Beyond Screen Size: How Rendered FOV Shapes Virtual Museum Visitor Behavior

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Abstract
360° virtual tours (VTs) are increasingly used by museum audiences to explore collections remotely, yet visitor behavior differs markedly across devices. Prior cross-device studies document these gaps through usability and presence scores but treat the device as a categorical black box, leaving unexplained *why* the same tour produces different exploration patterns on a phone. We argue that a key factor is the platform's *rendered horizontal field of view* (hFOV): Matterport displays ~112° of the panoramic sphere in landscape mode but only ~39° in portrait, a ~65% reduction in visible scene content that plausibly drives the excessive zooming, disorientation, and shallow exploration patterns observed in mobile VT use. We outline a between-subjects study comparing a laptop in landscape, a smartphone in landscape, and the same smartphone in portrait, all viewing a Matterport scan of an Impressionism exhibition for which we have prior behavioral baselines from an earlier study. Because the two landscape conditions share a comparably wide rendered hFOV (~112–118°) but differ in screen size and input modality, while the two smartphone conditions share screen size and input but differ in FOV, this design disentangles rendered FOV from device form factor. We log navigation behavior—attraction power, holding power, coverage breadth, room transitions, and zoom usage—to test whether rendered FOV predicts cross-device behavioral differences better than screen size or input modality alone.

Keywords
360° Virtual Tours, Cross-Device Visitor Behavior, Rendered FOV, Museum Engagement, Cultural Heritage

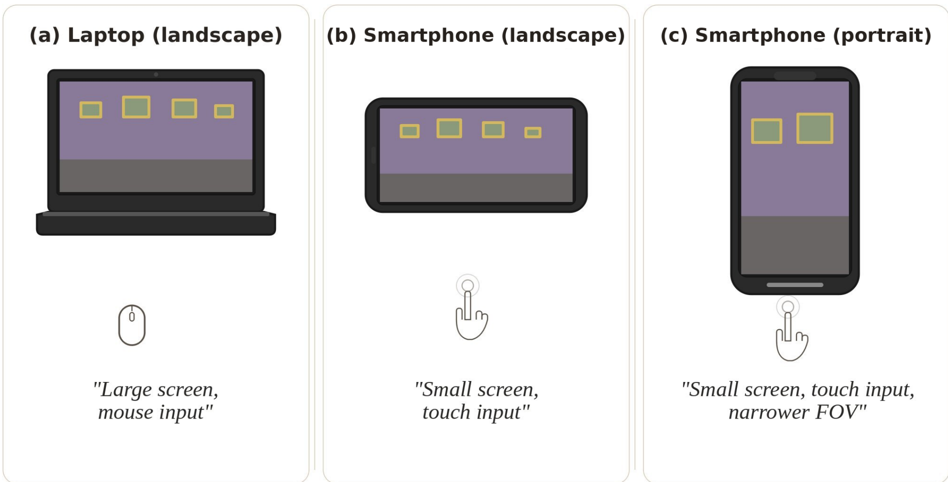

Figure 1: The three viewing conditions in our planned between-subjects study; each differs in rendered FOV, screen size, and input modality.

1. Introduction and Related Work

360° virtual tours (VTs) have become a widely adopted format for remote cultural heritage engagement [1, 2]. Platforms such as Matterport[1] and Google Arts & Culture[2] enable millions to explore museums

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[1]https://matterport.com
[2]https://artsandculture.google.com

(a) Zoom out (hFOV ≈ 138°). (b) Default zoom (hFOV ≈ 112°). (c) Zoom in (hFOV ≈ 67°).

Figure 2: The same Matterport scan point at three zoom levels on a laptop in "To Catch a Fleeting Moment: 150 Years of Impressionism" (Tel Aviv Museum of Art). The VT software controls the rendered hFOV (~67° to ~138° in laptop landscape), with ~112° as the default; equivalently, Matterport pins vFOV at 75° by default and varies it from ~37.5° to ~107° across the zoom range. At any zoom level, the rendered FOV is identical across all devices for the same orientation.

from personal devices, a trend accelerated by the COVID-19 pandemic [3]. These platforms render a rectangular slice of the full 360°×180° panoramic sphere of every image spot onto the viewer's screen, with the rendered field of view (FOV) controlled by the software and adjustable via zoom (Figure 2).

Yet the same tour can produce markedly different experiences across devices [4, 5].

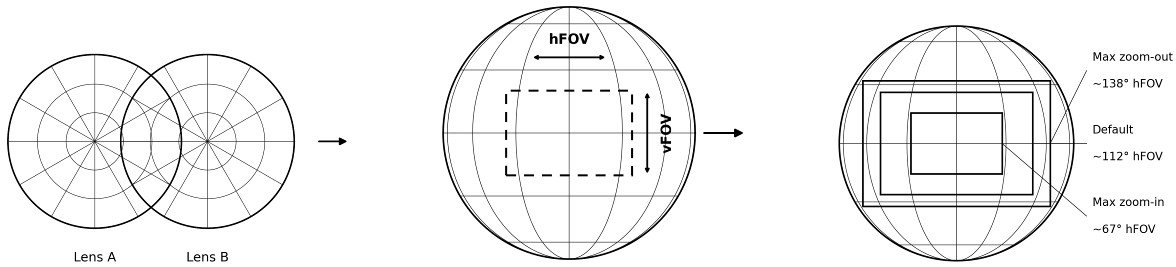
With smartphones increasingly embedded in daily activities [6], understanding the mechanism behind these behavioral differences is important for designing equitable virtual museum experiences.

Although cross-device VT comparisons consistently find experiential differences [4, 5, 7, 8], they treat "device" as a categorical variable, conflating screen size, input modality, and rendered FOV into a single label. We take a different approach: we focus on the **rendered horizontal FOV**—which Matterport sets to ~112° in landscape but only ~39° in portrait—as a key parameter that may account for important cross-device behavioral differences.

This work extends both our earlier and current behavioral studies of image-based 360° virtual tours. Our prior work identified navigation, movement, and control as central pain points that shape the 360° tour experience [9], and found that a high-fidelity virtual tour of the same exhibition matched the physical visit on standardized experience measures yet was rated lower on spatial usability such as navigation ease, orientation, and backtracking [10]. This work builds on the broader tradition of personalization in cultural heritage, where adaptive museum systems use visitor modeling to tailor the experience [11, 12, 13, 14]. Recent works have demonstrated device-dependent experiences across a growing range of visitor interfaces [15, 16, 17, 18, 19], yet none account for how rendered FOV shapes visitor behavior in the virtual space. This study advances the cross-device research agenda we previously outlined for virtual tours [20], narrowing its focus to rendered FOV as a specific mechanism.

1.1. Virtual Museums and Behavioral Metrics

Museum engagement is commonly measured via *attraction power* (AP: proportion of exhibits at which visitors stop) and *holding power* (HP: average time spent at each exhibit) [21, 22]. Lanir et al. [23] showed mobile guides substantially alter both metrics, and subsequent work developed systems for tracking and analyzing visitor movement patterns in physical museums [14, 24]. Visitor typologies [25], visitor modeling approaches [26], and circulation models [27] further characterize exploration. 360° VTs introduce distinct challenges: prior work has framed their design along dimensions of navigation, information presentation, proactiveness, and interactivity [28], with discrete navigation via predefined scan positions [9] and limited interaction [29, 30]. Recent work found that a high-fidelity virtual visit can match a physical one on standardized experience measures while differing on spatial usability [10], and that engagement metrics can transfer from physical to virtual visits even as text vs. artwork engagement diverges [31]. This builds directly on our prior qualitative study of 360° VT navigation [9], which used think-aloud and interviews to surface orientation and wayfinding difficulties among other pain points; the present work moves from those qualitative accounts to a controlled behavioral comparison across rendered-FOV conditions.



(a) Dual fisheye capture. (b) Stitched sphere with visible slice. (c) Zoom changes slice size, not the sphere.

Figure 3: How a 360° virtual tour goes from camera capture to the slice displayed on screen.

1.2. Cross-Device VT Comparisons

The cross-device VT literature spans laptop, smartphone, Google Cardboard, HMD, desktop VR, and wearable VR configurations [4, 5, 32, 7, 8]. Findings include lower usability scores on smartphones [4, 5], reduced presence on non-immersive devices [7]. However, because all studies use device as a categorical independent variable, they cannot explain *why* these behavioral differences arise nor predict outcomes on untested configurations. We wish to address this by isolating rendered FOV: portrait orientation renders roughly 65% less of the panoramic sphere than landscape, a difference that exists independently of which device is being used.

1.3. Screen Size, Input Modality, and Spatial Cognition

Larger displays improve spatial orientation performance, even when the subtended visual angle is matched [33], and enhance task performance in information-rich environments [34]. Input modality interacts with display size: gesture-based interaction can improve spatial recall compared to indirect input such as trackpad [35]. Smaller screens constrain the information visible at any moment and increase visual attention demands [36], raising the cognitive effort of building spatial understanding through repeated panning; narrower viewing angles further reduce the sensation of reality [37], though restricting the field of view does not degrade all spatial judgments and depends on the depth cues available [38, 39]. These findings create a tension for 360° VTs on smartphones: direct manipulation (touch) may benefit spatial encoding, but the smaller screen and narrower rendered FOV reduce visible context. Disentangling these factors requires a study design that varies them independently.

2. Rendered FOV Across Devices and Orientations

A 360° VT captures multiple points in a museum or cultural heritage site, with each point showing a 360-degree image of its surrounding. Users of VTs can move from one point to another viewing the museum space. Each point shows the full surrounding environment as a seamless spherical panorama (Figure 3a–b). At any moment, the viewer sees only a rectangular slice of this sphere, whose angular width and height are defined by the rendered hFOV and vFOV. Zooming changes how much of the sphere is shown on screen, not the sphere itself (Figure 3c).

We measured the rendered FOV values used by Matterport, which fall within the range used by other panoramic viewers [40, 41, 42]: ~112° hFOV on a laptop in landscape (~118° on a phone in landscape) and ~39° in phone portrait, with a ~67°–138° hFOV zoom range in landscape (Matterport pins vFOV at 75° by default and varies it from ~37.5° to ~107° across the zoom range). These values are *software-determined and identical across all devices* for the same orientation. However, the same rendered slice occupies vastly different proportions of the viewer's visual field depending on the physical screen.

The critical observation is that **rendered FOV changes with device orientation**: a smartphone in landscape renders ~118° hFOV (comparable to a typical laptop at ~112°), while the same phone in portrait renders only ~39° hFOV—a ~67% reduction in the visible horizontal slice of the panoramic sphere. Matterport (as well as other platforms) adapts the rendered hFOV to the screen's aspect ratio, showing less of the sphere when the screen is vertical than when it is horizontal. Because horizontal panning is the dominant navigation action in virtual tours, this reduction in horizontal context may have effects on spatial awareness and exploration behavior.

3. Planned Study

We plan a study to compare three viewing conditions that sample different combinations of rendered FOV, screen size, and input modality: (1) laptop in landscape (hFOV ≈ 112°, large screen, interaction through mouse), (2) smartphone in landscape (hFOV ≈ 118°, small screen, interaction through touch), and (3) smartphone in portrait (hFOV ≈ 39°, small screen, interaction through touch).

We focus on the aspect ratios of two common devices, a laptop and a smartphone; we exclude tablets because their aspect ratios span a wide range rather than a single characteristic value, which would confound the clean separation of rendered FOV, screen size, and input modality that our design relies on; they remain a natural target for follow-up work.

We hypothesize that a narrower rendered FOV degrades the virtual visit through reduced spatial awareness, lower navigation efficiency, and shifted engagement patterns. This prediction draws on evidence that smaller displays impair spatial performance [33, 34], that mobile interfaces add interaction friction [36], and on device-dependent engagement differences in virtual tours [31].

Concretely, we predict that when remote visitors visit a museum virtual tour using the portrait condition (~39° hFOV), they will show reduced exhibit coverage breadth, lower holding power, increased room-transition rate, and more frequent zoom-as-navigation behavior compared to the landscape conditions (~112–118° hFOV).

The Smartphone-landscape condition is the key diagnostic: it shares rendered FOV with the laptop but shares screen size and input modality with the Phone-portrait condition. This enables us to analyze the effects of differences in hFOV by comparing Phone-landscape with Phone-portrait conditions, and to analyze the differences in interaction mode between smartphone-landscape and the Laptop condition.

3.1. Design and Procedure

Between-subjects, $N = 45$ (15 per condition), recruited from the university community and screened for normal or corrected vision. Sessions run in a controlled lab (HCI Lab, University of Haifa) on lab-provided devices. Each participant freely tours the same Matterport scan of the museum's Impressionism exhibition at their own pace, with no task list or time limit. Based on our prior study of this exhibition, in which visits averaged roughly 22 minutes [10], we expect the free-exploration phase to last on the order of 20–30 minutes. After exploring, participants complete the post-session questionnaires (~10 min) and a semi-structured interview (~10 min), for a total session of roughly 40–50 minutes. The exhibition spans four connected rooms with 77 exhibits (70 artworks and 7 text panels), captured at over 200 scan points. This is the exhibition used in our prior study of this site [10], which provides behavioral baselines for interpreting the cross-device results. Screen recordings are coded for the behavioral metrics via manual video annotation by two independent coders following a predefined coding scheme, with a subset of sessions double-coded to assess inter-coder reliability.

3.2. Behavioral Measures

The primary outcome measures are behavioral: *total visit time*, *exhibit viewing time*, *walking/idle time*, *coverage breadth* (proportion of available artworks encountered during the visit), *attraction power* (proportion of visitors stopping at an exhibit), *holding power* (mean viewing time per exhibit), *room transitions* (count and per-minute rate) [21, 22], and *zoom usage* (frequency), which is specific to this cross-device study and indexes how participants compensate for a narrower rendered FOV.

Subjective measures comprise two MEC-SPQ spatial-presence subscales (Attention Allocation, Spatial Situation Model) [43], the short-form UEQ-S (Pragmatic and Hedonic Quality) [44], and six custom museum-experience items (navigation ease, orientation vs. lost, exploration freedom, backtracking ease, overall satisfaction, and revisit interest). A post-session semi-structured interview elicits participants' reflections on navigation, orientation, and their use of zoom, complementing the behavioral and questionnaire data; interview transcripts will be analyzed thematically.

4. Expected Contributions

1. Rendered FOV as an explanatory variable for cross-device behavioral differences. Unlike prior work that reports device-level usability differences without fully explaining the cause for the difference [4, 5], our work aims to identify rendered FOV as a specific, optically grounded mechanism: a narrower hFOV reduces visible spatial context, potentially impairing spatial awareness [34, 33] and altering exploration behavior. The three-condition design disentangles FOV from input modality and screen size: If smartphone-landscape and smartphone-portrait differ behaviorally despite identical device and input modality, rendered FOV is implicated as the dominant driver. Comparing Laptop and smartphone-landscape, which share a comparably wide rendered hFOV (~112–118°) but differ in screen size and input modality, can reveal whether these factors also shape behavior.

2. A behavioral dataset linking rendered FOV to museum engagement metrics. We will (manually) analyze and log actual visitor navigation behavior—AP, HP, coverage, transitions, zoom usage, and text vs. artwork engagement—in a controlled free exploration of the same exhibition at three FOV levels. Prior cross-device studies [4, 5] compared devices categorically using subjective and task-based measures without behavioral logging. Building on our current study of the same exhibition, this dataset enables within-exhibition comparisons across physical visits, desktop VT visits, and now cross-device VT visits.

3. Toward FOV-aware adaptive cultural heritage systems. Rendered FOV adds a perceptual layer to adaptive museum systems [11, 12, 13, 14, 17]: if behavioral patterns differ systematically with FOV, systems could adapt content density, navigation aids, and annotation style to the visitor's current viewing configuration. Image-based 360° virtual tours are the most widely used museum VT format [2, 1], yet cross-device research has focused almost exclusively on VR comparisons [32, 7, 8]. Our work addresses this gap for the broadest audience—visitors on laptops and smartphones—informed by known design challenges in 360° VTs [30, 29].

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Declaration on Generative AI

During the preparation of this work, the authors used Claude by Anthropic for language editing, LaTeX formatting, and assistance in creating visualizations. All AI-assisted content was reviewed and approved by the authors, who take full responsibility for the final manuscript.

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