Immersive 3D-Sketching: A multidisciplinary collaborative workflow incorporating virtual reality in early design stages

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4 authors:

Mohammed Faraj Al-Suwaidi
University of Liverpool

Asterios Agkathidis
University of Liverpool

Adonis Haidar
University of Liverpool

Davide Lombardi
Xi'an Jiaotong-Liverpool University

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Immersive 3D-Sketching: A multidisciplinary collaborative workflow incorporating virtual reality in early design stages

Mohammed Faraj Al-Suwaidi [1] Asterios Agkathidis[2], Adonis Haidar[3], Davide Lombardi[4]

[1,2,3] University of Liverpool, Liverpool, United Kingdom, [4] Xi'an Jiaotong- Liverpool University, Suzhou, China

[1,2,3] m.f.al-suwaidi@liverpool.ac.uk; asterios.agkathidis@liverpool.ac.uk; adonis.haidar@liverpool.ac.uk; [4]davide.lombardi@xjtlu.edu.cn

Abstract. This paper explores virtual shape-finding methods, merging conventional and digital techniques in early stages of architectural design. We focus on VR implementation guided by a developed design workflow to address the following research questions: (1) How can we develop a pedagogical framework for incorporating VR as a design tool in a collaborative architectural design project? (2) How can immersive 3D sketching contribute to shape-finding and iterative workflow during the conception stage of the architectural design process? The workflow includes four stages: site data collection with 2D sketches, 2D-to-3D sketch/model translation in VR, model optimisation in CAD software, and exporting the model into a game engine for simulation and analysis. Validation involved 40 students working in groups, evaluated through surveys, portfolio submissions, and tutor observations. The study highlights the framework's strengths and challenges in utilising VR as an accessible tool that enables diverse user contributions to the architectural design conception stage.

Keywords: Design Studio, Virtual Reality, Architectural Education, Gravity Sketch, Meta Quest

1 Introduction

The architectural design process involves a diverse set of activities and tools utilised in various stages of the design workflow, ranging from initial conception to final design (Kuyumcu, 2010). Freehand techniques such as 2D sketching and trace-form iteration are critical starting points of the design conception process, as they are not influenced by software toolsets (Jormakka et al., 2014). With the increase in digital tool adoption in the design industry, conventional tools have become overshadowed due to increased demand for rapid results and software-assisted visuals. This leads to fewer opportunities for self-expressive design iteration through sketching that is not influenced by software tools. However, novel immersive sketching technologies offer new possibilities to reintegrate these analogue-based design approaches based on the traditional design process, into a digital design workflow. We focus on the utilisation of VR to explore freeform shape-finding design techniques, enabling various users to conceptualise, iterate, and develop their designs individually and collaboratively. This paper specifically seeks to address the following questions:

i. How can we develop a pedagogical framework for incorporating virtual reality as a design tool in a collaborative architectural design project?
ii. How can immersive 3D sketching contribute to the shape-finding and iterative workflow during the conception stage of the architectural design process?

To answer these questions, we developed a workflow that utilises VR tools in the modelling, optimisation, and simulation stages of the design process (Figure 1). This starts with conceptual 2D sketching iterations; followed by VR 2D>3D translation in VR; design refinement using CAD software, and game-engine simulation for model analysis. Our tools include Gravity Sketch (GS), a 3D sketching software using the Meta Quest 2 coupled with the LandingPad online collaborative platform which enables multi-user collaboration between desktop and VR platforms. Finally, the Unity game engine enables model simulation to analyse their designs both in VR and non-VR platforms.

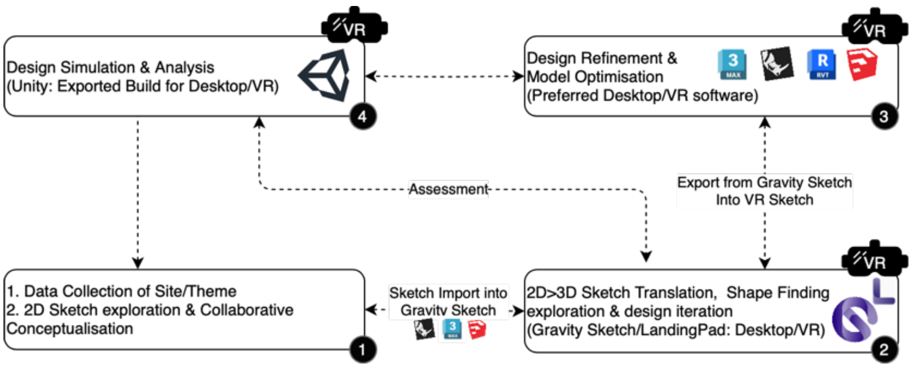

Figure 1. Design framework utilising VR in the conception and simulation/testing stages of the design process.

We validated the workflow in a 4-week design experiment involving 40 students from different disciplines forming a total of eight groups of five. Each group of students were provided with one VR headset and was tasked to collaborate through VR and LandingPad to design a themed pavilion through learning and applying Gravity Sketch as a conceptual design tool to develop a 3D sketch of a pavilion structure. Each group then developed a walk-through simulation to evaluate their design using the Unity game engine. We later observed, assessed, and compared the student and group performance, which included: the utilisation of a variety of VR software and hardware tools; engagement and collaboration with other group members between VR and non-VR-based CAD software used by each group throughout the application period.

2 Background and Literature

> *"Conventional Computer Aided Design tools lack intuitivity for being used in conceptual architectural design process"(Rahimian & Ibrahim, 2011)*

Computer-aided Design (CAD) tools have advanced in the industry, providing various automated solutions for generative design and development. Due to the nature of CAD tools, the conceptual and haptic aspects of the early-stage design process become less adopted. Architectural sketching is a skill often introduced in undergraduate courses to develop communication and design engagement. The freehand nature of 2D sketching leads to continuous exploration, iteration and ideation that would otherwise be limited in digital CAD software (Ozdemir, 2016).

2D sketching is a developed skill that is limited to the X and Y axes where the designer must learn various sketching techniques such as natural gestures, pencil/pen pressure, perspective and scale to develop and communicate their ideas effectively. Through experience and practice, designers often develop their unique style of sketching which often leads to a refined design language. 3D freehand sketching faces a familiar learning curve which builds on the 2D sketching skillset, with the addition of the Z axis to sketch in the 'air'. 3D sketch conceptualisation also extends the designer's understanding of space through the ability to preview designs in various scales such as 1:1 to 1:1000, leading to a more holistic sense of the spatial quality from the 3D sketches in contrast to 2D drawings.

Immersive tools such as VR, have continued to evolve, with the added ability to move, rotate and explore with Six Degrees of Freedom (6DoF) in the virtual space (Basu, 2019). With the addition of various input methods, multiple VR software evolved to enable users to interact, scale and sketch in the virtual environment. This paper further expands on our previous research which allowed us to revisit the haptic realm to reintegrate freehand sketches from a modern perspective, and potentially allow users to integrate this conceptually explorative and collaborative design nature through the lens of VR using Gravity Sketch (Al-Suwaidi et al., 2023).

Given the increase of VR utilisation in various industries, software developers continue introducing various immersive and/or collaborative software that can be utilised in the design field. We expand upon previous research that explored the implementation of various collaborative and immersive design software in conceptual and architectural design projects (Al-Suwaidi et al., 2022). This leads to a comparative systematic review to analyse a series of immersive software, leading to a filtration process of design tools. Tools such as Gravity Sketch are implemented to complement the proposed design framework catered to utilising VR and immersive tools as a design medium, in various stages of the architectural design process.

Gravity Sketch is a 3D sketching and modelling platform, initially developed with the designer in mind, that includes, in addition to architectural design, automotive and interior design. The platform enables users to transform the controller's movements and gestures into an input tool for sketching in 3D space in both virtual and mixed reality. An additional intuitive feature of the software is its ability to enable collaborative design between multiple users using both VR and desktop platforms (*Gravity Sketch | 3D Sketching and Design Software*, n.d.).

We draw a specific focus on the influence of freehand 3D sketching techniques applied in a collaborative design environment through the utilisation of the virtual platform using both VR and desktop mediums prior to the implementation of any CAD tools for refinement. The focus of this research leads to findings that shed light on the impact that software has on the designer's final output. This is done through the integration of analogue-based conceptualisation in a 3D immersive learning environment that functions both remotely and in person. Through this application, we assess VR's influence on each group's design thinking and collaborative approaches which lead to unique design outcomes based on how they have embraced the framework during the 4-week period. Our validation methods also include student surveys, portfolio submissions, external examiner reports and tutor observation. We also compare our VR framework to non-virtualised design tasks running in parallel.

3 Materials and Methods

The applied methodology shown in Figure 1 integrates the use of VR and desktop hardware in various phases of the architectural design process. The framework splits into four stages that cycle through various platforms to develop and refine the design. The stages include Stage 1: Data collection and research of design theme along with 2D conceptional sketching; Stage 2: 2D sketch to 3D model translation using Gravity Sketch; Stage 3: optimising the the exported model(s) using preferred CAD modelling software; and Stage 4: Simulating and Evaluating the model through the Unity game engine. Contrasting previous implementations of this framework which took place in an architectural design studio environment (Al-Suwaidi et al., 2022), we modified the framework for this implementation, to integrate a series of exercises that focus on the interdisciplinary; multi-software Integration for collaboration and coordination between group members in addition to supporting group supervision throughout the design process.

Figure 2. 360 panoramic photos of the interior rooms allocated for 3D modelling.

For the first three weeks of the semester, stage 1 consists of site data collection and 3D modelling of the existing base site, to assist with rebuilding the initial interior space using CAD 3D modelling software (Figure 2). Students are encouraged to utilise various tools including both analogue and digital tools for the data collection, this includes using tools such as a tape measurer and smart-laser measurement devices to gather spatial data. Photographs for reference and texture collection are also integrated alongside 3D scanning methods using the LiDAR enabled devices or photogrammetry software for contextually detailed information including materiality and proportion that can assist the 3D modelling process. Group members must then work collaboratively to coordinate, model and develop the entire interior space shown in Figures 2 and 3 using 3DS Max as the primary 3D modelling software. The detail of the site model also includes details such as elements found in the space including the walls; floor; ceiling; dividers; doors; windows; mezzanine; stairs; and railings in addition to the furniture (tables and chairs). To assist with this, students are introduced to 3DS Max through a series of tutorials in the first 3 weeks, consisting of both beginner and advanced tools within the software, additional guidance is also provided throughout the semester to support the completion of this task. The 3D model serves as a base to contextually design around and aid the conceptualisation of the pavilion design in the following stage. Prior to stage 2, each group is assigned a country coupled with a set of topics to choose from including fashion; architecture; history; food and culture, this allows them to thematically develop their concept within the existing interior space and pavilion context in the purple region highlighted in Figure 3.

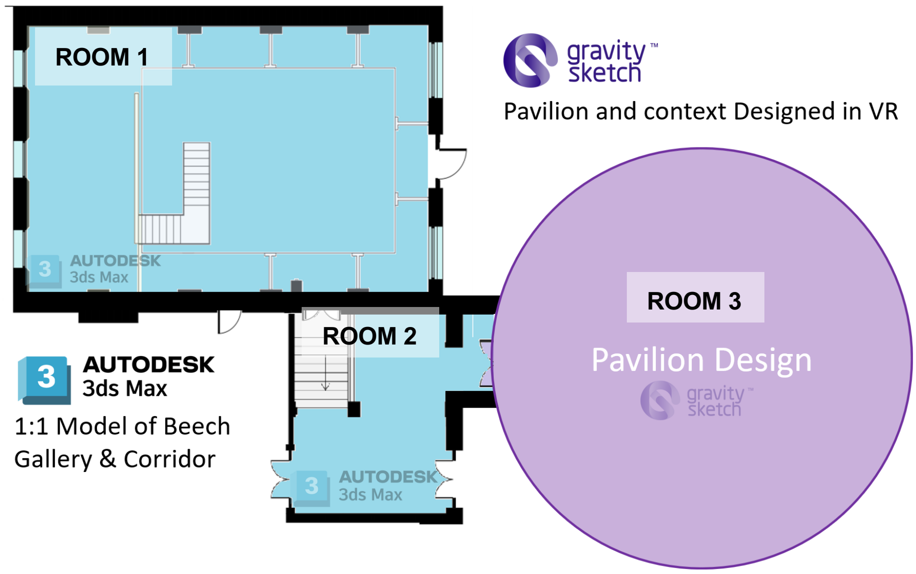

Figure 3. The site plan of Rooms 1 & 2 was modelled using 3DS Max in addition to highlighting the pavilion extension designed and modelled in VR using Gravity Sketch.

The process for Stage 2 focuses on setting up each group with a VR headset and setting up a LandingPad account to create an online Collab room that is shared amongst group members to collaborate using both VR and desktop platforms. Group members are then tasked to conceptualise a series of elevation; plan or perspective pavilion design sketches based on the allocated country and selected topic. The developed sketches are scanned and imported into VR as flat images to trace over and guide the 3D sketching process. During this transition period between tangible and digital, all participants are briefly introduced to the Gravity Sketch toolset and design techniques through a brief workshop at the beginning of each session. These brief workshops and sketching exercises increase software familiarity and allow users to effectively translate their 2D sketches into 3D iterations using free-hand and orthogonal sketching techniques in VR. Additional refinement techniques are later introduced allowing users to further enhance their designs in VR.

After completing the 3DS Max and VR design exercise, stage 3 requires each group to refine and optimise their 3D sketch models. Refinement and model optimisation is crucial when it comes to developing customised virtual experiences. The optimisation consists of refining the model's polygon count; mesh alignment; UV texture map and overall model geometry. Model optimisation can be done using Gravity Sketch in VR and/or desktop 3D modelling software. As each group only has a few weeks to learn and apply their skills in the VR platform, they are also provided with the option to refine their model using their preferred CAD modelling tool(s).

Stage 4 focuses on exporting both optimised models from 3DS Max and Gravity Sketch and combining them to develop a walk-through simulation using the Unity game engine. This stage allows each group to explore the combined design from a first-person perspective to assess and analyse spatial quality, scale, circulation and overall simulation performance. Unity is introduced through a series of workshops, familiarising the students with the software UI and its capabilities. Introductory topics such as materiality; lighting; model collision and first-person character integration are covered to set up the unity project file. Additional skills including animation are also covered which allows each group to further enhance and transform their virtual environment by integrating performative elements into the scene. Structural or ornamental elements can be animated to explore and implement visual, interactive and functional properties to the scene.

4 Implementation & Verification of VR Methodology

The workflow was tested in the Virtual Environments module (VE), a multi-disciplinary module consisting of 40 students from different backgrounds including Architecture, BIM and Digital Transformation, Sustainable Heritage Management and Civil Engineering. By utilising a multi-software/platform toolset, we explored the overlap between both VR and desktop-based applications that integrated multiple users to simultaneously communicate, collaborate and contribute to the design conception stage of the design process while enabling lecturer communication and supervision. Working in groups of five and sharing a single VR headset, the module embraced group collaboration, software exploration and integration, specifically in the virtual realm, through the integration of industry-standard software merged with Immersive tools including Virtual, augmented and mixed-reality (VR, AR and MR), all of which fall under the Extended Reality (XR) toolset.

The focus was to offer knowledge and tools that allowed students to critically explore and understand the potential of VE in architecture and the wider context of the AEC industry while developing a critical understanding of XR technologies within a design project context. Throughout the semester, students were introduced to the project brief which included site data collection, 3D modelled a site as a group using 3DS max and also researched the history and development of XR tools. An AutoCAD site plan was also sourced and shared amongst all groups to guide the modelling process. This was followed by introduction and training for selected VR and desktop-based CAD hardware and software including Gravity Sketch, LandingPad and Unity.

During the 3DS Max workshop from weeks 1-3, a basic set of integrated modelling tools was introduced, including primitive shape modification such as movement, scale and rotation. Advanced tools were later presented to develop more complex modelling strategies such as lofting, Boolean and Sweep. In week 2, a site visit took place to assist in gathering the required data including the wall, ceiling and floor dimensions and all other information to begin developing the 3DS Max model, following each workshop, each group started to coordinate their roles to model different sections of the site and later combine them into a single file to optimise (Figure 4). Toward the end of the site visit, countries and themes were randomly allocated to each group to guide their concept development. All groups completed the model effectively with minor merging issues involving overlapping meshes and import/export issues.

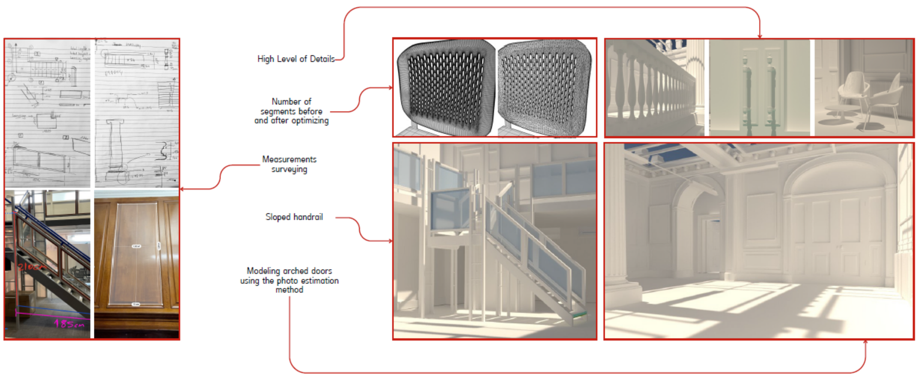

Figure 4. Group 2 modelling process using 3DS Max using digital and analogue assisted surveying tools.

In addition to 3D modelling the interior space, students are also introduced to the VR 3D sketching platform where they were tasked to collaborate and conceptualise a 2D sketch of a pavilion that can then be transformed to 3D using Gravity Sketch in conjunction with other collaborators using the LandingPad Collab desktop platform.

The VR introduction session took place twice through weeks 4 and 5. As four Oculus Quest 2 headsets were circulated between groups 1-4 and groups 5-8, in total, each group had full access to a VR headset for 2 weeks. During the software introduction, each collaborated as a group to translate their 2D sketches to 3D models using both LandingPad and Gravity Sketch (Figure 5). A remote online session also ran outside of class times each week for each group, allowing the lecturer to meet each group in the Collab room in VR. The lecturer was able to provide further guidance to enhance VR utilisation through optimising and refining the 3D model in VR. The pavilion model design is then added as an extended space, accessible from Room 2 (Figure 3). The entire model including the 3DS Max and Gravity exports are combined in the simulation stage of the project.

Figure 5. Group 2 model translation from 2D sketch and desktop-based CAD tools to VR freehand sketch model developed collaboratively in Gravity Sketch/LandingPad.

Based on each group's design intentions from the initial 2D sketch or CAD drawing, some decided to either further iterate and develop their designs from the initial concept using GS, while others decided to commit to the original idea by fully redesigning the pavilion in VR (Figure 6). The refinement process showcased varied outcomes between both 3DS Max models and Gravity Sketch, as both software exports had to be optimised differently. The level of optimisation using both VR and non-VR platforms was commonly based on the user's level of familiarity with the software and modelling workflow.

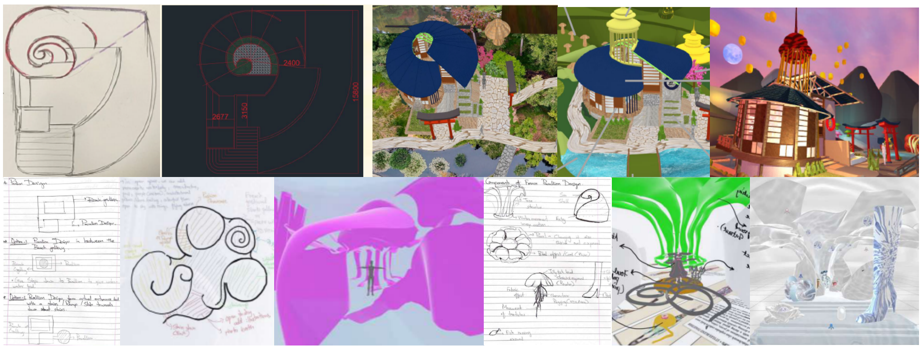

Figure 6. Contrasting development methods and approaches between Groups 5 (top row) and Group 6 (bottom row) model translation from sketch to VR 3D sketch modelling and refinement.

Following the model optimisation phase of the project, students are tasked with exporting both 3DS Max and Gravity Sketch models to FBX (Filmbox) 3D format to import into a Unity project (Autodesk, n.d.). All groups were introduced to the Unity game engine to develop a custom walk-through, combining all models to explore a walk-through simulation from a first-person perspective using both VR and desktop platforms. This provided further insight into the performance, accessibility and spatial quality of the model (Figure 7). The simulations resulted in multiple groups revising their designs by repeating framework stages 1, 2 or 3 (Figure 1), to further enhance their design and develop new iterations.

Students were also taught how to optimise and build their project to function separately as a program file outside of Unity. Throughout this process, groups were consistently required to document their project development and provide a comparative overview of their experience using both desktop and VR software platforms.

Figure 7. Group 8 Unity integration to simulate lighting, animation and spatial quality analysis.

Towards the end of the semester, each group was required to present their development to other peers and showcase a walk-through simulation of their virtual model, the walk-through was developed for both VR and/or desktop experiences. This stage allowed groups to learn from each other's experiences while also receiving tutor feedback for further development. This presentation provided further self-reflective insight into their experience working collaboratively both in and out of VR.

The presented content was finally documented and collated into a final group portfolio showcasing research, design development and final project outcomes. In addition to the portfolio, each group also submitted the original 3D model files of both the pavilion design and interior space, an independently running Unity project build was also provided for assessment. The submission files collectively provided a thorough insight into each group's development process and self-reflection; this was investigated during the assessment of each submission for grading. A final survey was then distributed to all students to share additional information regarding their personal experiences of collaborating while learning and integrating the introduced methodology throughout the semester.

5 Findings, Discussion and Conclusion

Throughout the semester, students were tasked to research the diverse set of XR tools implemented in architectural/engineering practice, design and entertainment platforms. During this stage, students were able to build further awareness of several XR and desktop-based hardware and software which provided a series of comparative case studies. This exercise contextualised and provided further insight into the immersive hardware and software during the VR introduction stage.

Based on the survey findings which included 29 responses out of the 40 students, results showcase positive feedback regarding the accessibility of VR tools. Even though many participants (21/29) have not used VR in the past, the user-friendliness of using Gravity Sketch during the first session received a 3.34/5 average rating which was higher than 3DS Max, which was rated an average accessibility rating of 3.1/5. In addition, participants also rated their initial VR collab taster session an average of 4.1/5. The minor setback consists of 12/29 users facing some discomfort during long sessions, ranging between eye strain (most common), motion sickness and headaches. Some discomfort can be further resolved by providing further awareness to adjust the VR lens to the users' IPD (Interpupillary distance) and turning on Vertical Lock in VR to prevent users from rotating upside down when navigating the VR space.
Cycling between each stage in the framework influenced some groups to reconsider certain design decisions based on their increasing familiarity with the VR software as showcased in Figure 8. To further expand on this point, considering the short VR period to complete the exercise, the iterative process in VR displayed well-controlled translations that felt true to the initial 2D sketches (Figures 6 & 8). Utilising Unity’s real-time render engine, some also groups achieved great visual results that further enhanced the final visualisation of the model.

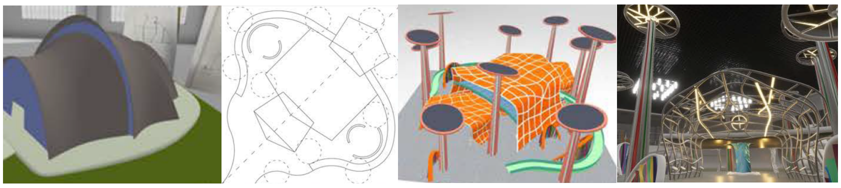

Figure 8. Group 7 design development through increased familiarity with VE tools. Incorporated skills include geometry control; symmetry; and light system integration.

The collaborative aspect involving VR and non-VR users further enhanced the experience embrace VR as a design tool while encouraging multi-user participation. The small learning curve to refine the drawing techniques in Gravity Sketch led to diverse approaches and design styles influenced by the applied shape-finding exercises. Notable advantages of incorporating VR also included an enriched exploration of design concepts that were unrestrained by physical forces such as gravity, further encouraging the conceptualisation process and providing valuable insight into the VR pedagogy as observed in Figures 5, 6 and 7. We address the continuous development of the design framework in various academic and workshop-based platforms while translating conventional and analogue design techniques into the virtual realm. This develops an evolving dialogue to integrate XR tools in architectural design practice and collaborative learning environments.

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