Visualizing Customization: The Impact of Product Visualization Modalities on User-Friendly Description in Online Configurators

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Abstract

This study investigates the influence of various product visualization modalities on the user-friendly product space description capability of online sales configurators (OSCs). As the possibility for customers to self-customize a product becomes more and more common in e-commerce, understanding how different visualization techniques affect OSC users' comprehension and decision-making is important. We examine ten visualization modalities, including 2D and 3D visualizations, augmented reality, and virtual try-on, across four aspects of user-friendly product space description capability: comprehensive presentation, balanced description, adaptability to user expertise, and versatility in highlighting product capabilities and structure. Using data from 516 evaluations of different OSCs, we employ regression analysis to examine the effectiveness of each modality. Our findings reveal that static and semi-interactive modalities, such as 2D visualization and virtual images, consistently enhance user-friendly product space description capability across all its considered aspects. In contrast, more complex modalities, such as 3D walkthroughs, show mixed results. We also explore the impact of visualization timing and gender differences, finding that end-of-configuration visualizations generally outperform real-time updates. These insights contribute to the optimization of OSC design, potentially improving user experience and decision-making in digital customization environments.

Keywords

Online Sales Configurator, Product Visualization Modalities, User-Friendly Description Capability

1. Introduction

On the current market, more and more online sales configurators are being introduced by major consumer companies [1]. These configurators enable customers to personalize products based on their preferences. Functionally, they are knowledge-based systems that support potential customers in completely and correctly specifying a product solution within a company's product space [2, 3]. From a technical viewpoint, sales configurators are rule-based systems that guide users through the configuration process, based on predefined product options and combinability constraints modeled into the configurator [4, 5].

While the technical aspects of configuration systems are well-developed, research on user perceptions and consumer behavior within the configuration process continues to evolve. Recent studies have highlighted the critical role of visualization in shaping user experience and decision-making within configurators. In particular, Sandrin and Forza [6] emphasize the importance of re-examining visualization strategies in light of modern technologies. They argue that advancements in augmented reality (AR), virtual reality (VR), and other immersive technologies have opened new avenues for enhancing product representation and user interaction in configurators.

Building on these insights, Petterle et al. [7] introduce an evaluation framework to better understand how visualization tools function in practice and to assess the effectiveness of these tools.

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This framework categorizes visualization modalities according to eleven descriptors, such as presence, embodiment, realism, vividness, and interactivity. This framework enables researchers and practitioners to compare different visualization modalities within configurators in a structured and meaningful way.

Indeed, these technological advancements, including virtual try-on, 3D visualization, and 360-degree views, have transformed how consumers engage with customizable products. However, despite the availability of multiple visualization modalities, their effectiveness in improving the user-friendly product space description capability of configurators remains unclear. According to Trentin et al. [2], this is one of five key capabilities that OSCs should deploy to reduce cognitive load and anticipated regret, alongside focused navigation, flexible navigation, benefit–cost communication, and easy comparison. As Blazek [8] points out, the evolution of product configurators must focus not just on technological capabilities but on creating customization experiences that truly support user understanding and engagement. Accordingly, in order to augment our knowledge on how technological advancements in the area of product visualization enhance customization experiences, this study aims to investigate how different product visualization modalities influence the user-friendly product space description capability of online sales configurators. Specifically, we examine four key aspects of this capability:

- Comprehensive Presentation Across Time Constraints
- Balanced Description for General and Detailed Understanding
- Adaptability to User Expertise Levels
- Versatility in Highlighting Product Capabilities and Structure

Additionally, we explore the impact of visualization timing (real-time updates vs. end-of-configuration visualization) and gender differences in shaping user evaluations of this capability. In doing so, we respond to recent calls in the field to consider both the technological and human factors in configurator design [9].

This study is exploratory in nature: our goal is to uncover meaningful patterns and generate insights into what makes the experience clearer, easier, or more engaging for users. By exploring this still underdeveloped area, we hope to contribute to a deeper understanding of how visualization supports user decision-making in digital configuration settings. In the long run, these findings can help e-commerce platforms, digital marketers, and UX designers seeking to optimize online configurators and enhance product comprehension, user engagement, and overall satisfaction in digital product customization.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on product visualization in online sales configurators. Section 3 describes the research method, including data collection, measures, and data analysis. Section 4 presents the empirical results of the regression analyses, organized around regression model performance, visualization modality effectiveness, and the effects of visualization timing, gender, and product type. Section 5 discusses the findings in relation to prior research, while Section 6 concludes with the main contributions of this research to theory and practice as well its limitations and related opportunities for further research.

2. Literature Review

Online sales configurators (OSCs) have become indispensable tools in implementing mass-customization strategies within e-commerce environments. These systems are designed to support customers in specifying a valid product configuration that matches their needs and preferences, within the constraints of a firm's product offering [2, 3]. As highlighted by Walcher and Piller [10], OSCs empower customers to define their desired product configurations within a company's predefined solution space, thus fostering co-creation, as customers actively participate in defining their individualized product solutions [11, 12].

The effectiveness of OSCs largely depends on their ability to present product information clearly and intuitively. As emphasized by Forza and Salvador [13], the commercial dialogue in OSCs should mirror the natural way customers describe their product preferences. Recent research by Grosso and Forza [14] suggests that integrating social interaction features in OSCs can further enrich the customization experience by enabling users to seek advice from friends, online communities, or company representatives.

In this context, Trentin et al. [2] propose five key capabilities that effective configurators should deploy: user-friendly product-space description, focused navigation, flexible navigation, benefit–cost communication, and easy comparison. Each of these capabilities contributes to reducing the user's cognitive and emotive costs [2] while increasing perceived customization value [15, 16]. Among these capabilities, the ability to present the product space in a user-friendly manner is particularly important, as it allows the configurator to adjust its presentation according to different usage contexts, such as the user's level of expertise or available decision time [2]. This principle resonates with Forza and Salvador's call for configurators to reflect natural customer language and behavior [13].

A growing body of research underscores the central role of product visualization in enhancing user experience and facilitating informed decision-making in OSCs. For instance, Di et al. [17] highlight the important role played by product images in capturing consumer attention, building trust, and increasing conversion rates. The evolution of visualization technologies has led to a shift from static 2D images to more interactive and immersive formats. Recent work by Petterle et al. [7] offers a structured framework for evaluating these advancements, identifying eleven key variables, including presence, realism, vividness, and interactivity, that differentiate traditional and advanced visualization modalities.

Among traditional tools, 3D visualization has gained significant attention in recent years. For instance, Ozok and Komlodi [18] found that users perceived 3D product representations as more detailed, engaging, and informative than 2D images, resulting in higher consumer satisfaction. Similarly, Moritz [19] established that interactive 3D visualizations were particularly beneficial for customizable products.

At the frontier of product visualization technologies are augmented reality (AR) and virtual reality (VR), which offer immersive product interaction and represent the cutting edge of product visualization in e-commerce. A study by Jessen et al. [20] suggests that AR enhances customer engagement, influences purchase decisions, and fosters positive brand perception. In parallel, Liu et al. [21] find that VR shopping environments can simulate physical stores, offering consumers a sense of presence and engagement comparable to in-person shopping. However, the effectiveness of these advanced visualization modalities is not universally established. For instance, Befort [22] compares the effectiveness of 3D product visualization via AR and VR in e-commerce and finds that, while traditional 2D images remain effective, AR outperforms VR in user engagement, particularly among older generations.

Another key factor influencing the effectiveness of product visualization is the timing of visualization. Whether visual information is delivered in real time during the configuration process or at the end plays an important role in shaping the user experience. Sandrin and Forza [6] highlight the need for further research on how these different timings of visualization impact user comprehension and decision-making in OSCs.

Additionally, user diversity is emerging as a relevant consideration in configurator design. Gender-based differences in how users interpret and respond to visual content have been noted in various studies, but their specific impact on OSC visualization effectiveness remains underexplored. However, Yi et al. [9] have stressed the importance of considering user diversity in configurator design to create more inclusive and effective customization experiences. Similarly, recent work by Blazek [8] underscores the importance of balancing technological advancements with user-centric design principles in creating effective customization experiences.

In summary, while extensive research exists on various aspects of OSCs and product visualization, there remains a gap in understanding how specific visualization modalities impact the user-friendly

product space description capability of sales configurators, particularly when considering factors such as visualization timing and gender differences. This study aims to address this gap and contribute to the ongoing evolution of OSC design and effectiveness.

3. Method

This study adopts a quantitative approach to explore the impact of different product visualization modalities on the user-friendly product space description capability of OSCs. In this exploration, the research also considers the potential moderating effects of visualization timing and gender.

In line with established methodological guidelines for such research, this section begins by outlining the data collection procedure and describing the sample characteristics. It then presents the measures of the focal constructs and concludes by illustrating the statistical techniques employed to analyze the data.

3.1. Data collection procedure

The data were collected from students enrolled in a digital customization course at the University of Padova during the 2022-2023 academic year. Each participant was randomly assigned a list of OSCs by the course professor to ensure a diverse range of visualization modalities. From the assigned list, each student selected four configurators and, with each of them, configured a product from start to finish and then modified his/her configuration to explore different options. Each participant completed individual evaluation forms, including pre- and post-surveys, which were specifically designed to collect data on various dimensions used to evaluate the online configurators. The final dataset includes 516 evaluations, with 348 (67.4%) from male participants and 168 (32.6%) from female participants (Figure 1). All respondents were native Italian speakers enrolled in the same course with similar academic backgrounds.

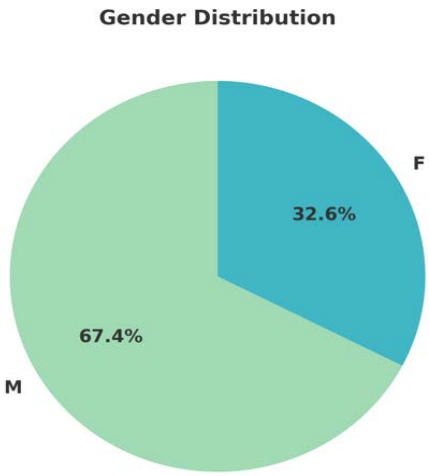

Figure 1: Gender Distribution of Respondents.

3.2. Measures

3.2.1. Independent Variables

Ten visualization modalities were assessed for their availability within each configurator (see Table 1). These included virtual try-on, augmented reality, 3D walkthrough, 3D visualization, 360 view, 2D visualization, product video, photo of the real product, virtual image, and the product in motion. The availability of each modality was coded: present (1) or absent (0).

Table 1: Independent Variables - Product Visualization Modalities

CODE	NAME	DEFINITION	RANGE
Q367	Virtual Try-On	Allows users to see how a product would look on their face or body, typically used for makeup, accessories, clothing, shoes, etc.	0 – NO 1 – YES
Q368	Augmented Reality (AR)	Displays products within the user's real-world environment, such as furniture in their living room or other items in their space.	0 – NO 1 – YES
Q369	3D Walkthrough	Enables users to virtually explore an environment, such as walking through an apartment or other spaces.	0 – NO 1 – YES
Q370	3D Visualization	Products are presented in three-dimensional models, allowing a more detailed and interactive experience.	0 – NO 1 – YES
Q371	360 View	Provides a full, interactive view of a product from all angles.	0 – NO 1 – YES
Q372	2D Visualization	Traditional flat images of a product, such as pictures from various perspectives, typically used in online shopping.	0 – NO 1 – YES
Q373	Video	A moving image of the product in action, often used to demonstrate its features or functionality.	0 – NO 1 – YES
Q374	Photo of the Real Product	A photograph of the actual product, offering a realistic view of what the consumer would receive.	0 – NO 1 – YES
Q375	Virtual Image	A digitally created image or model of the product, generated by software to visualize the product in a simulated environment.	0 – NO 1 – YES
Q376	The Product in Motion	The product is shown in action or in motion, allowing users to see how it operates or behaves during use.	0 – NO 1 – YES

3.2.2. Dependent Variables

Each aspect of the user-friendly product space description capability was measured by means of one item taken from validated instruments used in previous OSC-related studies [e.g., 2, 3] (see Table 2). Each item was measured on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree).

Table 2: Dependent Variables - Item-level of User-Friendly Description Capability

CODE	NAME	DEFINITION	RANGE
Q58	Comprehensive Presentation Across Time Constraints	The system gives an adequate presentation of the choice options for when you are in a hurry, as well as when you have enough time to go into the details.	1=Low 7=High
Q60	Balanced Description for General and Detailed Understanding	The product features are adequately presented for the user who just wants to find out about them, as well as for the user who wants to go into specific details.	1=Low 7=High
Q86	Adaptability to User Expertise Levels	The choice options are adequately presented for both the expert and inexpert user of the product.	1=Low 7=High
Q90	Versatility in Highlighting Product Capabilities and Structure	The site gives an adequate representation of the products for when one wants to know what the product is used for, as well as what it consists of.	1=Low 7=High

3.2.3. Moderating Variables

Visualization timing and gender were included in the analysis as possible moderating variables. The two alternative solutions concerning visualization timing were measured with the binary variables reported in Table 3.

Table 3: Visualization Timings Variables

CODE	NAME	DEFINITION	RANGE
Q377	Real-Time Visualization	Product visualization updates simultaneously or immediately after a modification of selected options.	0 – NO 1 – YES
Q377	End-Point Visualization	Product visualization is displayed only at the end of the configuration process, requiring users to complete all selections before viewing the final product.	0 – NO 1 – YES

3.3. Data Analysis

The dataset was analyzed using Generalized Least Squares (GLS) regression with a hybrid weighting approach. This approach combines the frequency of visualization modality availability and the distribution of product types to assign weights that account for both common and rare cases, ensuring each is fairly represented in the results. This type of regression was chosen to address issues of heteroscedasticity and autocorrelation in the residuals identified during preliminary Ordinary Least Squares (OLS) regression analyses. To enhance interpretability and address potential non-linearity, we applied a log transformation to the dependent variables.

Separate GLS models were estimated for each of the four dependent variables to assess the impact of the visualization modalities. In addition, subgroup analyses were conducted to explore the role of visualization timing and gender as moderating variables.

4. Results

This section presents the results from the GLS regression analyses. The findings are organized according to five thematic dimensions: (1) overall model performance, (2) effectiveness of visualization modalities, (3) influence of visualization timing, (4) influence of gender, and (5) influence of product type.

4.1. Overall Model Explanatory Power

The GLS regression models demonstrate modest explanatory power across the four dimensions of user-friendly product space description capability. *R*-squared values range from 0.033 to 0.070 (Figure 2), indicating that visualization modalities account for a small but meaningful portion of the variance in user evaluations. Among the four dimensions, Balanced Description for General and Detailed Understanding shows the highest *R*-squared value at 0.070, suggesting that visualization choices explain this dimension better than the others. Comprehensive Presentation and Versatility in Structural Description follow with *R*-squared values of 0.044 and 0.048, respectively. In contrast, Adaptability to Expertise shows the lowest explanatory power ($R^2 \approx 0.033$).

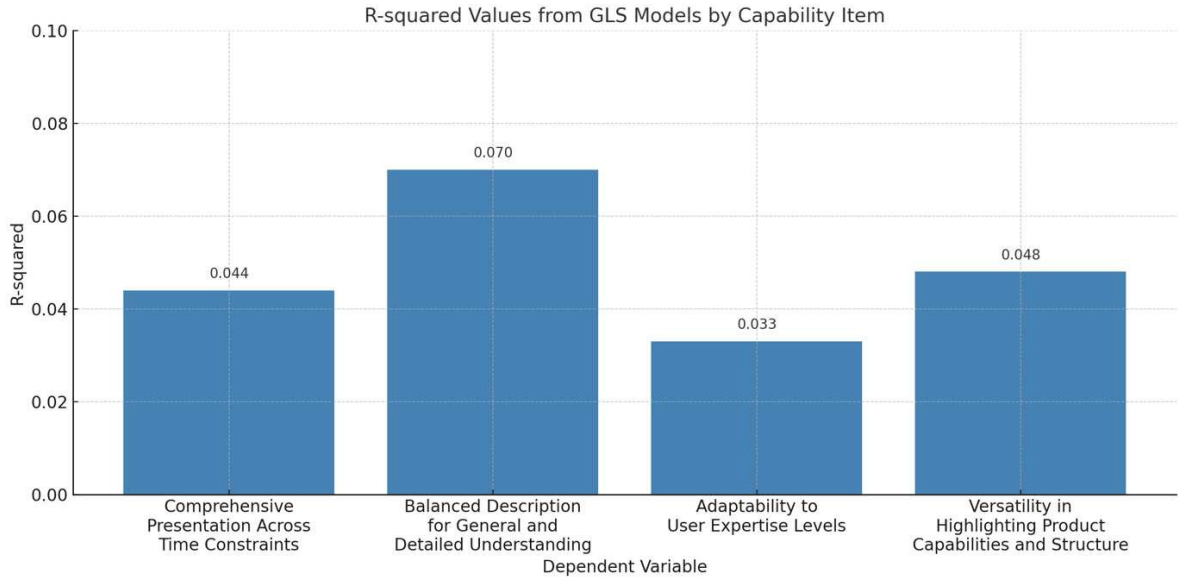

Figure 2: Bar Chart of *R*-Squared

4.2. Effectiveness of Visualization Modalities

The heatmap presented in Figure 3 illustrates the standardized regression coefficients derived from the GLS models across the four dimensions of the user-friendly product space description capability. A few patterns emerge across visualization categories:

Static and semi-interactive formats, including 2D visualization, virtual image, photo of the real product, and 3D visualization, tend to be positively associated with all four dimensions. For instance, photo of the real product has significant positive effects on presentation comprehensiveness across time constraints ($\beta = 0.07$, $p = 0.023$) and balanced description for general and detailed understanding ($\beta = 0.06$, $p = 0.018$). Similarly, interactive formats, such as 360 view, have a significant positive effect on balanced description ($\beta = 0.05$, p = 0.075).

Conversely, immersive technologies, particularly virtual try-on, exhibit significant negative effects across multiple dimensions, particularly balanced description (β = -0.12, p = 0.005) and versatility in highlighting product capabilities and structure (β = -0.13, p = 0.007), suggesting potential challenges in terms of user-friendly product space description capability.

Finally, dynamic formats, such as video, show positive effects, particularly for comprehensive presentation across time constraints ($\beta = 0.08$, $p = 0.091$) and balanced description ($\beta = 0.07$, $p = 0.054$), indicating their value in supporting user-friendly product space description capability.

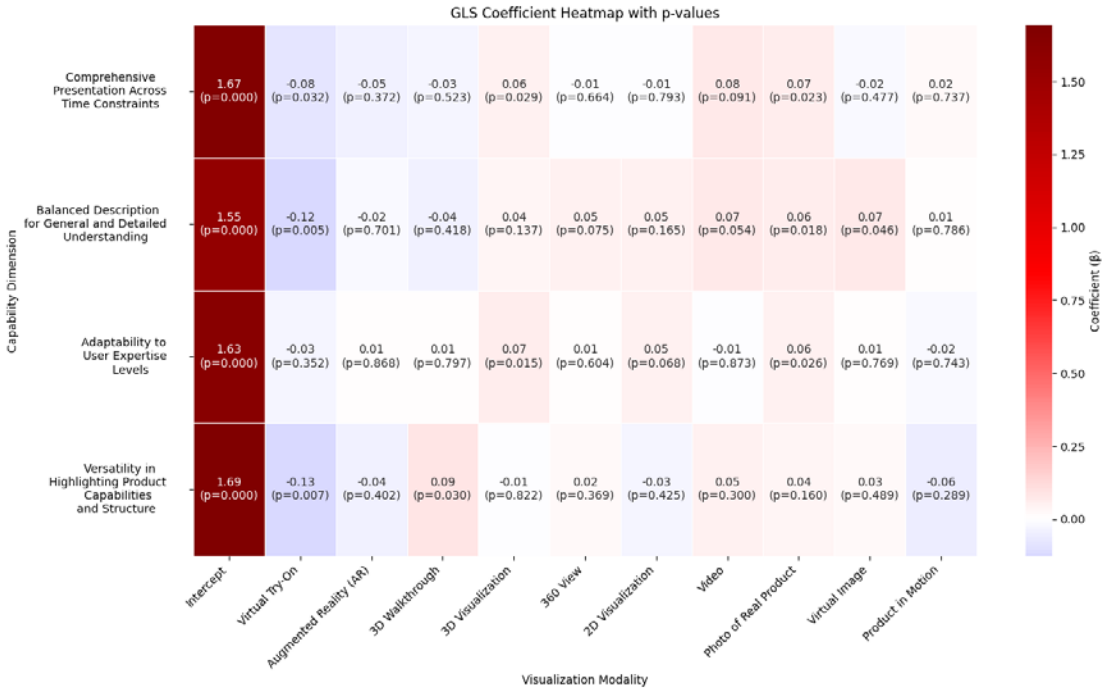

Figure 3: Heatmap of Regression Coefficients.

These results are complemented by the regression coefficient plot with confidence intervals presented in Figure 4, which visually represent the statistical significance and direction of effects across modalities.

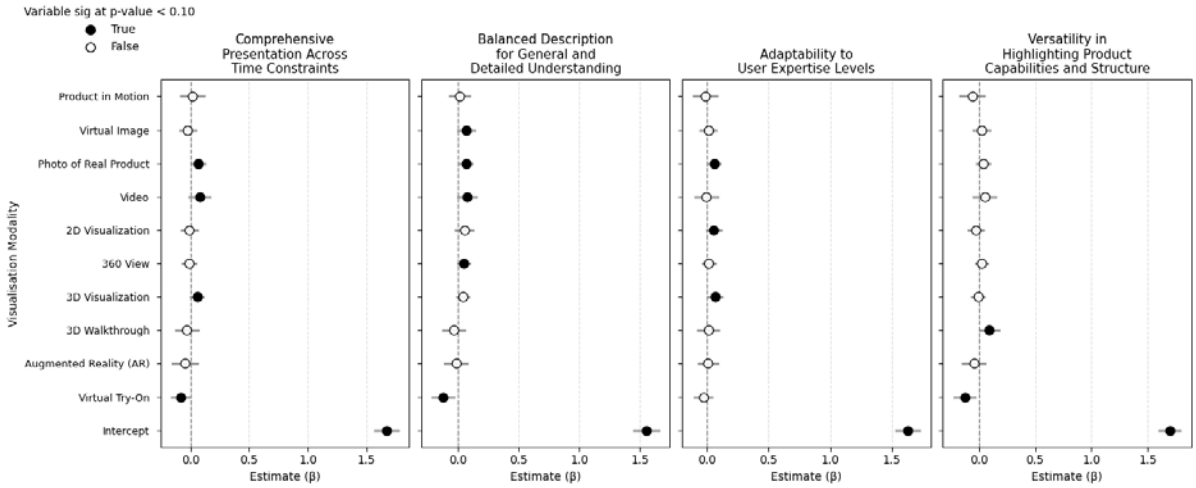

Figure 4: Regression Coefficient Plots.

4.3. Visualization Timing Influence

The timing of visualization (i.e., product visualization during the configuration process or at the end of the configuration process) emerges as a critical determinant of configurator effectiveness. Its role is clearly illustrated in the heatmap (Figure 5), which compares immediate updates and end-of-configuration visualization.

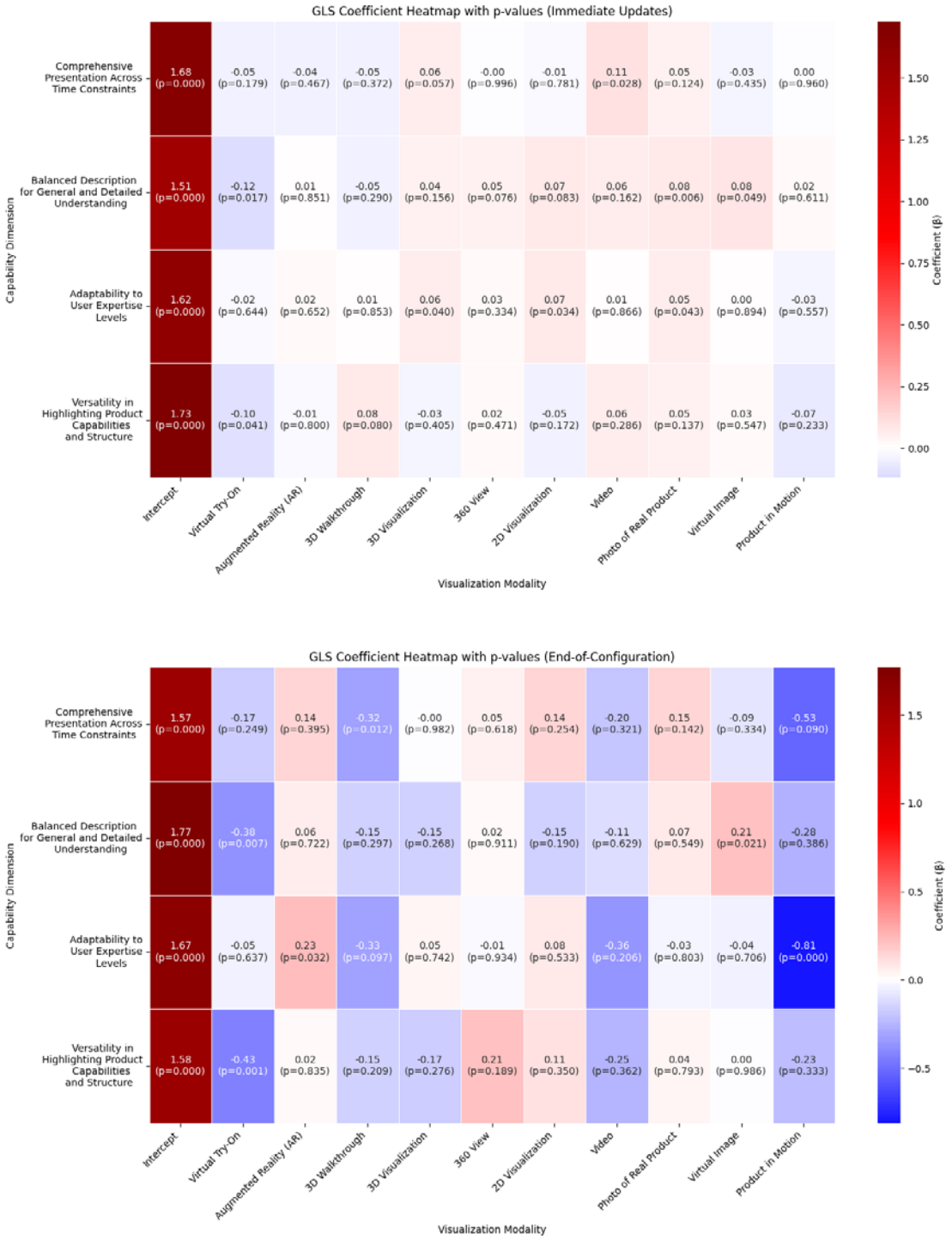

Figure 5: Heatmap of Regression Coefficients For the Two Values of Visualization Timing.

These results are complemented by the regression coefficient plots (Figure 6), which visually represent the statistical significance and direction of effects across modalities.

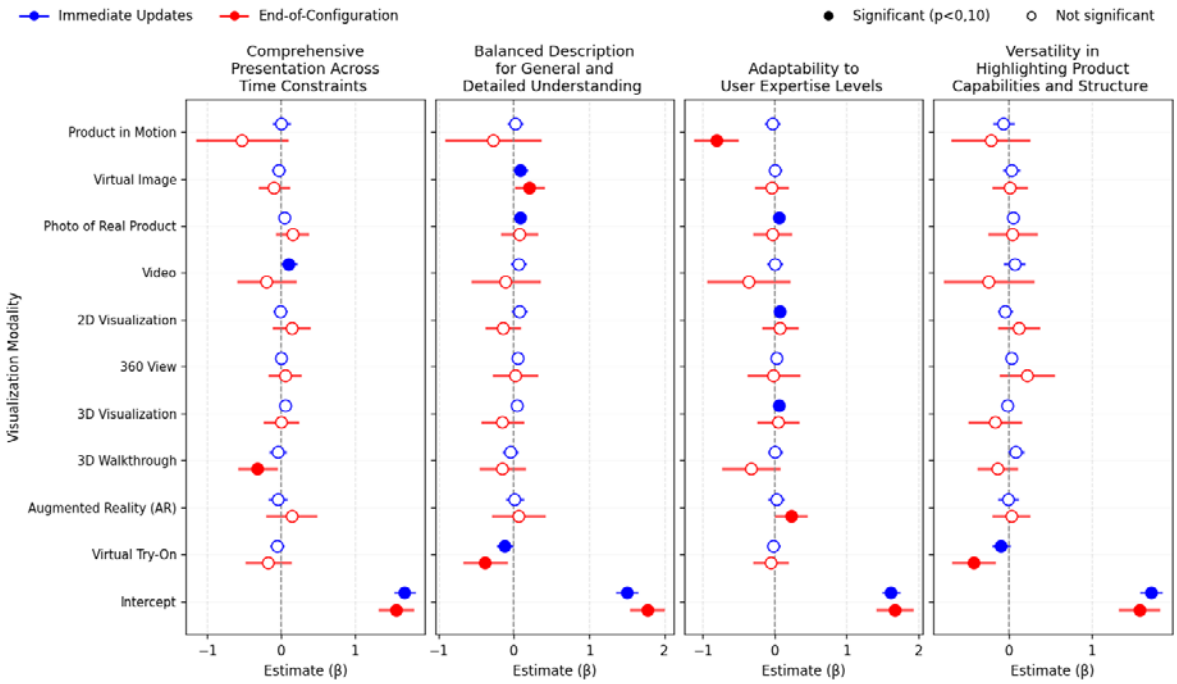

Figure 6: Regression Coefficient Plots For the Two Values of Visualization Timing.

End-of-configuration visualization consistently outperforms real-time updates in explanatory power across all four dimensions. For instance, the *R*-squared value for presentation comprehensiveness across time constraints increases from 0.045 for immediate updates to 0.281 for end-of-configuration visualization (Figure 7).

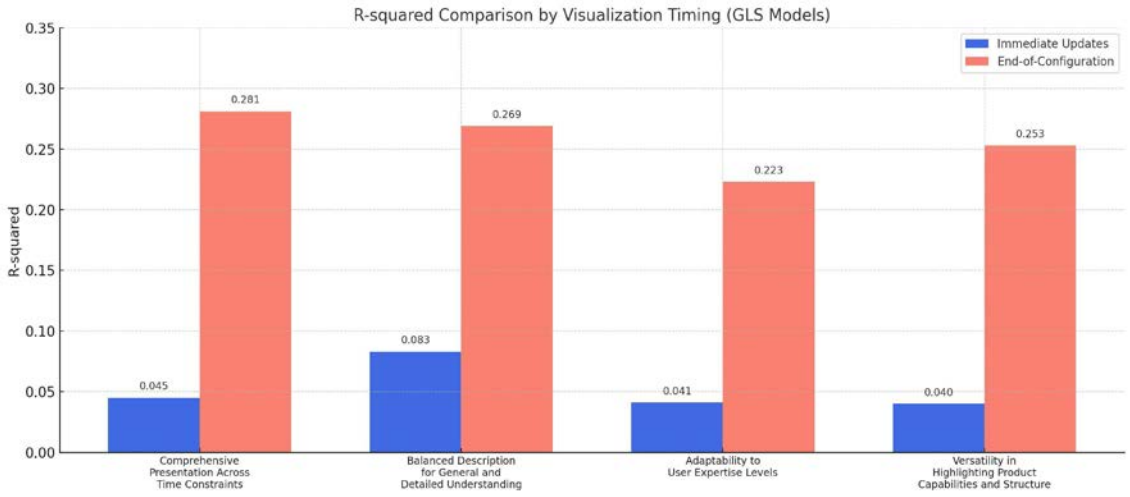

Figure 7: Bar Chart of R-squared for Visualization Timings.

4.4. Gender Influence

Gender-based models reveal notable differences in how visualization modalities impact the configurator capability. These patterns are clearly visualized in the gender-based heatmap (Figure 8), which illustrates the variation in modality effectiveness across gender groups.

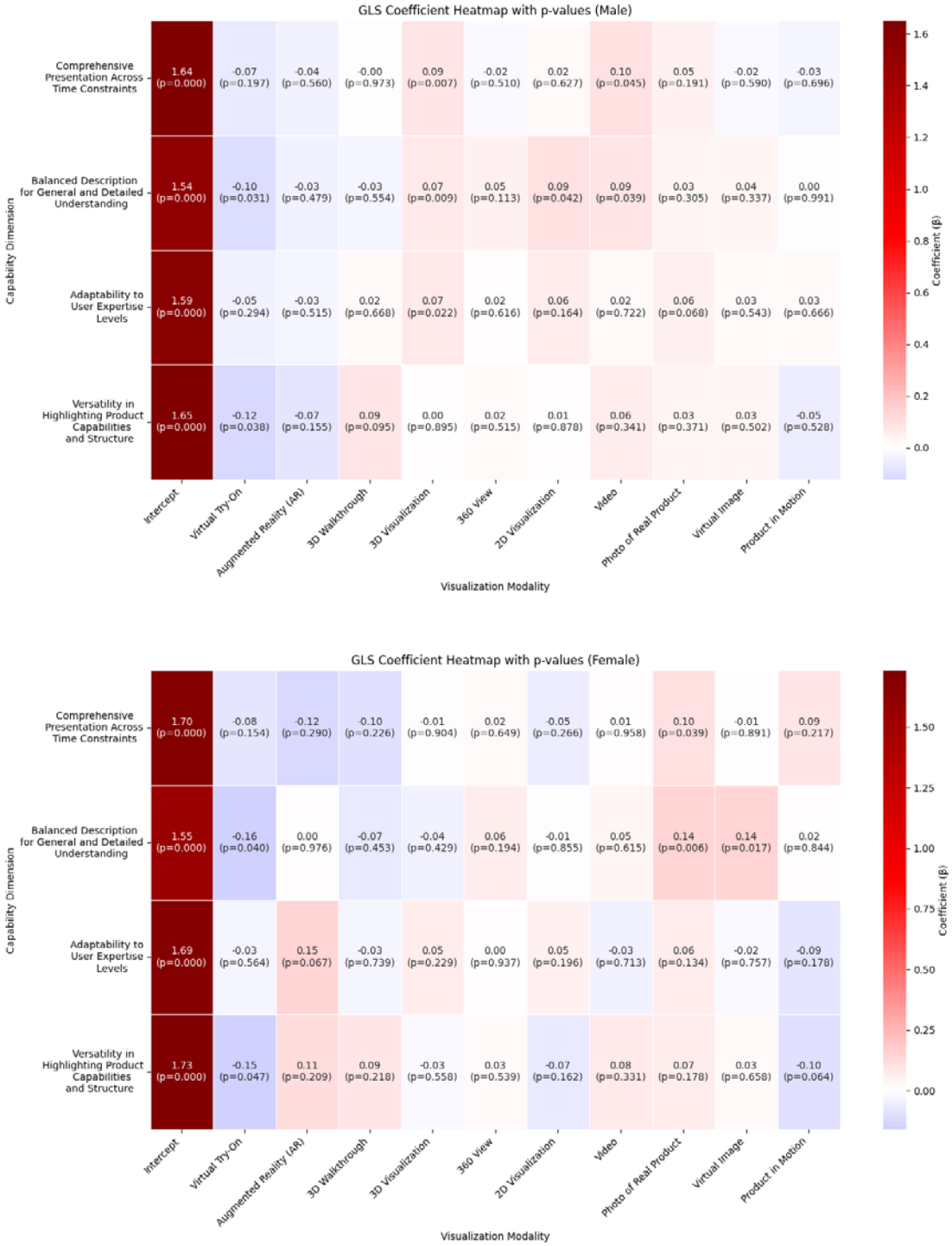

Figure 8: Heatmap of Regression Coefficients for the Two Genders.

These results are complemented by the regression coefficient plot with confidence intervals presented in Figure 9, which visually represent the statistical significance and direction of effects across modalities.

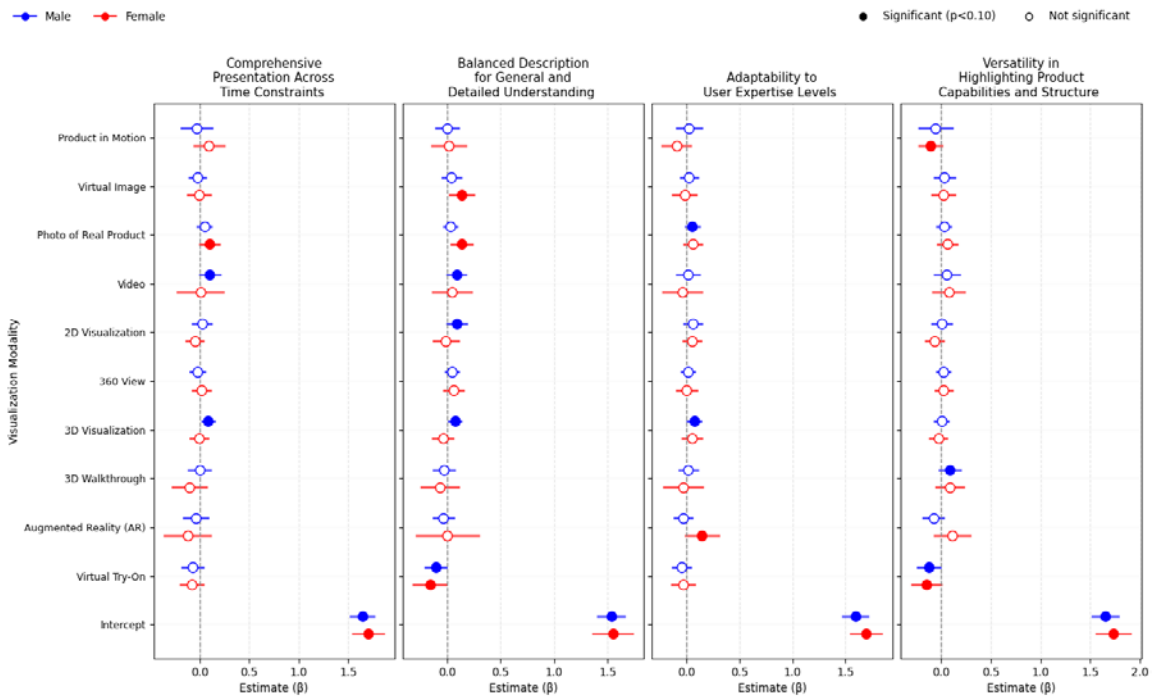

Figure 9: Regression Coefficient Plots for the Two Genders.

Female-specific models yield higher *R*-squared values across all four capability items compared to male-specific models (Figure 10). The largest gap appears in presentation comprehensiveness across time constraints, where the female model achieves an R^2 of 0.091 versus 0.043 for males.

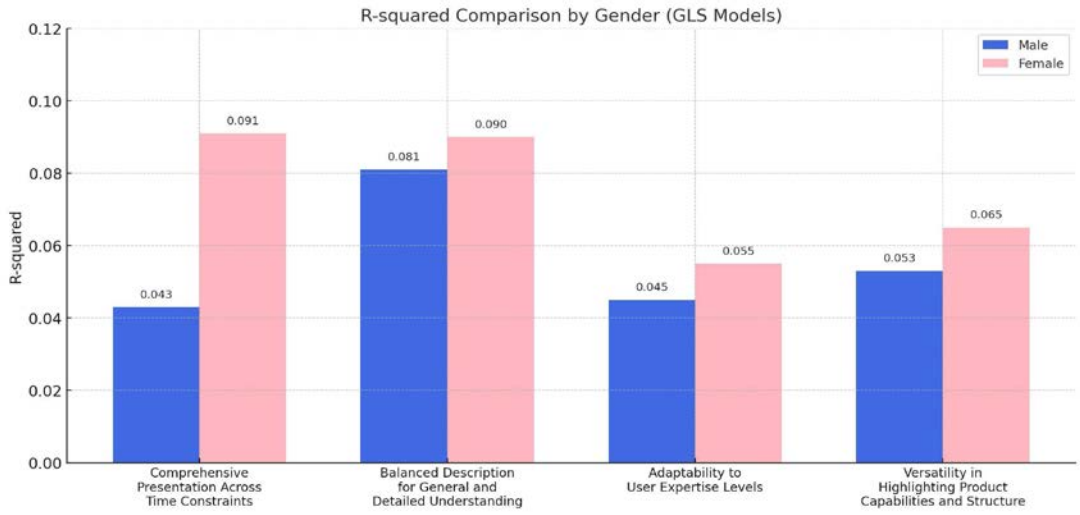

Figure 10: Bar Chart of *R*-Squared Comparison by Gender-Based

Among male users, 3D visualization and video show consistent positive effects across all dimensions. In contrast, female users respond more favorably to photo of the real product and virtual image, particularly as regards comprehensiveness and balanced understanding.

4.5. Product Type Influence

Although not a primary focus of the study, the descriptive analysis indicates that the adoption of visualization modalities varies across product types. The presence of the ten visualization modalities, in percentage of the total number of configurators analyzed in the study, is shown in Figure 11, suggesting that many OSCs adopt multiple modalities.

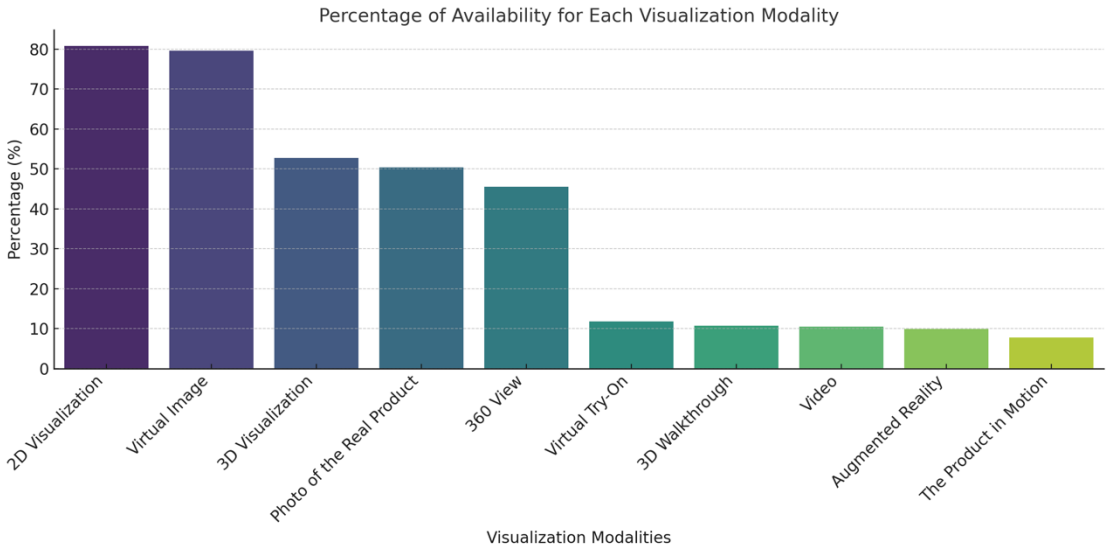

Figure 11: Distribution of Visualization Modalities in Online Sales Configurators.

Building on this, the counts of products across visualization modalities are reported in Figure 12, where products are classified into 14 product categories.

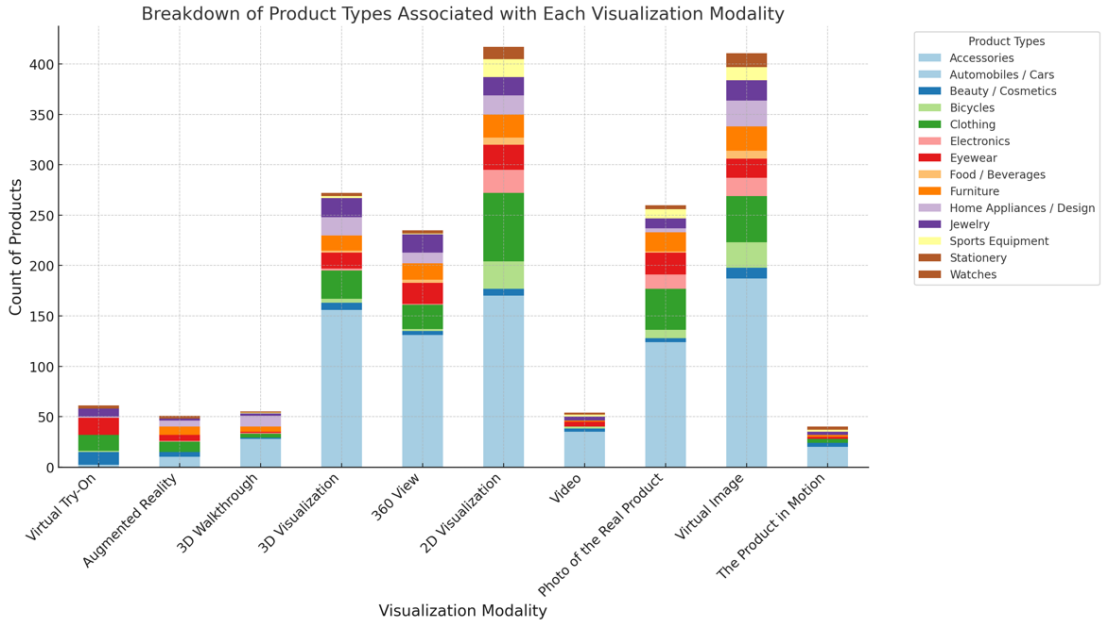

Figure 12: Count of Visualization Modalities Across Product Types.

Finally, Figure 13 emphasizes differences in modality adoption within each product category. The data are normalized per category to highlight the proportion of configurators adopting each modality, allowing comparison of preferred visualization strategies across domains such as beauty, eyewear, automobiles, furniture, and electronics. For instance, virtual try-on shows higher adoption rates in beauty/cosmetics (22.0%) and eyewear (12.7%) configurators, compared to other product types.

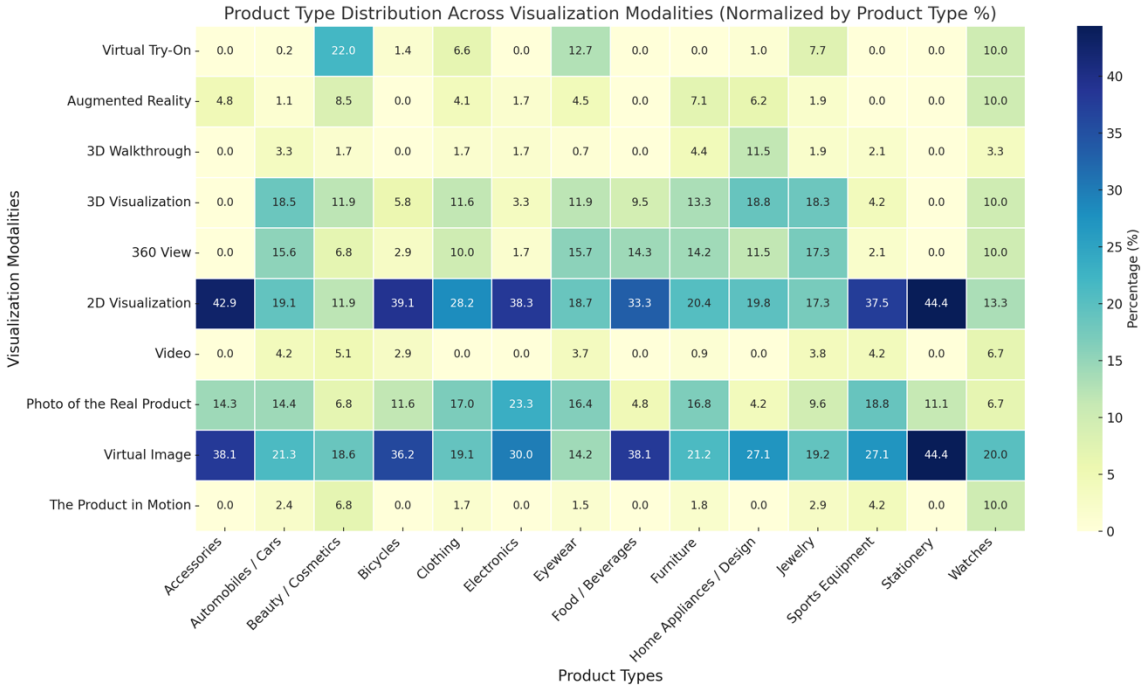

Figure 13: Distribution of Visualization Modalities by Product Type.

5. Discussion

The findings of this study offer nuanced insights into the role of visualization modalities in shaping the user-friendly product space description capability of online sales configurators (OSCs). Rather than pointing to a single optimal solution, the results suggest a complex interaction between visualization modality, visualization timing, user profile, and product context. These dynamics influence how users comprehend, evaluate, and interact with configurable product spaces.

5.1. Effectiveness of Static and Semi-Interactive Formats

The consistent positive associations of 2D visualization, virtual image, photo of the real product, and 3D visualization across all four dimensions of the focal capability underscore the enduring value of clear, easily interpretable visual information. These formats appear to strike a balance between providing sufficient detail and maintaining cognitive ease, aligning with findings from earlier studies [e.g., 17, 18]. Their effectiveness may be attributed to their ability to reduce cognitive load while still offering essential product information, thereby supporting efficient decision-making processes.

5.2. Challenges with Immersive Technologies

The negative effects associated with virtual try-on, particularly for balanced description and versatility in highlighting product capabilities and structure, present an interesting contrast to some previous research that has highlighted the potential benefits of immersive technologies in e-commerce [e.g., 20, 22]. While immersive formats such as AR and VR can enhance user engagement and brand perception, our results suggest that these benefits may not always translate into improved clarity or usability within the context of product configuration. This finding aligns with Blazek's [8] observation that the complexity and novelty of immersive technologies may sometimes disrupt rather than support user decision-making.

5.3. Importance of Visualization Timing

End-of-configuration visualizations significantly outperform real-time updates across all four capability dimensions. The strongest effect is observed for presentation comprehensiveness across

time constraints, where explanatory power more than triples when visualization is presented after the user has finalized their selections.

This result aligns with Sandrin and Forza's [6] assertion that visualization timing should be treated as a deliberate design variable rather than a default setting. Their work emphasizes that end-of-configuration visualization allows users to process the configured product as a whole, reducing decision fatigue and supporting clearer interpretation. In contrast, real-time updates, while more dynamic, can fragment the user's cognitive focus, particularly in complex configurations.

5.4. Gender-Based Differences

The observed gender-based differences in visualization effectiveness add to a growing body of literature advocating for user-personalized interfaces. Female users responded more positively to realistic and static formats, such as photos and virtual images. Male users, by contrast, showed stronger alignment with dynamic formats like 3D visualization and video. These results echo the arguments of Yi et al. [9], who emphasize the importance of demographic-sensitive design in digital tools. Moving forward, adaptive configurators that tailor visualization types to individual user profiles may offer significant gains in usability and satisfaction.

5.5. Product Context and Modality Effectiveness

Product-type data point toward important contextual effects. For instance, while virtual try-on showed generally negative associations, its use was concentrated in product categories where physical fit and aesthetics are paramount, such as beauty and eyewear. While this modality demonstrated lower effectiveness overall in supporting user-friendly product space description, its frequent adoption in these contexts may point to a niche functional value that is not adequately captured by generic usability measures. A visualization format that enhances configurator usability in one category may fail to do so in another if it lacks alignment with the product's core interaction features.

6. Conclusion

This study makes several contributions to the literature on mass customization and e-commerce. First, it extends the understanding of user-friendly product-space description in online configurators by empirically examining the impact of various visualization modalities. This addresses a gap in the literature identified by Sandrin and Forza [6], who called for more research on the effectiveness of modern visualization technologies in configurators. Second, our findings on the superiority of end-of-configuration visualization over real-time updates challenge existing assumptions about immediate feedback in digital interfaces. Finally, the observed gender-based differences in visualization preferences contribute to the growing literature on user diversity in digital interfaces. These results highlight the need for more nuanced theoretical models that account for demographic variation in interaction patterns with customization tools.

From a practical standpoint, this study offers valuable suggestions for OSC designers and e-commerce platforms. They suggest that, while advanced visualization technologies offer exciting possibilities, their implementation should be carefully considered in the context of user cognitive processes and preferences. Prioritizing clear, easily interpretable visual formats and providing comprehensive visualization at the end of the configuration process may enhance the overall user experience and decision-making efficiency. Additionally, our results on gender differences in visualization preferences suggest that adaptive interfaces catering to different user groups could significantly enhance the overall user experience and potentially increase conversion rates.

However, it's important to note the limitations of this study. The participants were university students, which may limit generalizability to broader consumer populations. Future research could explore these relationships in more diverse consumer groups and investigate how user preferences and the effectiveness of different visualization modalities evolve over time.

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Declaration on Generative AI

During the preparation of this work, the corresponding author used ChatGPT (GPT-4) and Grammarly to check grammar and spelling and to improve writing style. After the use of these tools/services, all the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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