windsock to visualise wind speeds in a traditional format

User can add trees to visualise wind speeds, lightning etc. (tree uprooting, for example)

User can add people to visualise conditions e.g. falling over, shivering

This user has added a tree which they can see being buffeted by the wind

It is necessary to warn users about relying on this tool for safety.

Digital objects aid visualisation

Specify advice or action

Bolstering AR and CV with data (GPS, web etc.)

Ensuring safety

Conveying complex information simply, through AR

Users learn through usage

Smartphone AR

Depict weather

First stage: Preparation

Possible Scenario

Phil is planning a walk up a munro with his family

He checks the weather and sees the forecast doesn't seem great. He doesn't know whether to go ahead with the plans.

He remembers he installed the ARWeather app when he sees it on his home screen.

He uses the app and is unhappy with the distance he can see and the amount of rain.

He reschedules a trip and the family watches a film instead.

A.1.3 RescueBot (Image from [70])

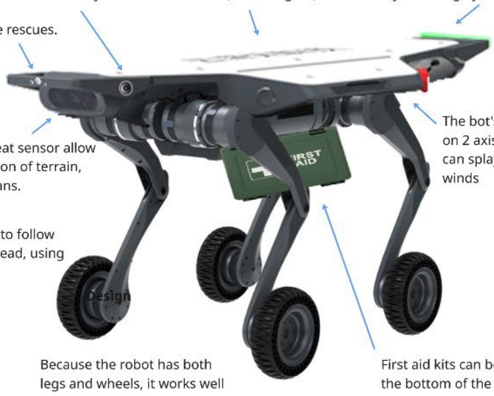
RescueBot

Speaker and mic allow for remote communication between MR and casualty

This large flat surface can be used to strap stretchered casualties to (or other gear)

Cyalume glowstick allows for easy following by MR volunteer.

Torch for nighttime rescues.



Camera and heat sensor allow for CV recognition of terrain, path, and humans.

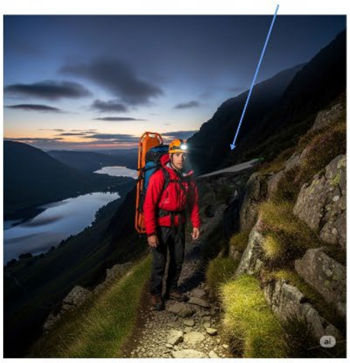
The bot's joints work on 2 axis so the legs can splay in high winds

The bot can be set to follow volunteer, or go ahead, using a manual switch.

Because the robot has both legs and wheels, it works well on varied terrain.

First aid kits can be strapped to the bottom of the bot.

There he is!



Depiction

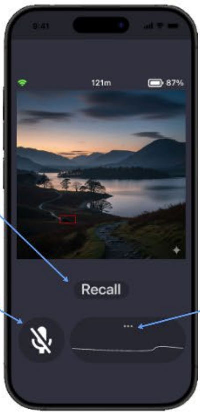
Rescuebot is a hypothetical future tool in which a **robot** uses **Computer Vision** to traverse mountainous environments, **assisting mountain rescue.**

The primary use case for this is to assist mountain rescue in various ways, **ensuring the safety of injured or stuck walkers**.

This is a future look at how rescue operations can be **enhanced** by robotics, in particular robotics that **do not need to be independently maneouvered** since they use CV.

The user simply turns the robot on and inputs **data on the location of the casualty** using a mobile app. By combining **map data, GPS, CV and other sensors** the robot can **traverse typical upland paths** and simple **offroad**, towards the casualty.

The rescuer can view what the bot is seeing including identified casualites



The rescuer can recall the bot to their location if needed.

The rescuer can turn their mic on and off using this button

Audio is visualised and speech transcribed for usage in poor conditions like noisy wind.

Possible User

Helen

60 year old woman

Mountain rescue volunteer

Lack of volunteers in her area

Has arthritis in hands

Finds volunteering tiring but rewarding

Possible Scenario

Camper falls ill by Tarn, and calls mountain rescue

Helen answers call, but she is the only person available to respond. She is anxious about doing this alone.

She enters the casualties location in to a Rescuebot.

She deploys the bot at the car park and sets off herself.

The bot arrives at the camper before her. The camper can self-medicate while communicating with Helen over radio speaker.

Once Helen arrives she can get the casualty to the hospital safe and sound by strapping her to the bot.

Robotics tailored to mountains

Identify casualties

Heat sensors aid CV

Users are rescuers

Robots as leaders and followers

CV for mountain pathfinding

Identify immediate terrain for robotics

A.1.4 Smart Maps

Smart maps

First stage: Preparation

Users learn through usage

AR depiction closer to real-world than traditional solution (less abstraction)

Design

The map incorporates both a traditional topographic map and an AR maker for an AR display.

"Smart maps" are a hypothetical future design in which **Augmented Reality is used to view a 3D depiction of an area** emerging from the surface the map is placed on.

The primary use-case for this is **collaboration** and learning in a **group route-planning** setting.

This is a future equivalent to **crowding around a map** together and discussing routes and plans.

The users scan the AR marker with their **phone camera**, which opens a multi-user **application** that displays the 3d depiction and **collaborative features**.

Digital features respond dynamically to conditions

Interactive AR for collaboration in planning

Maintain real-world details in digital object

Depiction

Possible Users

<u>Kirstie</u>

45 year old woman

mountain leader

Leads walks for company that sells team-bonding exercises

Often struggles to capture attention of large groups

Fan of traditional navigation methods

Frustration when explaining route to people who can't read maps well

<u>Max</u>

30 year old man

accountant

Taking part in team-bonding exercise walking in the Scottish highlands

Frequent smarphone user

Can't read topographic maps

Feels on edge knowing that he might be unable to understand route before embarking

Kirstie utilises a smart map to show the route to Max and his coworkers

- The 3d visualisation captures their attention
- They are used to smartphone apps so they find this familiar
- They can understand the landscape as it is portrayed from an eagle-eyes perspective, including paths etc.
- Kirstie can draw a route on to the app which the group can follow
- Max is now confident in his understanding of the day ahead
- Kirstie folds up the map to bring with her. She will use the printed topographic map on the other side for navigation.

<u>Screen 1: Default</u>

The user can touch the terrain to show a pointer to other users.

<u>Screen 2: Draw</u>

Route etc can be drawn

<u>Screen 3: POI</u>

A suggested viewpoint by one user

The user can add Points of Interest, like viewpoints or rest stops.

<u>Screen 4: Weather</u>

The user can simulate snow or rain, to see it's impact such as possible cornices or river crossings.

A possible cornice as detected by app

The snow overlay, showing altitude snow can be expected.

Can be set to snow or rain

The speed of snow/rain simulation can be changed.

<u>Screen 5: Topographic</u>

Various layers can be viewed, besides the photo view is a topographic layer to help the user understand the underlying representation.

<u>Screen 6: Zoom</u>

A.1.5 Exotrail

Image from [75]

A.2 Heuristics cont.

Table 10: examples of scope of current research and solutions categorised by stage

Title	Explanation	Details
Then danger of over-reliance and tempering overconfidence	Users are concerned about over-reliance and the dangers this poses, like inexperienced walkers dealing with	- Integrate traditional methods where possible, so that users have a fallback where CV and AR fail.

Title	Explanation	Details
	failure of tools. They are also quick to point out how overconfidence could lead to emergencies e.g. planning overly difficult walks using AR planning tools.	- CV-based navigation should integrate GPS (or paper maps and compass) - AR overlays should include information presented in a traditional way e.g. compass direction, grid reference. - AR Planning tools should accurately represent danger.
Trust through reliability and optics	Users lack trust as they are aware of the inherent unreliability of CV and AR since these tools rely on estimation, and are associated with AI and a lack of competency compared to humans. As such, reliability is paramount - and trust must be built. Users won't use tools for hillwalking/mountaineering without trust, due to anticipation of emergencies.	- Long-term trust is naturally built through reliability as the users doubts are erased. - Initial trust can be asserted through grounded functionality claims, like warning users about capability to make mistakes. - Optics are important - tools should be seen as an advancement not a replacement.
Supplementation to reduce effort	Users are particular to ideas that supplement typical processes in a way that reduces effort involved, eliminating "faff".	- AR can be used to provide a clear visualisation of difficult aspects of traditional techniques like understanding topographic maps, reducing the effort associated with reading these or learning how to. - CV identification should reduce time spent on tasks involving recognition and/or sorting at each stage of the activity's process, where requested.
Weatherproofing and activity-proofing	Varied conditions and the nature of hillwalking/mountaineering activities can have unexpected impacts on physical devices as well as smartphones. In particular, AR and CV are usually reliant on cameras, which need further consideration.	- Tools must be designed to minimise the impact of raindrops, snowflakes, etc. on the lens reducing the accuracy of CV or clarity of AR. - This could be through warnings, or designing to reduce the chances of this happening to begin with. - Naturally, tools with embedded electronics should be waterproof. - Robotics may struggle in high winds. Consider low centre-of-gravity etc. - Consider longevity of AR-markers through reinforcement e.g lamination and positioning. - hydrophobic lenses for CV
CV and AR most helpful for experts and beginners	The most compelling reasons to adopt CV and AR tools are specific to inexperienced and highly experienced walkers. Inexperienced walkers are less confident in their ability to use current solutions and lack knowledge that can be provided by CV or conveyed through	- Design for inexperienced or highly experienced users - these tools will still have a use for the average user but they are less compelled to adopt them. - Design for navigation or education. These are the most common

Title	Explanation	Details
	AR. Experts who are implicated in hillwalking/mountaineering in a professional capacity could use these tools for education and leading, or use cutting-edge tech like casualty identification for rescue where time is of the essence.	use-cases for the aforementioned user groups.
Managing accessibility and cost	Cutting-edge applications of CV and AR are likely to be at significant cost to the user due to implication of wearables or robotics. This is an accessibility issue to users who do not have disposable income to spend on these supplementary technologies. This is excepted by tools that would allow access to hillwalking/mountaineering where previously not feasible. These tools are well-received by users.	- Encourage adoption through comparable affordability to traditional techniques. - Favour tools with significant impact on accessibility where possible.
Not replacing humans	Vision is a human characteristic and tools that utilise it are often capable of completing human tasks and jobs. This is not well-received by users and is considerd an unfavourable future where non-human tools must be relied on in all scenarios, both due to lack of trust and ethical concern.	- Tools should be designed to assist humans, not replace them. - "Reduce automation and ensure customisation" aids this
Design for leading and following	Walking/Mountaineering activities are typically stratified into leading/following roles to a degree. It is important to support this through tools.	- Leaders can be educators, and CV tools should aid in this by supplementing knowledge, while AR tools should information in a clear and guided way to increase engagement. - AR overlays can provide important collaboration details for leaders like tracking companions.
AR must not be self-evident	Users prefer AR presenting information that is unclear or inconvenient when depicted with traditional modalities. Current solutions are preferable to AR if AR does not offer significant advantage in this, since users would rather continue with an "if it ain't broke don't fix it" mentality.	- Don't use AR if unecessary to communicate meaning and doesn't offer significant convenience advantage - For example, overlaying walking route on to the real world offers context and convenience, but overlaying identification of simple features like "tree" and rock" is obtrusive since it can easily be done by the user themselves.
Sharing features paramount	Users frequently reference AR and CV tools ability to communicate plans and experiences and the utility of this.	- implement sharing features where possible that communicate CV insights, and use AR to enhance this communication. - Plans should be communicated using these techniques to convey the experience more holistically, for example a visualisation of the activity rather than a route on a map. - Shared experiences can be automatically enhanced with

Title	Explanation	Details
		information ascertained by CV e.g. names of mountains, encouraging engagement from the recipient.
Identification for recreation	Users are most responsive to ideas regarding the use of CV for recreation and enjoyment.	- CV can solve arguments in real-time by identfying features and routes. - CV can enhance the reflection process by curating and expanding on images, videos and other captured data. - Users enjoy tools they do not feel like they are relying on since this reduces stress.
Build into existing equipment	Users enjoy the idea of technologies being built into equipment they already carry.	- Sunglasses or goggles are popular in walking/mountaineering and AR can be integrated. - Users carry smartphones which are useful for both CV and AR, however they require active usage. - Cameras for CV can be integrated into various worn items like headtorches.
Consider military implications	Users are concerned of military misuse of AR/CV tools designed for hillwalking/mountaineering, given their use in wilderness environments and the use of cutting-edge technologies.	Utility in military situations can be reduced by ensuring features as specific as possible to UK upland terrain, including data CV trained on.

A.3 Background Research Table

Table 11: examples of scope of current research and solutions categorised by stage

Stage/Focus	Preparation	Activity	Reflection
Support: Safety	AR Research: Use of snow visibility simulation for disaster preparedness. [44]	CV Research: Use of YOLOv5 CV system to guide search-and-rescue UAVs outdoors. [5]	Gap in research: possible solutions include crowdsourcing of route difficulty data.
Support: Navigation	CV Research: Use of AI vision models based on LLM for map-reading. [57]	AR Research: Proposed use of projected navigation cues from hiking stick. [70]	State-of-the-art: Reflecting on route visualisation as available on tracking apps like Strava [48] can illuminate navigation mistakes for future rectification.
Support: Accessibility	State-of-the-art: LLMs designed specifically for hiking can reduce barrier to entry by providing knowledge like which gear to bring etc. [53, 64]	CV Research: Alternative sensory modality for rock climbing (useful for people with impaired vision) based on computer-vision analysis of holds. [43]	Gap in research: Possibility for tool that utilises data from activities to provide experience for those unable to participate, such as allowing *google streetview*-esque [20] digital traversal of friends hikes.

Stage/Focus	Preparation	Activity	Reflection
Enhancement	AR Research: Use of AR overlay for topographic maps to enable collaborative route planning. [56]	AR Research: Tourism application of AR to enhance *points-of-interest* on predetermined trail through virtual objects. [27, 47]	Other research: Unobtrusive device that captures images and data like colour and elevation to later present reflective experience of a hike. [37]