

Reducing Food Waste in Restaurants Through Augmented Reality (AR)-Based E-Menus: The Central Role of the AR-Enhanced Dining Experience for Sustainability

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Type of manuscript: Work in progress

Abstract

Food waste in restaurants is a major sustainability challenge, often driven by portion-size misalignment and limited consumer anticipation. This study investigates how AR-based e-menus, which enable portion customization and preview, foster anticipated meal completion as a proxy for perceived food waste. Drawing on the AR-enhanced dining experience (AR-EX) model and the Online Customer Experience (OCE) framework, this study introduces eudaimonic experience, defined as personal meaning and reflection from value-aligned choices, as a fourth dimension alongside utilitarian, hedonic, and social ones. A mixed method design with structural equation modelling examines how the AR-based e-menu's verbal and visual design elements shape AR-enhanced dining experiences and influence anticipated meal completion and reuse intentions.

Keywords: food waste; augmented reality; eudaimonia; dining experiences.

Résumé

Le gaspillage alimentaire dans les restaurants constitue un défi majeur en matière de durabilité, souvent lié à un décalage entre portions perçues et portions servies et à la capacité limitée des consommateurs à anticiper leur consommation. Cette étude analyse la manière dont les e-menus en réalité augmentée (RA), qui permettent de personnaliser et de prévisualiser les portions alimentaires, favorisent la complétion anticipée du repas en tant que proxy du gaspillage alimentaire perçu. S'appuyant sur le modèle de l'Expérience Améliorée par la RA (AR-EX) et sur le cadre de l'Expérience Client en Ligne (OCE), cette étude introduit l'expérience eudémonique, définie comme le sens personnel et la réflexion issus de choix alignés avec les valeurs, comme quatrième dimension de l'expérience aux côtés des dimensions utilitaire, hédonique et sociale. Un design mixte, combiné à une modélisation par équations structurelles, examine comment les éléments de design verbaux et visuels du e-menu en RA façonnent ces expériences et influencent la complétion anticipée du repas ainsi que l'intention de réutilisation.

Mots-clés : gaspillage alimentaire ; réalité augmentée ; eudaimonia ; expériences de restauration

1. Introduction

Dining out is pleasurable but also poses serious environmental challenges. Across Europe, out-of-home catering services generate over 10.5 million tons of food waste annually (Feedback EU, 2022). Although EU policy promotes food waste reduction, compliance at the restaurant level remains limited (Filimonau et al., 2020). This waste not only intensifies greenhouse gas emissions (Meier et al., 2021), but also undermines food security efforts (Mejjad et al., 2023; Sousa et al., 2021). A central driver of this problem is portion-size misalignment. Consumers struggle to perceive portion size accurately before ordering (Ordabayeva & Chandon, 2016) and tend to underestimate intake when portions are large (Keenan et al., 2017). Consequently, plate waste becomes common (Xu et al., 2020). To address this, augmented reality (AR) offers promising solutions by overlaying virtual food servings over a plate (Rollo et al., 2017), allowing portion visualization before ordering. Beyond functionality, AR enriches the dining experience (Batat, 2021). The design of digital interfaces—especially their verbal and visual elements—further shapes experiences and influences consumer behavior (Bleier et al., 2019). In restaurants, well-designed electronic menus (e-menus) improve food quality perceptions and increase behavioral intentions (Lin et al., 2023). As restaurants adopt immersive technologies like AR, e-menu design becomes key to enhancing dining experiences and shaping sustainable behavior.

This research builds on the AR-enhanced dining experience (AR-EX) framework (Ali, 2022), which outlines utilitarian, hedonic, and social dimensions. Prior studies show that AR can stimulate appetite and food desirability (Fritz et al., 2023), often through enhanced visual realism (Shaheen et al., 2024). While this may improve portion perception and reduce waste, it can also increase food appeal and risk overconsumption—making it essential to disentangle these effects. In sustainability contexts, consumer motivations stem not only from pleasure or utility, but also from moral obligation (Ünal et al., 2018) and a desire to live meaningfully (Guillen-Royo, 2019). This eudaimonic perspective is crucial because it emphasizes psychological well-being, personal meaning, and self-reflection (Lengieza et al., 2019), which drive sustainable behavior (Ünal et al., 2017; Steg et al., 2016). Therefore, we extend Ali's (2022) framework by adding a fourth eudaimonic dimension, which we conceptualize as the "AR-enhanced dining experience for sustainability".

Grounded in the Online Customer Experience (Bleier et al., 2019) and AR-EX (Ali, 2022), we examine how verbal (e.g., linguistic style, descriptive detail, bulleted points) and visual (e.g., feature crop, picture size) design elements of AR-based e-menus influence these four experiential dimensions, and how these affect two outcomes: anticipated meal completion—used as a proxy for perceived food waste—and reuse intention of the AR-based e-menu. Consumers' information processing preferences (Mayer & Massa, 2003) are also considered as a moderating factor.

2. Theoretical background and hypotheses

2.1. AR-based e-menu design elements and AR-enhanced dining experience

AR-based e-menus can convey information through verbal and visual design elements, which act as external stimuli that attract consumer attention and shape perception at the interface level (Kim, 2019). Verbal elements are defined as “the written word” (Bleier *et al.*, 2019, page 102), including linguistic style, descriptive detail and bulleted points (Bleier *et al.*, 2019). Visual elements are defined as “the sensory and structural features” of an interface (Jeannot *et al.*, 2022, page 5), such as feature crops—referring to the ability to zoom in on a product—and image size (Bleier *et al.*, 2019). Studies show that verbal cues improve product understanding and perceived credibility (Tang *et al.*, 2004) contributing positively to customer experiences (Bleier *et al.*, 2019). On the visual side, aesthetically appealing design elements positively influence consumers’ judgments and evaluations (Jeannot *et al.*, 2022).

AR positively influences customer experiences in restaurant contexts (Shaheen *et al.*, 2024; Batat, 2021). Similarly, Bleier *et al.* (2019) show that verbal and visual design elements enhance online customer experiences. Building on this, we argue that these effects may also extend to AR-enhanced dining experiences for sustainability. *Utilitarian dimension* reflects perceptions of AR’s functionality and practicality; *hedonic dimension* captures playfulness and enjoyment, *social dimension* emphasizes “perceptions of AR’s ability to provide an interactive experience” (Ali, 2022, page 7). In sustainability contexts, the eudaimonic dimension is key to understanding how AR shapes consumer behavior. While hedonic dimension centers on pleasure and enjoyment (Alba & Williams, 2013), *eudaimonic dimension* is rooted in long-term psychological well-being, purpose, and individual fulfillment (Mugel *et al.*, 2019), fostering more reflective experiences (Cole & Gillies, 2019).

H1. Verbal elements of the AR-based e-menu (e.g., linguistic style, descriptive detail, bulleted points) positively influence the AR-enhanced dining experience for sustainability

H2. Visual elements of the AR-based e-menu (e.g., food picture size, feature crop) positively influence the AR-enhanced dining experience for sustainability

2.2. Information processing preference

Consumers differ in how they engage with information, and this shapes how they might respond to AR-based e-menus elements. Mayer and Massa (2003, page 833) describe learning preferences as “the ways that people like information to be presented to them,” either through words or images. Building on this idea, some individuals are more naturally drawn to textual content, while others are more responsive to visual formats. Those who prefer written information tend to connect more with descriptive text, whereas visually oriented individuals are more engaged by images and interactive elements (Yoo & Kim, 2014). When the content of online interfaces aligns with a consumer’s preferred

way of processing information, the experience tends to feel more satisfying due to increased fluency (De Bellis *et al.*, 2019). We therefore expect a congruence effect: verbal elements should be more effective for consumers with a verbal processing preference, whereas visual elements should be more effective for those with a visual preference. In this sense, information processing preferences can play a key role in determining how effective design elements are in delivering a compelling experience.

H3. The relationship between AR-based e-menu's verbal (H3a) and visual elements (H3b) and the AR-enhanced dining experience for sustainability is moderated by the consumer's information processing preference.

2.3. AR-enhanced dining experience for sustainability and behavioral intentions

2.3.1. Anticipated meal completion

In this study, we define anticipated meal completion as a consumer's expectation of finishing their meal, serving as a proxy for perceived food waste and reflecting an alignment between portion size and consumption. Augmented reality (AR) has emerged as a promising tool to enhance dining experiences by fostering sensory immersion (Batat, 2021), mental simulation, and personal relevance of food items (Fritz *et al.*, 2023). These immersive experiences can promote food-related well-being, which in turn can encourage positive consumer behaviors (Batat, 2021). Notably, eudaimonic motivations have been shown to guide more sustainable purchasing decisions (Polisetty *et al.*, 2024). Within this context, AR-enhanced dining experiences for sustainability may influence not only what consumers choose to eat, but also their intentions to finish their meals.

H4. The AR-enhanced dining experience for sustainability positively influences consumers' anticipated meal completion.

2.3.2. Intention to reuse the AR-based e-menu

The effectiveness of AR in restaurant contexts extends beyond immediate engagement to include long-term behavioral intentions, such as intention to reuse. Key features of AR such as telepresence, enjoyment, and connectedness have been found to positively influence users' continuance intentions in technology-mediated environments (Hung *et al.*, 2021). In particular, AR-enhanced experiences that emphasize sustainability may activate eudaimonic motivations, thus encouraging repeated engagement. For instance, Ye *et al.* (2022) found that eudaimonic factors significantly enhanced students' intention to keep using immersive technologies like virtual reality. Supporting this, Ali (2022) identifies intention to reuse as a primary behavioral outcome of AR-enhanced experiences.

H5. The AR-enhanced dining experience for sustainability positively influences the consumers' intention to reuse the AR-based e-menu.

2.4. The mediating role of the AR-enhanced dining experience for sustainability

Grounded in the Stimulus-Organism-Response (S-O-R) framework (Mehrabian & Russell, 1974), the AR-enhanced dining experience for sustainability can be conceptualized as a mechanism through which design stimuli shape consumer responses (Figure 1). Prior research has shown that menu's verbal elements influence perceived food quality and consumer expectations (Behnke *et al.*, 2024), while visual elements influence consumer choice and increase product selection (Shafei *et al.*, 2016). Furthermore, interface design and narrative engagement enhance eudaimonic experiences (Daneels *et al.*, 2021), and overall customer experiences (Bleier *et al.*, 2019). In turn, eudaimonic (Polisetty *et al.*, 2024), along with hedonic and utilitarian experiences (Vieira *et al.*, 2022), can ultimately influence consumer behavior.

H6. The AR-enhanced dining experience for sustainability mediates the positive relationship between AR-based e-menu's verbal elements and consumers' anticipated meal completion (H6a), as well as the consumers' intention to reuse the AR-based e-menu (H6b).

H7. The AR-enhanced dining experience for sustainability mediates the positive relationship between AR-based e-menu's visual elements and consumers' anticipated meal completion (H7a), as well as the consumers' intention to reuse the AR-based e-menu (H7b).

3. Methodology

This study adopts a mixed-method research design to examine how AR-based e-menus influence anticipated meal completion and intention to reuse through experiential mechanisms. The qualitative phase will involve *in-depth interviews* with 15 English-speaking European participants with prior AR exposure. Interviews will explore general dining behavior, portion perception in restaurants, attitude toward food waste, perceptions of AR in e-menu design and its role in portion customization. Data will be thematically analyzed. The quantitative phase will include a pre-study and a main study, both conducted through online surveys. The *pre-study* aims to validate and assess the quality of the AR-based e-menu prototype, developed by QReal. A sample of 100 European participants, VR headset owners will evaluate the e-menu on realism, attractiveness, interactivity, engagement, immersion, imagination, and credibility. The *main study* will use the validated prototype to test the research model (Appendix A) through a between-subject design. A sample of 250 participants with the same profile will be randomly assigned to either a standard or customized portion condition. After interacting with the AR-based e-menu, participants will complete an online survey measuring all variables in the research model. Data will be analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). Appendix B presents the AR-based e-menu prototypes used in the experimental conditions,

showcasing the verbal and visual elements designed to activate the AR-enhanced dining experience for sustainability.

4. Theoretical contributions

This research is expected to make three main theoretical contributions. *First*, it extends the AR-EX framework (Ali, 2022) to a sustainability-oriented restaurant context. Prior work has framed AR primarily as a driver of utilitarian, hedonic, and social experiences in hospitality and entertainment (Ali, 2022; Batat, 2021; Shaheen et al., 2024). By focusing on portion-size visualization and customization, this study positions AR not only as an engagement tool but also as a mechanism for reducing food waste. In doing so, the AR-EX model is adapted to account for ecological and prosocial outcomes. *Second*, the study introduces eudaimonia as a fourth dimension of AR-enhanced dining experience. Unlike hedonic experiences (pleasure), utilitarian experiences (functionality), or social experiences (connectedness), eudaimonic experiences emphasize personal meaning, reflection, and value alignment (Lengieza et al., 2019; Mugel et al., 2019). Integrating this dimension demonstrates that AR interactions can foster deeper, value-driven engagement, thereby extending customer experience theory toward sustainability. *Third*, the research conceptualizes AR-based e-menus as behavioral design interventions rather than merely informational tools. Drawing on the Online Customer Experience framework (Bleier et al., 2019), it theorizes how verbal and visual design elements influence anticipated meal completion and reuse intentions via experiential mechanisms. This reframes AR-based e-menus as design levers that can simultaneously promote consumers' sustainable behavior in restaurants (e.g., meal completion, waste reduction) and enhance their dining experiences.

5. Implications, limitations and future research directions

This study is expected to offer practical guidance for restaurateurs by showing how AR-based e-menus with customizable portion previews can contribute to food waste reduction. The solution can be cost-effectively integrated into existing digital systems, scaled gradually, and optimized through user-centered design. Additionally, framing AR-based e-menus around food waste reduction and regulation compliance can not only support operational efficiency but also enhance brand image. This alignment with global sustainability frameworks, including the Paris Agreement, further positions restaurants as proactive actors in addressing climate and food system challenges.

This study's limitations include the use of a simulated AR setting, calling for real-world validation. Additionally, future research should explore eudaimonia in other sustainability areas and examine ethical risks like overconsumption linked to AR's persuasive power.

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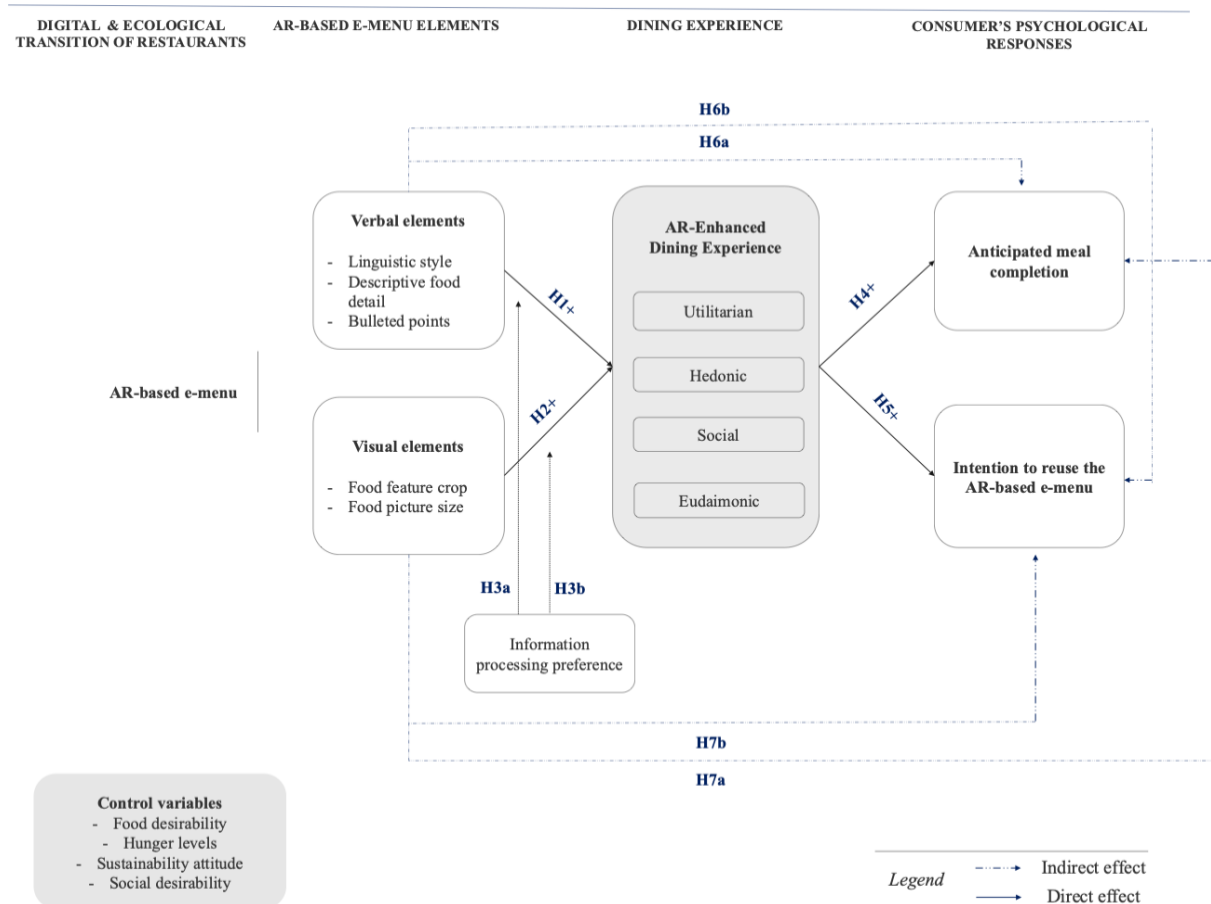
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Appendices

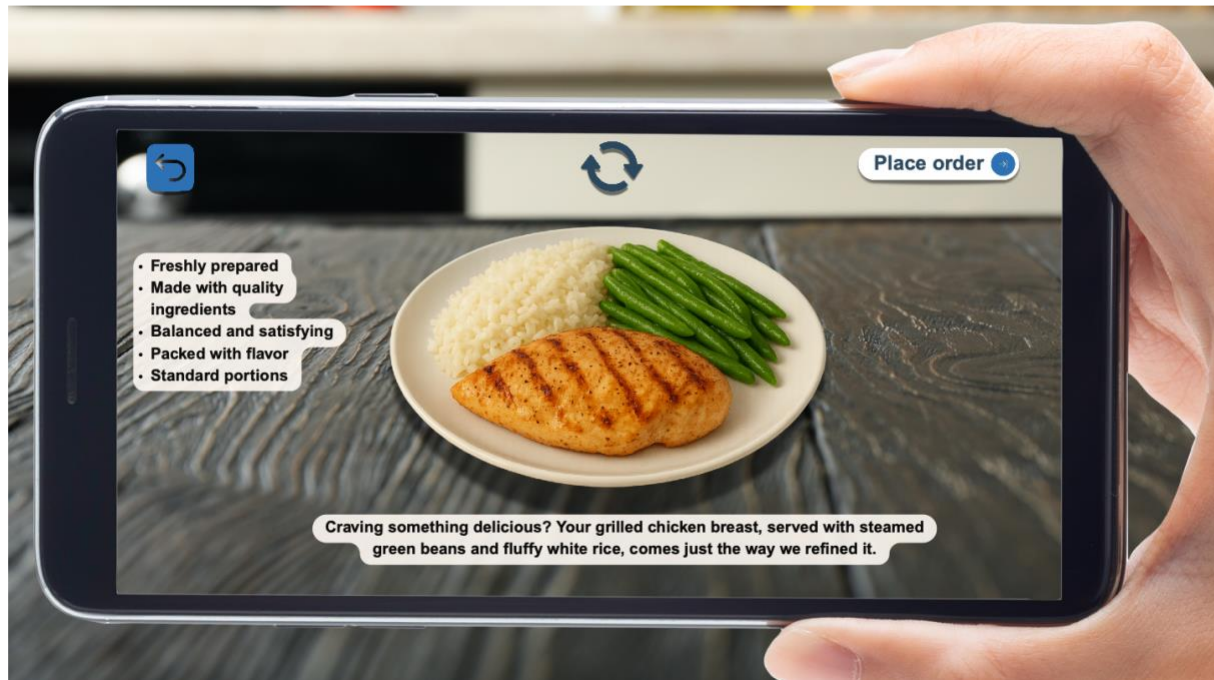
Appendix A

Figure A.1. A model of the AR-enhanced dining experience for sustainability



Appendix B. AR-based e-menu prototype across conditions

Appendix B.1. Standard portion (control condition)



Appendix B.2. Customized portions

