Affordance as an Interactive Feature to Enhance Usability in Virtual Reality

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Abstract. Although the use of Virtual Reality (VR) has been steadily increasing in diverse domains thanks to its unique characteristic of immersiveness, the platform is still struggling to enter the mainstream or ubiquitous arena. One of the culprits is the usability: many currently available VR applications exhibit a poor incorporation of design knowledge available in the field of Human-Computer Interaction (HCI). We posit that there are ways to improve the usability of VR applications by more explicitly taking design principles/guidelines into the design of actual interactivity. In this paper, we start exploring this direction by taking one of the most well-known design/usability principles, Affordance, as an explicit end-user feature in navigating a VR environment – this is by visually highlighting only those objects in the surrounding that can be approached and interacted with, so that the users will be aware of what objects they should focus on. We developed a full-fledged VR prototype where a typical household environment with a number of interactable and non-interactable objects are available; recognizing that any forms of highlighting will reduce the sense of immersiveness, the affordance on the interactable objects is only temporarily activated, either automatically in regular time intervals, or a controller button to switch on or off, or a user-maintained interaction in which the affordance is shown only while the user is holding down a controller button. A usability testing with 15 participants revealed a number of insights on how such an explicit incorporation of a design principle could improve the VR interaction.

Keywords: VR, Human–computer interaction, User interface, Affordance.

1 Introduction

The evolution of Virtual Reality (VR) technology has impacted various sectors due to its unique ability to simulate immersive environments that enables users to gain practical experience in controlled, yet realistic settings. For instance, VR games offer players interactive and engaging scenarios [1][2], while applications in medical training allow practitioners to hone their skills in life-like simulations without risk [3][4]. Similarly, VR has been used in professional training and logistics by providing a platform for safe experimentation and process optimization (e.g. [5][6]). In the realm of education, VR facilitates experiential learning, making abstract concepts more tangible and memorable for learners (e.g. [7][8]).

Despite these promising applications, VR has yet to achieve more widespread adoption due to persistent challenges. Among these are steep learning curves and usability issues that deter potential users from fully embracing the technology [9]. Failure to effectively apply design principles and usability guidelines in the unique context of VR environment results in inconsistencies in user experiences, particularly in the areas of navigation, interaction, and feedback mechanisms [10].

A critical gap in VR interaction design is the insufficient application of Human-Computer Interaction (HCI) principles, such as affordance, feedback, constraints, and visibility. These principles have been widely adopted in web and mobile interaction design, yielding high levels of usability and user satisfaction [10]. However, their underutilization in VR design has led to difficulties in intuitively understanding and interacting with virtual elements. For example, users often struggle to identify which objects in a virtual environment are interactive, leading to trial-and-error approaches that increase cognitive load and frustration.

This study investigates the integration of affordance - a key design principle - as an interactive feature to improve VR usability. Affordance refers to the sensory cues that indicate possible interactions with objects, guiding users intuitively thus potentially reducing the need for explicit instructions. By appropriately embedding affordance cues in VR environments, users should be able to more easily discern interactive elements, thereby enhancing efficiency, satisfaction, and overall experience.

To explore the effectiveness of affordance in VR, this research designs, develops and evaluates three affordance activation methods, which were tested in a VR environment with 15 participants of varying expertise levels to assess their impact on task efficiency, learnability, and user satisfaction. By analyzing both qualitative and quantitative usage and feedback data, this study aims to bridge the commonly-noticed usability gap in VR designs today, offering actionable insights for creating intuitive and effective VR interfaces.

While the principle of affordance was the main focus of this study, the findings underscore the necessity of more stringently applying HCI principles to VR interaction design if we want to achieve broader adoption of this potentially transformative technology.

2 Related Work

Despite the increasing use of VR technology in various sectors, usability remains a considerable challenge. Numerous existing VR applications feature a poor incorporation of HCI concepts, principles and guidelines as available in the field. This section summarizes an overview of how VR community has been making use of the existing interaction design and HCI knowledge available given its unique interaction characteristics, reviewing some of the studies that focus on applying HCI knowledge to enhance the VR usability, especially the affordance principle.

2.1 Advances in VR Interface Design

Since 2015, VR interaction design research has increasingly focused on intuitive and immersive interactions to optimize user engagement. Designers face the challenge of creating interfaces that support both intuitive and intricate interactions across domains such as engineering, architecture, and entertainment, each of which might require special interactivity techniques to make the most of the VR's unique properties. Multi-sensory input - haptic, auditory, and stereoscopic visual signals - has proven effective in enhancing user immersion and efficacy [11].

Recent advances in interaction methodologies include gesture-based controls and natural language processing, which simplify interactions. Xiao et al. [12] emphasize the creation of gesture-based interaction frameworks for natural and hands-free VR engagement. Other systems explore gesture-assisted manipulation of 3D objects, showing that it is more efficient than desktop-based approaches [13]. Enhanced feedback systems are critical to improving user comprehension and reducing cognitive burden in VR. The integration of AI with VR has further streamlined usability in design settings, illustrating the potential for VR systems in complex environments [14].

2.2 Usability Challenges in Virtual Reality Applications

Despite its transformational potential, many VR applications face usability issues due to how (if at all) interaction design knowledge has been incorporated or implemented. These challenges often result in user frustration, fatigue, and even motion sickness, hindering adoption [15].

One of the key problems we posit in this study is the absence of affordances. Many VR training systems fail to provide distinct visual indicators for interactable items, forcing users to rely on trial and error, which also violates the visibility principle [16]. Similarly, in e-commerce VR systems, replicating real-world store layouts without VR-specific considerations often disorients users [17]. Inadequate affordance design elevates cognitive load, impeding navigation and engagement.

Feedback mechanisms also pose a challenge. Many systems fail to provide explicit feedback after actions such as object selection or task completion. Studies show that immediate feedback, such as highlighting or sound cues, enhances user confidence and task efficiency (e.g. in [18]).

Complex interactions are another obstacle. Overly sophisticated controls and cluttered interfaces often disregard simplicity. Research comparing radial and list menus highlights that simpler designs improve selection speed and accuracy; yet, many VR applications continue to use cumbersome, 2D menu-like designs [19]. While hand tracking and gesture recognition hold potential, they remain underutilized in mainstream VR systems [20].

Several studies demonstrate the benefits of usability principles for VR applications. Sutcliffe and Gault [21] proposed criteria emphasizing immersion and usability, effectively applied in evaluating VR training systems and collaborative environments [22]. Zhang and Simeone [23] adapted Nielsen's heuristics to identify universal usability issues in VR health applications, including viewpoint fidelity and hardware limitations. Studies also explore usability improvements in specific applications: Thanh et al. [24] designed a heuristic-guided VR therapy game to alleviate children's phobias through intuitive interactions; similarly, Azai et al. [25] introduced body-based menu systems, which simplified interaction and enhanced usability in immersive scenarios.

2.3 Affordance Principle for Virtual Reality

Affordance principles are crucial in interaction design, directing users on natural interactions with virtual objects. In VR, affordances reduce cognitive load and enhance task efficiency. However, VR presents unique challenges, requiring seamless integration of contextual, physical, and sensory feedback methods.

Successful affordance design in VR combines visual indicators with multi-sensory input. Moloney et al. [26] emphasize immersive analytics that align sensory mappings with environmental perceptions, reducing cognitive burden and enhancing engagement. Steffen et al. [27] propose frameworks for leveraging spatial, auditory, and tactile feedback to optimize interaction and decision-making.

In educational settings, affordances support embodied cognition. Johnson-Glenberg [28] highlights how gesture-based interactions enhance learning by enabling physical engagement with virtual elements, fostering deeper understanding. Such embodied affordances are increasingly central to VR’s educational applications.

Task-specific affordances are also critical. Elliott et al. [29] demonstrated how VR can use innate human motions to improve interface designs for software engineering tasks, enhancing productivity and user satisfaction.

Overuse of affordances, however, can lead to fatigue and reduced immersion. Holopainen et al. [30] argue that effective VR designs must balance visibility with natural user experiences, necessitating an understanding of cognitive and emotional affordances.

3 Design for Affordance in Virtual Reality

In contrast to conventional 2D interfaces, which include static and relatively straightforward affordances such as visual signals and feedback, VR environments pose distinct problems owing to their immersive, three-dimensional characteristics. In virtual reality, affordances must be dynamic and contextually responsive, adapting to users' motions and activities/de-activates in real time. This requires the creation of interactive techniques that provide explicit visual direction while preserving the realism and immersive attributes characteristic of virtual reality.

3.1 Highlighting the Affordance in VR Environments

Considering the methods for indicating the affordance so that the user can be aware of those things around him/her that could be approached and interacted with is an essential first step for featuring the affordance in a VR environment. Iterative design exercises with literature review and evaluating various ideas have identified candidate strategies for highlighting (i.e. indicating those objects that can be interacted with): making the interactable objects brighter/shiny either occasionally or permanently; dimming ambient light enhances visual contrast without disrupting aesthetics [7][8]; object outlining (silhouette) effectively distinguishes interactable items from surroundings while maintaining realism [1]; text indicators explicitly mentioning the number of interactable objects around the user provide situational awareness without cluttering the interface [22]. An important factor to take into account was how such highlighting might reduce the realism of the environment, and thus the mechanism of ‘temporary affordance’ (see Section 3.2). Ambient light dimming, object outlining and text indicators of the number of interactable objects were ultimately selected to be used together.

If an interactable object is not obstructed by barriers such as walls, a bright yellow highlight effect is applied to the object's edges. However, if the object is not directly within reach (e.g. behind a wall or in another room) a white highlight effect is used: this is to further differentiate those directly interactable within the user’s surrounding and those that are interactable but not within immediate surrounding, going one step further in the incorporation of affordance (see Figure 1).

3.2 Need for Temporary Affordances

Affordances such as blue, underlined hyperlinks in 2D web interfaces reduce cognitive load and enhance usability [7]. However, such static 2D affordances are less effective in immersive 3D environments, where persistent or permanent indicators disrupt realism and reduce immersion (this could be compared to the fact that the blue and underlined hyperlinks permanently shown on a web news article might disrupt in reading the article itself).

Persistent visual signals can be problematic in VR applications where realism is critical. For instance, continual affordances shown in VR real estate applications distract the users from appreciating the architectural features. Similarly, in VR gaming, constant visual prompts limit exploration and spontaneity, diminishing enjoyment and immersion [31]. To maintain usability and immersion, VR designs should allow users to toggle or contextually activate affordance cues, ensuring that such a visual guidance appears only when necessary.

The "Witcher Sense" feature in the computer game The Witcher 3: Wild Hunt[1] highlights enemy footsteps in red with a blurred backdrop, offering situational guidance that users can toggle on or off. This approach preserves immersion by providing assistance *only when required*, making it an effective strategy for VR affordances [1]. Similarly, VR applications could adopt contextual affordances, such as highlighting objects based on gaze or proximity, while avoiding constant overlays that overwhelm users [22].

3.3 Triggering the Highlight Mode for Affordance

Having established that temporarily highlighting the affordance is a reasonable solution that balances usability with immersion, we can term this as a “mode” that can be temporarily triggered or activated in some ways.

One approach is to automate such a mode at regular intervals. For example, The Legend of Zelda[2] uses visual cues to highlight items of interest, providing automated assistance without requiring manual intervention. This method could help novice VR users by reducing the amount of intentional interaction effort (and most likely a

[1] The Witcher 3: Wild Hunt. https://www.thewitcher.com/us/en/witcher3
[2] The Legend of Zelda. https://zelda.nintendo.com/

consequent cognitive load). However, automatic cues may disrupt immersion by introducing stimuli that feel intrusive, out of place and probably most importantly, out of control.

An alternative is granting users control over the timing of the affordance mode. In games like Civilization VI[3], players can toggle overlays on or off based on their needs. Adapting this to VR, a toggle-based system enables users to activate visual guidance as needed, resulting in a less visually-overwhelming interface. However, frequent toggling required by the users means more frequent and intentional action on the side of the users.

Another interesting option is the use of user-maintained mode/interaction in which the mode is triggered only during the time when the user keeps pressing/holding a button [38][39]. Such an interaction is suitable when the mode or state in concern is to be entered for much shorter duration than other mode(s)/state(s), potentially making it suitable for triggering the affordance mode which might need to be on only for a short period of time in an overall VR session.

Currently, most VR interactions rely on controllers, influencing the practicality of affordance-triggering methods. While proximity-based [32], gaze-triggered [33], gesture-based [34][35], voice-activated [36], and contextual highlighting [37] systems offer innovative alternatives, they face many and varying types of challenges. For example, gaze-triggered systems often suffer from the Midas touch problem, causing unintended activations [33]. Gesture-based methods can be prone to misrecognition, particularly in dynamic environments requiring fine control [34]. Proximity-based approaches may result in accidental activations due to overlapping objects or rapid user movement [32]. Voice-activated systems are constrained by environmental noise and clarity of speech [36]. Contextual highlighting struggles with accurately detecting user context and environmental disruptions.

Considering all these factors, the methods for triggering the temporary affordance mode became the main focus of this study, and three triggering methods were designed for an experimentation: *Auto-Highlight* which automates periodic affordance activation to reduce user input; *Switching Highlight* which allows users to toggle cues on or off, offering greater control; and *Hold-to-Display* which applies user-maintained interaction, temporarily activating the mode only while the user holds a controller button.

4 Methodology

4.1 Participants

The study involved 15 participants aged 20 to 40, comprising 8 men and 7 women from diverse backgrounds including students, researchers, and engineers. VR experience levels were categorized as novices (7), moderate (5), and advanced (3). This diversity enabled a comprehensive analysis of user interactions and preferences regarding affordance activation methods in VR. Ethical approval was obtained from the University's review board, and all participants provided informed consent.

[3] Sid Meider's Civilization VI. https://civilization.2k.com/civ-vi/

4.2 Overall VR Environment

The VR environment simulated a realistic domestic setting (see Fig. 1 (top left)), including two rooms and a kitchen. Interactive objects such as vases and gaming controllers were arranged across the space, mixed with various non-interactable objects (i.e. the user cannot do anything with them) such as tables, light stands, etc. When the affordance mode was activated/triggered, the whole environment became slightly darker and the interactable objects were highlighted according to the visual strategy addressed in Section 3.1. Highlights were designed with yellow edges for unobstructed objects (Fig. 1 (bottom)) and white for occluded ones (top right). A counter in the bottom-right corner on the user's vision displayed the number of interactable items visible. The VR prototype was developed using Unity 3D (version 2021.3.11f1) and optimized for Oculus VR devices using the Oculus Integration SDK.

Fig. 1. Highlighting Techniques in a VR Living Room — Standard/normal view (top left); Highlight mode with ambient dimming, object outlines in yellow, and a text indicator (bottom); Highlight mode with an object beyond the wall outlined in white (top right).

4.3 Procedures

Each participant was invited to the lab where the VR device was set up. After briefing on the process and reading and signing the consent form, the participant filled in an initial demographic questionnaire. A simple VR training was offered at the start using an environment without any affordance mode available, during which the participant familiarized him/herself in the environment, navigating and grabbing and interacting with objects in the virtual house. Taking the within-subject setting, the participant then was introduced to each of the 3 affordance triggering methods one by one as the main conditions: (i) Auto-Highlight Mode: Automatically activates affordance cues for 2 seconds every 5 seconds, which provides periodic visual indicators of interactable elements; (ii) Switching Highlight Mode: Users toggle affordance mode on or off via a button press, allowing continuous visual feedback until deactivated, offering control over when to view affordances; (iii) Hold-to-Display Mode: Affordance cues remain visible while the user presses a controller button and disappear immediately upon release. For each mode, the participants were asked to identify all interactable objects within a virtual room and move them to pre-designated, nearby marked areas in VR environments.

The order of these 3 affordance modes as well as the locations of interactive objects placed were randomized to minimize any learning effects. The participant completed a short questionnaire after each condition and a final survey to collect qualitative feedback on usability and preferences. Throughout the interaction, the researcher observed the participant for any notable behavior and also to answer any questions. Task completion times were recorded for analysis. Total duration for each participant conducting all these tasks was around 20-25 minutes.

5 Findings and Analysis

In this section we summarize the findings including task completion times, user preferences, and the perceived efficacy of each approach, followed by discussions on the findings as emerged from the analysis in terms of the usability of the 3 affordance activation methods.

5.1 Task Completion Time and Usefulness Ratings

To analyze the effects of each affordance activation method, task completion time and usefulness ratings were examined (Table 1). Auto-Highlight exhibited the widest time range (86–322 seconds, mean = 151 seconds), while Switching Highlight showed faster times (72–152 seconds, mean = 113 seconds), and Hold-to-Display had the shortest durations (65–245 seconds, mean = 130 seconds). Usefulness ratings ranked Hold-to-Display highest (4.07/5), followed by Switching Highlight (3.87/5) and Auto-Highlight (3.47/5). Auto-Highlight was intuitive for novices but confusing due to its unexpected and automated nature regardless of the user's needs; Switching Highlight balanced control with user fatigue; and Hold-to-Display was intuitive but occasionally physically demanding. Gender differences showed that overall women preferred Switching Highlight, whereas men favored Hold-to-Display (not statistically significant due to the sample size).

Table 1. Participants' data on three methods.

Method	Auto-Highlight	Switching Highlight	Hold-to-Display
Completion Time (Mean; seconds)	151	113	130
Time standard Deviation	65.3	27.5	57.8
Usefulness (Average)	3.47/5	3.87/5	4.07/5

5.2 Influence of Virtual Reality Proficiency

Novices exhibited extended task completion durations, especially with Auto-Highlight (M = 161.6 seconds). Intermediate and Advanced users executed tasks more swiftly, particularly with Hold-to-Display (Intermediates: M = 115.2 seconds; Advanced: M = 108.6 seconds). Novices assigned the highest rating to Switching Highlight (M = 4.14, SD = 0.69), but Intermediate and Advanced users evaluated both Switching Highlight and Hold-to-Display similarly (M = 4.17, SD = 0.56).

5.3 Qualitative Analysis

User feedback revealed varied opinions on the affordance activation methods, highlighting preferences, challenges, and suggestions.

Auto-Highlight: Participants, especially novices, found this method intuitive due to its low interaction demand. However, its automated, sporadic nature caused confusion, with users noting difficulty in tracking brief visual indicators by relying on its pre-set intervals. Suggestions included adjustable durations and frequencies. Advanced users criticized the lack of control, describing it as "overwhelming" and immersion-breaking in complex environments.

Switching Highlight: Participants valued its balance of control and guidance, calling it “the least interruptive and most fluid.” Novices appreciated its simplicity, while advanced users liked it for its on-demand and toggling nature. Some found repeated activation tiring over extended use and suggested combining toggle functionality with periodic prompts to minimize fatigue.

Hold-to-Display: Widely praised for its intuitive design, users likened it to realistic interactions such as “press-and-hold” in games. However, prolonged button pressing was physically taxing for extended tasks for some users, as expected.

Participants emphasized the importance of customizable affordance settings, such as adjustable visuals and display durations. A recurring theme was to align cues with real-world interactions to maintain immersion without overwhelming the users. One participant noted, “The cues should match real-life effects to sustain the VR experience.”

5.4 Discussions

Interaction Cost of Adding the Affordance: Stemming from the need to maintain the immersiveness of VR environment, introducing the “mode” so that it can be activated temporarily means that there is a need for navigating between the modes/states. Having to notice the changing environmental cues (in the case of Auto-Highlight) and/or explicitly managing and controlling it (in the case of Switching Highlights and Hold-to-Display) all end up demanding more cognitive/physical maneuvering on the side of the users. However, we expect that a judiciously and carefully designed interactive feature could help minimize such a sense of extra burden, and instead enhance the VR navigation which is inherently more complex than a typical 2D interface.

Need for Customization: The findings emphasize the need for customizable affordance settings. Participants consistently expressed a preference for options to adjust visual elements such as display durations and the dimming level. and interaction modes to align with individual preferences and varying expertise levels. Since offering a way to customize various design parameters generally enhances the usability of a system thus widely used in today's interactive (2D) products especially in their Operating System level, so should the mechanisms to allow such a customization within a VR environment result in the usability improvement.

Designing in Scalability: Showing the visual affordance in the form of silhouette around the objects worked OK partly because the room sizes were small and there were only a limited number of interactable objects. If the room is much larger or potentially there are many more interactable objects in that environment (e.g. an outdoor open area with an endless array of shops, cars or people around), the idea of activating the affordance mode to highlight all interactable objects will become less meaningful. In such cases more scalable design solutions (e.g. highlighting the objects within a certain distance or gradient highlights based on distance) will need to be devised.

Integration of Multi-Sensory Feedback: The post-task survey indicated a strong interest in expanding affordance cues beyond visual indicators. Participants suggested incorporating auditory or haptic feedback to complement visual cues, which could improve accessibility and reduce reliance on a single sensory channel. This aligns with the broader trend of leveraging multi-sensory input to enhance immersion and usability in VR.

6 Conclusion

This study attempted at explicitly integrating an affordance principle as a pre-defined feature within a VR environment, and evaluated how different affordance activation methods affect VR user experience. The findings show that intermediate and advanced VR users favored Hold-to-Display due to its suitability in requiring only a small portion of the session where the mode activation is needed. However, the physical strain from extended button pushing was a recognized restriction.

The results emphasize the need of user-centric design in virtual reality, notably adaptation to different experience levels and preferences. While novice users may benefit from more automated methods like Auto-Highlight, experienced users tend to prefer manual control, as seen with the Switching Highlight and Hold-to-Display methods. These findings highlight the necessity for configurable affordance activation to enhance usability for different user profiles.

Many influential and impactful usability principles and guidelines are available in the HCI research and practice community, having been accumulated as the result of many decades of studies, experiments, productizations and numerous trial and errors in the markets. Fuller applications of this knowledge in new media platforms such as VR will be a promising way to enhance the usability of these new platforms. While in this study we focused on the affordance principle and its immediate applications in terms of showing what objects in a VR environment the user can interact with, there is room for many other principles and guidelines that could and should be designed in a more explicit manner in order to find ways to enhance their usability.

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