AwARe: Using handheld augmented reality for researching the potential of food resource information visualization

Nina Rosa, Wageningen University and Research, nina.rosa-dejong@wur.nl

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TO APPEAR

Abstract

Consumers have the potential to play a large role in mitigating the climate crisis by taking on more pro-environmental behavior, for example by making more sustainable food choices. However, while environmental awareness is common among consumers, it is not always clear what the current impact of one's own food choices are, and consequently it is not always clear how or why their own behavior must change, or how important the change is. Immersive technologies have been shown to aid in these aspects. In this paper, we bring food production into the home by means of handheld augmented reality. Using the current prototype, users can input which ingredients are in their meal on their smartphone, and after making a 3D scan of their kitchen, plants, livestock, feed, and water required for all are visualized in front of them. In this paper, we describe the design of the current prototype and, by analyzing the current state of research on virtual and augmented reality for sustainability research, we describe in which ways the application could be extended in terms of data, models, and interaction, to investigate the most prominent issues within environmental sustainability communications research.

Keywords: Handheld augmented reality, visualization, food, sustainability.

FIGURE 1 - TEASER. Screenshots of the handheld augmented reality *AwARe* prototype. (A) Home screen. (B) Ingredients list for a simple meat-centered meal. (C, D, E) Crops, water and livestock required for the meat-centered meal, visualized in a kitchen and dining room. (F) Room scanning process, where the user sets boundaries in which the visualization may appear. (G) Ingredients list for a simple salad. (H, I, J) Crops and water required for the salad, visualized in a kitchen.

1 Introduction

Climate change is a wicked problem that requires large-scale change from various directions, including governments, businesses, and consumers. Although there is an abundance of knowledge available to consumers on issues of climate change, and environmental awareness and pro-environmental attitudes are common, there are still issues with communication of this knowledge, such that there is not always effective behavior change [34]. That is, there remains to be an attitude-behavior gap [49].

There are numerous barriers that can prevent behavioral change, including a perceived psychological distance [32]: problems related to climate change are perceived as temporally, hypothetically, spatially, and socially distant. At the same time, current production and trade systems have ensured that certain processes in fact do happen distantly from a consumer perspective. Taking food as an example: food is imported from afar, because it may cheaper than producing it locally, and/or it allows people to eat all foods without being restricted by local seasonal production. Consumers are not always aware of how their food is grown, processed, transported and/or sold [26].

To this end, immersive technologies such as virtual reality (VR) and augmented reality (AR) are interesting innovative communication media. While VR allows users to immerse themselves into completely virtual worlds, AR augments the real world by virtual components, and users experience a new merged world. Users can interact with these virtual objects and other virtual information, and engage with the information in a different way than when using conventional communication methods. Studies have shown that in the context of environmental sustainability, VR and AR could aid in learning [28], creating interest [18], decreasing psychological distance [9], and even change behavior [4].

Accordingly, in project *AwARe* we are interested in understanding whether and how an immersive and interactive AR visualization of information on food resources has the potential to more effectively communicate environmental issues related to food production and engage consumers in sustainable food activities. In this paper, we present the current state of VR and AR for sustainability research and zoom in on food sustainability specifically, in order to create an overview of the most prominent questions and topics in this field. Then, we present the current prototype of our *AwARe* application, which brings food production into the home by means of handheld AR. Lastly, we describe potential future research directions and expansions to the application in order to investigate the earlier identified questions and topics.

2 Related Work

2.1 Current state of XR for sustainability research

Recently, a systematic literature review on the use of extended reality (XR) for environmental sustainability was conducted [13]. Here, XR refers to VR and AR collectively. The authors categorized the literature by domain, and identified the most prominently studied effects and barriers. Firstly, 55% of XR studies were in the education domain, 18.75% in the sustainable behavior domain, 7.5% in the awareness domain, 7.5% in connecting with nature, 5% in crowdsourcing, 3.75% in decision making, and 2.5% in the training domain. Effects that are of highest interest are accordingly mostly knowledge retention and recall, environmental inclination and behavior, and immersion and embodiment. There were also a few studies measuring barriers and mediators including emotion, self-efficacy, experience and/or psychological distance.

Based on these findings, the authors drew a number of thematic, theoretical and methodological conclusions, some more specific to environmental research than others. Firstly, there is an urgent need within this research field to not only study effects of XR experiences on engagement, behavior and participation in environmental issues, but especially also the effects on the barriers preventing these. It was also noted that empirical research on AR is especially lacking. Secondly, XR applications were often created without a substantial reasoning of why certain features were implemented, suggesting a lack of understanding of the benefits of these features. Thirdly, they advised to focus on XR's known strengths and avoiding it's known limitations in terms of interaction. Fourthly, they urged the research community to focus on the role of user personality traits and tailoring to specific audiences. Next, inconsistent measures are being used, making most research incomparable. Also, questionnaires were heavily employed in the studies, and researchers should look into both alternative methods when suitable and applying a combination of measurement methods. Lastly, researchers should perform more comparative studies with other, possibly more accessible, media.

2.2 XR for food sustainability

Although food is absent as a domain in the systematic review [13], the number of XR studies on food and sustainability has been steadily increasing in the past few years.

For example, regarding education on sustainable agriculture, Garzón et al. developed a handheld AR application to foster aquaponics as an alternative sustainable agricultural technology in vocational education students [23]. The application used markers to place stations of an aquaponics system, trigger-images provide additional information, and each level provides extra activities. The application was rated highly in a pilot study in terms of learning content, motivation and as a multimedia learning resource. In a following study, Garzón et al. used the same AR application to understand the potential to promote eco-agritourism, and found that while both condition (i.e. using AR during a field trip versus receiving verbal explanation by a professional during the field trip) showed an increase in knowledge directly after learning, the AR group retained more knowledge than the control group one week later, and learning about aquaponics was deemed more motivating when using the AR application compared to traditional field trips [27].

Other studies have focused on designing XR applications to visualize information that is otherwise difficult to find or interpret. For example, Lee et al. designed an AR application to encourage the consumption of local foods by tourists [31]. The prototype visualizes additional information about a scanned dish, such as the food miles and stories of each ingredient and a locality score for the dish, and uses gamification elements to encourage eating more local foods. Honee et al. created an AR application to visualize the volume of food waste in a canteen setting based on real world data [25]. They found that the majority of users preferred either a handheld application over an application designed for a head-mounted display (HMD) for practical reasons or a hybrid approach, and that the majority felt the visualization helped them understand the volume and types of waste, especially when compared to conventional methods such as pie charts and static images, and incentivized them to reduce food waste.

Sometimes the studies are focused on presenting potential futures. Pimentel et al. created a VR seafood buffet, where users could pick any seafood they desired, after which they experienced a 360° ocean acidification video [38]. The experience ends with the decreasing of the color richness of the selected seafood, as a means of illustrating the decrease in the overall quality as a result of ocean acidification. Similarly, Zhang et al. created a VR museum where the different pavilions were dedicated to portraying different types of information: one for the impact of food choices on health, and another for the impact on the environment [52]. The museum includes interactive installations, with the aim to make the typically text-based information more comprehensible and impactful. This included seeing exaggerated environmental changes based on different food choices. In a pilot study the majority of participants stated that the experience prompted them to reflect on their eating habits to some extent.

2.3 Intervention studies

Some studies have also investigated the influence of interventions using XR visualizations on real world food intentions or actual food choices. Plechatá et al. created a VR intervention with an emotional narrative where middle school students could directly see the impact of their food choices on the Rocky Mountain National Park 30 years into the future. Another group of students could see this, too, but could also change their food choices to see the changed impact [40]. Both groups experienced an equal increase in knowledge gain and response efficacy after the VR experience, but there was a larger increase in self-efficacy, intentions, and knowledge transfer ability in the latter group compared to the former group. Self-efficacy was shown to be a mediator of intentions and transfer. In another study by Plechatá et al. using the same VR application, the authors found that seeing the degradation and changing your food choices compared to no intervention resulted in a larger decrease in real world dietary footprint when comparing consumption one week before and one week after the intervention [39]. They also found an increase in response efficacy and knowledge directly after the VR intervention, but not self-efficacy, behavioral intentions, or psychological distance, and of the behavioral predictors only knowledge lasted one week after the intervention. Also, having split the VR group into four smaller groups based on feedback type (generic vs. normative) and geographical distance (proximal vs. distant; the experience was extended with Sonfjället National Park), normative feedback was shown to result in greater self-efficacy scores than generic feedback, but geographical distance had no effect on these scores, and no effects on psychological distance were found.

Meijers et al. used a VR supermarket to simulate AR product information enrichment through impact messages, where the messages could be in the context of health, the environment, or generic as a control [33]. They found that both environmentally and health-focused impact messages led to more environmentally friendly virtual food choices, and that this was mediated by personal response efficacy beliefs. They also found that personal response efficacy was a larger predictor when health-framing was used, and conversely that collective response efficacy was a larger predictor when environmental framing was used. The impact messages did not have a direct influence on purchasing decisions in the real world one or two weeks later, but there was an indirect effect through personal response efficacy.

3 Application

The main purpose of the *AwARe* application is to, given a list of real foods or ingredients input by the user, visualize the resources required to produce this food using a smartphone in their own kitchen. In the current first prototype, the resources are simply: the livestock and crops that correspond to each ingredient, feed for the livestock in the form of wheat, and water required for all components. There are numerous potential expansions, these are described in Section 4. Before describing a typical use session, a few design choices are addressed.

3.1 Initial design choices

Firstly, previous studies on psychological distance have almost exclusively used VR, often using it's persuasive qualities to evoke responses after experiencing a potential (fictitious) negative future. Sometimes this results in a decrease in psychological distance [42, 9], but not always [39]. I argue that using a well-designed AR application, where there is a meaningful connection between the content and context of the application, may aid in further decreasing this distance, by further enhancing the proximity and personal relevance of the environmental effects. This is achieved, on the one hand, by asking users to input their real world food choices or foods they were considering consuming, offering a level of customization [29] and stimulating self-efficacy. On the other hand, the user is asked to use the application in their kitchen, because a strong connection between the content and place, i.e. semantic coupling, has the potential to create more meaningful and impactful experiences [44].

Secondly, while similar types of visualizations have generally opted for using an HMD in order to offer a strong sensory experience, this was purposefully not chosen here, since a final version of the application is intended for long-term use in the home in the near future. While an initial prototype could have been created using an HMD to understand only the experience of merging the real and virtual, the choice was made to already perform initial user testing with a more understandable vision of the final product. Opting for using a smartphone does come as certain costs, such as arm fatigue, the phone temperature increasing after prolonged use, and a potentially smaller augmented field of view, but these points were not raised during initial user tests. When HMDs become more widespread in the future, it would be sensible to develop an HMD version of the *AwARe* application. The expected rise in visual recognition may also further alleviate the need to explicitly scan the kitchen and input food by text. This would facilitate quick hands-free use, for example, during meal preparation. Note that the application does not currently explicitly ask users to create visualizations during actual meal preparation, nor does the data need to be factual (e.g. to compare two fictional meals) , since for example the dietary footprint is not being measured. The application can be used before meals, after meals, during other food-related moments such as writing out a grocery list and meal-planning, and also simply during one's free-time as a leisurely activity.

3.2 Use description

The user starts the application and is asked to login. Once logged in, the home screen gives access to *Rooms*, *Recipes*, *Questionnaires*, and *Account*; see Figure 1 (A). During the first use, the user is asked to create a room, i.e. a digital twin, by scanning their kitchen. During this scan the user traces the boundaries of available detected floor surface, see Figure 1 (F), sets the available height, identifies any obstacles, and places two anchors. The anchors are required to save and load the room for future use, and are in the form of pictures that need to be aligned with the real world upon loading an existing room. While the kitchen is chosen as use space, the prototype does not restrict the user from using a different space.

The user can add a new recipe, i.e. a list of ingredients, or open an existing one. When creating a list, each ingredient can be searched via text using a search bar, and once found, the user can input the quantity of that ingredient. Once all ingredients and quantities have been input, the list can be named and saved (Figure 1 (B, G)), and loaded into the digital twin as 3D models (Figure 1 (C-E, H-J)). The resources are split between animal- and plant-based resources, and the user can toggle between both visualizations. The reason for this split was that during implementation it became clear that generally not all resources for a single meal would fit nicely in one kitchen space, and expansion of the space was required in some way. On the animal-based side, the livestock is shown, and on the plant-based side, the crops for both plant-based and feed are shown, organized in clusters, meaning all individual plants of one type are placed near each other. The amount of required water for both animals and plants is present in both views.

The amount of visualized animals, plants, and water are calculated in two different ways. 3D models for the animals and plants are calculated in a rounding up fashion. Specifically, for each plant a 'units-per-piece' is saved, referring to the number of fruits or vegetables (units) per plant (piece). The number of displayed models is the ceiling of the number of input pieces divided by the units-per-piece. The user can input the quantity per mass or units; a mass-per-unit number is used in the application so the user can use both quantity types. The number of displayed animals works in a similar fashion, i.e. the number of visualized animals is the ceiling of the input mass divided by the 'mass-per-piece'. Water is calculated relative to the quantity input by the user, i.e. when Xg of pork requires YL of water, then $0.5X$g of pork requires $0.5Y$L of water. The same holds for the water required for plants. Feed plants are also calculated relative to the animal quantity input by the user just like water, and then the ceiling is taken as before.

The models are placed in such way that they are separated as would be minimally required when farming, and such that there is always enough space for a user to traverse across the whole space without being forced to collide with the models. All models stay in a fixed position in the real space while the user walks through the space. A user can also select other lists of ingredients directly after visualizing one in order to compare the two.

The numbers used for the required water per plant or animal [10, 17, 15, 36], plant spacing [24, 22, 20, 21], yield per plant [37], feed per animal [16, 48, 46, 3, 47, 7], and other conversions [35, 51, 12] were taken from numerous scientific and non-scientific sources. The reason for this is that the intention was to have the application running on dummy data before looking into using solely scientific, validated data.

The questionnaire section provides a simple question-answer sheet that the user can fill in and submit. The questions are intended to be adjusted by a researcher, and can be custom questions or questions from standardized measures. These are implemented in the application in order to gain immediate reactions by users directly after experiencing the visualization, but also such that the user can receive notifications from the application to fill in additional questionnaires without having to use the AR component.

3.3 Implementation

The application was created in Unity 2022.3.13f1, and consists of a number of components, see Figure 2 for a simplified component structure. The main components are the:

- Questionnaire;
- Ingredients List, which allows the user to search for ingredients and construct a list. The latter is shown in Figure 1 (B, G);

- Object Generation, which takes care of visualizing the objects by communicating with the Ingredients List. Example visualizations are shown in Figure 1 (C-E, H-J);
- Room Scanning, which takes care of creating the digital twin. This process is shown in Figure 1 (F). Object Generation relies on this component to place objects within the real space;
- User Interface, which covers all screens the user can interact with. This includes, amongst others, all screens in Figure 1.

For a complete description and mobile downloads of the application, see the open source project at `https://github.com/AwAReUU/OpenAwARe`.

FIGURE 2 - Simplified overview of the different components of the current *AwARe* prototype with their relations.

4 Potential next research steps

In this section I use insights from Section 2 on the most important research questions and current research limitations to reflect on how the current prototype could be expanded to address these.

4.1 Experience

The current *AwARe* prototype can be used to create new AR experiences in the context of environmental sustainability. AR generally requires at least one of two relationships: a spatial relationship, e.g. integrating virtual objects into a real space as is typical with HMDs, or a contextual relationship, e.g. scanning QR codes for more information on a certain product [45]. These relationships can also occur simultaneously, e.g. adding spatially well-placed textual information to a city view. In the context of AR for environmental sustainability, simple contextual relationships have been attempted [14, 11], but spatial relationships are relatively unexplored. Yet, as explained in Section 3.1, it is exactly this feature that has potential to decrease psychological distance compared to what VR studies have achieved so far, where there is still a perceptual divide between your life and the concept of environmental sustainability. Furthermore, it can be argued that requiring the user to access enriched information on their phone also requires the user to keep switching between realities. The *AwARe* application provides a way to experience both real and augmentation simultaneously as a single, merged environment. Currently, the models are simplistic, and it would be interesting to investigate how more realistic 3D models may affect the degree to which the environment feels merged. It is possible that users become distracted by shortcomings in terms of realism, diminishing the potential to decrease psychological distance.

This potential to decrease the psychological distance through AR is an example of an aspect that should be tested in a comparative study with different media, e.g. one could compare the *AwARe* application with a VR version and a desktop version that show the resources in a 3D virtual replica of your kitchen. The underlying arguments here are that specifically the realness of the underlying environment may decrease the psychological distance when comparing AR with VR, and that previous studies have suggested that the immersiveness of VR decreases the psychological distance to a greater extent compared to a non-immersive desktop setting [9]. Similarly, one could study whether the closeness to your life also has an effect on psychological distance, by comparing the *AwARe* application used in the user's own kitchen to use in a stranger's kitchen, and to use in a neutral space. Here, it is expected that using a kitchen increases immersion due to semantic coupling compared to a neutral space, which may decrease psychological distance [9], and I argue that the use of your own kitchen may further amplify this decrease.

4.2 Intervention studies

Beyond studying experiences in general, the prototype can be used as an intervention tool, to study numerous outcomes and mediators. Firstly, it would be interesting to study whether the current simplistic visualization could raise awareness about a few aspects of food production in an initial pilot, such as what certain crops actually look like and the scale of growing these just for one human or one household. The prototype could provide an accessible and engaging way to become introduced to this topic.

Naturally, there are numerous opportunities to expand and improve the application that go hand in hand with certain interesting effects. One of the obvious steps would be to base the visualization on scientific data, which would be essential in the context of studying knowledge gain and transfer.

In terms of resource information, the visualization could more accurately portray livestock feed to not just include plant-based components, but also animal-based and other components such as medication. In terms of food production in general, one could seek out to visualize aspects that are not always tangible. These include (the effects of) fertilizers, pesticides, energy consumption, land use, biodiversity, organic farming, labor, social issues, financial aspects, food miles and greenhouse gases. While it is not entirely clear how to communicate these issues in ways that are not text- or graph-heavy, attempts have been made to understand how to best visualize these, e.g. representing CO2-eq emissions from food choices by balloons [43].

A future version of the application could also be used to study perceptions of environmental sustainability, attitudes, affective consequences, appreciation of food, and connection with nature. For example, studies have shown that taking the perspective of coral suffering from the effects of ocean acidification can increase the inclusion of nature in the self compared to a video experience [5]. This feeling of inclusion moreover increased the perceived imminence of risk and involvement in the issue of ocean acidification. While *AwARe* does not use perspective taking, it does place the user in the midst of the resources, confined in a space where they typically consume the final products. In this context, an exhibition of 2D aesthetic images that were reinterpreted for CAVE VR, with the intention of making viewers aware of what it means to be part of the natural world, made most viewers feel transported into nature and think about nature in new ways [19]. The exposition seemed to promote, amongst others, emotional insight and environmental sensitivity. The immersive CAVE experience, the author suggests, could "make people aware of things that they had become numb to, information that they had discarded–particularly, that we are a part of, not separate from nature. In the CAVE the ordinariness of a plant is powerfully transformed and re-discovered in virtual reality more so than if that same plant was discovered in the backyard." [19, sect. 3.1]. I argue that allowing users to see aspects of food production in a way they have never been able to experience before, could yield similar findings. Of course, there was likely a strong aesthetic component that played a role in the findings of the VR exposition. However, this only provides more reason to further understand the role of realism of the 3D models, and the experience of a merged environment using the *AwARe* application.

Besides this, it would be interesting to study whether an intervention with *AwARe* could result in behavior change, not only for example making more conscious food choices, but also activities that transcend their own food behavior, for example in relation to food policies. Of course, whether these are mediated by frequently studied factors such as self-efficacy, response efficacy, and psychological distance, will be key to understanding exactly which features of the application and of AR and communications in general has aided in making these changes occur. In Section 3.1 it was argued how *AwARe* has the potential to increase self-efficacy and decrease psychological distance.

4.3 Interaction

While the studies in Section 2.3 focused on directly visualizing the environmental impact of certain food choices, the current prototype of *AwARe* does this only indirectly by allowing the user to compare resources for different lists of ingredients. However, it is conceivable that by adding specific forms of interaction, similar effects could be achieved. For example, Ahn et al. showed that cutting down a tree in VR led to less use of paper napkins directly after the intervention, and increased self-reported paper-conscious behavior and intentions which persisted after one week, when compared to reading about excessive paper consumption through text and video [4]. A comparable interaction in *AwARe* could be to chop down the fully grown crops, or slaughter the livestock. This could be extended by the users having to put in the actual work of growing the crops and livestock [6]. However, from an experiential perspective, it is possible the most valuable interactions will result from creating more connections to the kitchen space, such as visualizing water as overflowing the sink, picking fruits and vegetables and placing them on real plates, and having to discard inedible parts of the crops into a real trash bin. The latter provides a segue towards addressing food waste through the application, which is highly relevant in this context, given almost 30% of produced food was wasted, of which nearly 60% is wasted in households [41].

For studying food behavior, there are two more relevant components that already exist to a certain degree in the current prototype, but should be investigated for further expansion in future iterations of *AwARe*. Firstly, the current prototype offers the user direct perspective for action, namely by seeing the difference in required resources between multiple given lists of ingredients. However, this does not guide users in how to make other decisions outside of the food choices they input in the application. This should be explored in combination with the second component, namely personalization. While the application offers customization of lists of ingredients, providing normative feedback could help users learn about how they as individuals should make pro-environmental choices that still fit within their lifestyle, financial means, and food availability, tailoring the experience and communication to specific audiences. It could be worthwhile to explore including more contextual information such as purchasing history, to better understand where and what foods users typically buy, complementing the data gathered by the application's questionnaire function.

4.4 Methodological prospects

One common hurdle in XR research is that for each new research idea, a new XR experience needs to be built, often from scratch. The current prototype has been made available to anyone who would want to use it for their own research, or to further develop it. This could help decrease costly development time, and aid in making future studies more comparable.

The potential to perform in-situ longitudinal studies is another aspect of the current prototype design that could be beneficial to sustainable behavior research in general. The application is designed as a handheld AR application in order for users to experience the application in their own home. This contrasts almost all studies discussed in Section 2 in two main aspects. Firstly, in most cases participants are asked to perform an experiment in a laboratory setting, where they are taken out of their daily activities. This could further exacerbate the divide mentioned in Section 4.1. Secondly, the experiences of those same studies generally last only a short period of time and are only performed once. Moreover, it is often the case that long-term effects are in fact only one-week-later effects. The intention of the *AwARe* application is for it to be used multiple times over the course of a much longer period, recording responses by users on any specific effect or mediator of interest along the way.

One important note here is that it would be particularly interesting to identify a range of potential participants for such a study. Common downfalls of studies is that participants may self-select into the study, causing a selection bias. For the *AwARe* application, it is conceivable that people that are already interested in environmental sustainability would be willing to use such as application. Using a known food-based consumer segmentation, such as meat eaters, meat reducers and vegetarians [8] or greens, potential greens and non-greens [50], one could first perform a pilot study in the form of focus groups to understand the wants and needs of each group and how to reach them through the application. Alternatively, it could be worthwhile to solely focus on "low hanging fruit" [30]. Kolodko and Read explain in the context of littering (using general behavioral science theory) that targeting groups with lower barriers to change, i.e. those who are ready to change, increase the chance of intervention success and maximize the chance of reaching a tipping point [30].

Purchasing history could also be a promising avenue to include ways to measure actual food behavior, without relying on self-report. From an implementation perspective, it could be interesting to allow users to input their ingredients not only by searching through text input, but also by scanning barcodes (e.g. with existing APIs [2]) or even full grocery receipts (e.g. see [1]). Naturally, there are privacy issues in this regard that would need to be resolved prior to implementation. Similarly, the current prototype includes one obvious privacy issue, namely the use of the camera in a user's real home. Note that the current prototype does not collect or record images, only digital twins that do not include any further imaging besides the two anchor images, and it is not the intention to do so in future iterations.

5 Conclusion

In this paper the literature was explored to understand which next steps are necessary in furthering research in the area of XR and environmental sustainability, and in particular food sustainability. The *AwARe* prototype was presented, and directions for future expansions and research were presented, in terms of data, 3D models, and interaction, but also in terms of awareness, attitudes and behavior. It is expected that the *AwARe* application could play a role in understanding the importance and potential of AR for environmental sustainability research, and the research community is invited to use the open source code to take the next steps in this research area.

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References

[1] Check your receipt (Check je bon). https://www.checkjebon.nl/. Accessed: 2024-06-12.

[2] UPC Lookup Database. https://www.upcitemdb.com/. Accessed: 2024-06-12.

[3] Agrifarming India. Sheep feed basic information for beginners, 2018. https://www.agrifarming.in/sheep-feed-basic-information-for-beginners [Accessed: September 4, 2023].

[4] S. J. G. Ahn, J. N. Bailenson, and D. Park. Short- and long-term effects of embodied experiences in immersive virtual environments on environmental locus of control and behavior. *Computers in Human Behavior*, 39:235–245, 2014.

[5] S. J. G. Ahn, J. Bostick, E. Ogle, K. L. Nowak, K. T. McGillicuddy, and J. N. Bailenson. Experiencing Nature: Embodying Animals in Immersive Virtual Environments Increases Inclusion of Nature in Self and Involvement with Nature. *Journal of Computer-Mediated Communication*, 21(6):399–419, 09 2016.

[6] S. J. G. Ahn, J. Fox, K. R. Dale, and J. A. Avant. Framing virtual experiences: Effects on environmental efficacy and behavior over time. *Communication Research*, 42(6):839–863, 2015.

[7] American Feed Industry Association. Species data, 2021. https://www.afia.org/feedfacts/feed-industry-stats/species-data/ [Accessed: September 4, 2023].

[8] C. Apostolidis and F. McLeay. To meat or not to meat? comparing empowered meat consumers' and anti-consumers' preferences for sustainability labels. *Food Quality and Preference*, 77:109–122, 2019.

[9] P. Breves and H. Schramm. Bridging psychological distance: The impact of immersive media on distant and proximal environmental issues. *Computers in Human Behavior*, 115:106606, 2021.

[10] C. Brouwer and M. Heibloem. Fao's irrigration water management, training manual no. 3, 1986 , chapter 2: Crop water needs, 2023. `https://www.fao.org/4/s2022e/s2022e02.htm` [Accessed: September 4, 2023].

[11] M. Carulli, M. Bordegoni, E. Spadoni, et al. Applications virtually augmenting real experiences for behavioral change. *Computer-Aided Design and Applications*, 19(1):176–190, 2022.

[12] Compassion in World Farming. The life of: Laying hens, 2012. `https://www.ciwf.org.uk/media/5235024/The-life-of-laying-hens.pdf` [Accessed: September 4, 2023].

[13] L. D. Cosio, O. O. Buruk, D. Fernández Galeote, I. D. V. Bosman, and J. Hamari. Virtual and augmented reality for environmental sustainability: A systematic review. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI '23, New York, NY, USA, 2023. Association for Computing Machinery.

[14] S. Dekhili and M. Ertz. Reinventing ecolabels in the era of augmented reality: An experimental study on the case of fair-trade coffee. *Journal of Cleaner Production*, 434:139987, 2024.

[15] Department of Agriculture, Environment and Rural Affairs. Water advice for livestock farmers, 2024. `https://www.daera-ni.gov.uk/articles/water-advice-livestock-farmers` [Accessed: September 4, 2023].

[16] Dutch Dairy Association. Cattle feed, 2019. `https://www.nzo.nl/en/quality/cattle-feed/` [Accessed: September 4, 2023].

[17] FAO. AQUASTAT - FAO's Global Information System on Water and Agriculture, 2024. `https://www.fao.org/aquastat/en/` [Accessed: September 4, 2023].

[18] E. Filter, A. Eckes, F. Fiebelkorn, and A. G. Büssing. Virtual reality nature experiences involving wolves on youtube: Presence, emotions, and attitudes in immersive and nonimmersive settings. *Sustainability*, 12(9), 2020.

[19] L. A. Frank. Using the computer-driven VR environment to promote experiences of natural world immersion. In M. Dolinsky and I. E. McDowall, editors, *The Engineering Reality of Virtual Reality 2013*, volume 8649, page 86490A. International Society for Optics and Photonics, SPIE, 2013.

[20] Gardening Know How. Fruit tree spacing: How far apart do you plant fruit trees in the garden, 2021. `https://www.gardeningknowhow.com/edible/fruits/fegen/fruit-tree-spacing-in-gardens.htm` [Accessed: September 4, 2023].

[21] Gardening Know How. Herb spacing chart - tips for spacing between herb plants, 2022. `https://www.gardeningknowhow.com/edible/herbs/hgen/herb-spacing.htm` [Accessed: September 4, 2023].

[22] Gardening Know How. Plant spacing guide - information on proper vegetable garden spacing, 2023. `https://www.gardeningknowhow.com/edible/vegetables/vgen/plant-spacing-chart.htm` [Accessed: September 4, 2023].

[23] J. Garzón, S. Baldiris, J. Acevedo, and J. Pavón. Augmented reality-based application to foster sustainable agriculture in the context of aquaponics. In *2020 IEEE 20th International Conference on Advanced Learning Technologies (ICALT)*, pages 316–318, 2020.

[24] Grow it Build it - The Blog. Vegetable garden height and spacing guide – 71 species, 2023. https://growitbuildit.com/vegetable-garden-height-spacing-guide/n/ [Accessed: September 4, 2023].

[25] D. Honee, W. Hurst, and A. J. Luttikhold. Harnessing augmented reality for increasing the awareness of food waste amongst dutch consumers. *Augmented Human Research*, 7(1):2, 2022.

[26] P. Howard. What do people want to know about their food? measuring central coast consumers' interest in food systems issues. *Center for Agroecology & Sustainable Food Systems*, 13(2):115–125, 2005.

[27] J. P. Juan Garzón, Juan Acevedo and S. Baldiris. Promoting eco-agritourism using an augmented reality-based educational resource: a case study of aquaponics. *Interactive Learning Environments*, 30(7):1200–1214, 2022.

[28] A. M. Kamarainen, S. Metcalf, T. Grotzer, A. Browne, D. Mazzuca, M. S. Tutwiler, and C. Dede. Ecomobile: Integrating augmented reality and probeware with environmental education field trips. *Computers & Education*, 68:545–556, 2013.

[29] H. Kang and S. S. Sundar. When self is the source: Effects of media customization on message processing. *Media Psychology*, 19(4):561–588, 2016.

[30] J. Kolodko and D. Read. Using behavioural science to reduce littering: understanding, addressing and solving the problem of litter. *Journal of Litter and Environmental Quality*, 2(1):21–36, 2018.

[31] J. Lee, K. Kaipainen, and K. Väänänen. Local foodie: experience design of a mobile augmented reality application for tourists to encourage local food consumption. In *Proceedings of the 23rd International Conference on Academic Mindtrek*, AcademicMindtrek '20, page 110–119, New York, NY, USA, 2020. Association for Computing Machinery.

[32] R. Maiella, P. La Malva, D. Marchetti, E. Pomarico, A. Di Crosta, R. Palumbo, L. Cetara, A. Di Domenico, and M. C. Verrocchio. The psychological distance and climate change: A systematic review on the mitigation and adaptation behaviors. *Frontiers in Psychology*, 11, 2020.

[33] M. H. Meijers, E. S. Smit, K. de Wildt, S.-G. Karvonen, D. van der Plas, and L. N. van der Laan. Stimulating sustainable food choices using virtual reality: Taking an environmental vs health communication perspective on enhancing response efficacy beliefs. *Environmental Communication*, 16(1):1–22, 2022.

[34] S. C. Moser. Communicating climate change: history, challenges, process and future directions. *WIREs Climate Change*, 1(1):31–53, 2010.

[35] National Dairy Council. How much milk do dairy cows produce?, 2022. https://ndc.ie/accordion/how-much-milk-do-dairy-cows-produce/F [Accessed: September 4, 2023].

[36] North Dakota State University. Livestock water requirements, 2021. https://www.ndsu.edu/agriculture/extension/publications/livestock-water-requirements [Accessed: September 4, 2023].

[37] Omnicalculator. Vegetable yield calculator, 2024. https://www.omnicalculator.com/biology/vegetable-yield [Accessed: September 4, 2023].

[38] D. Pimentel, R. Amaya, S. Halan, S. Kalyanaraman, and J. Bailenson. Climate change on your plate: A vr seafood buffet experience. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 1120–1121, 2019.

[39] A. Plechatá, T. Morton, F. J. Perez-Cueto, and G. Makransky. A randomized trial testing the effectiveness of virtual reality as a tool for pro-environmental dietary change. *Scientific reports*, 12(1):14315, 2022.

[40] A. Plechatá, T. Morton, F. J. A. Perez-Cueto, and G. Makransky. Why Just Experience the Future When You Can Change It: Virtual Reality Can Increase Pro-Environmental Food Choices Through Self-Efficacy. *Technology, Mind, and Behavior*, 3(4: Winter), nov 7 2022. https://tmb.apaopen.org/pub/s7ulq9uy.

[41] U. N. E. Programme. Food waste index report 2024. think eat save: Tracking progress to halve global food waste, 2024-03.

[42] U. S. Raja and A. R. Carrico. A qualitative exploration of individual experiences of environmental virtual reality through the lens of psychological distance. *Environmental Communication*, 15(5):594–609, 2021.

[43] C. Ramsdell and L. Barrera. Culinary fever (food emissions visualization education resource): A unique educational tool to empower the public to reimagine food choices for environmental sustainability. *Food Studies*, 14(1):1, 2023.

[44] N. Rosa. Examining semantic coupling in augmented reality. In *Experience 2.0 and Beyond – Engineering Cross Devices and Multiple Realities Workshop, Lecture Notes in Computer Science*, page To appear. Springer, 2025.

[45] H. Schraffenberger and E. Van der Heide. Everything augmented: On the real in augmented reality. *Journal of Science and Technology of the Arts*, 6(1):17–29, 2014.

[46] Scotland's Farm Advisory Service. How much grass do ewes and lambs need?, 2017. `https://www.fas.scot/article/much-grass-ewes-lambs-need/` [Accessed: September 4, 2023].

[47] The Big Book Project. Poultry feed formulation: Nutrition & homemade methods (layer/broiler), 2021. `https://thebigbookproject.org/agri/poultry-farming/feed-formulation-nutrition/` [Accessed: September 4, 2023].

[48] The Pig Site. How to farm pigs - feeding, 2016. `https://www.thepigsite.com/articles/how-to-farm-pigs-feeding` [Accessed: September 4, 2023].

[49] S. Venghaus, M. Henseleit, and M. Belka. The impact of climate change awareness on behavioral changes in germany: changing minds or changing behavior? *Energy, Sustainability and Society*, 12(1):8, 2022.

[50] M. C. Verain, J. Bartels, H. Dagevos, S. J. Sijtsema, M. C. Onwezen, and G. Antonides. Segments of sustainable food consumers: a literature review. *International Journal of Consumer Studies*, 36(2):123–132, 2012.

[51] I. Vredenberg, R. Han, M. Mourits, H. Hogeveen, and W. Steeneveld. An empirical analysis on the longevity of dairy cows in relation to economic herd performance. *Frontiers in Veterinary Science*, 8:646672, 2021.

[52] H. Zhang and J. C. F. Ho. VR diet museum: A virtual experience designed for better learning and reflection on eating habits and its effects. In A. L. Brooks, editor, *ArtsIT, Interactivity and Game Creation*, pages 253–268, Cham, 2023. Springer Nature Switzerland.