UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Arquitectura de Madrid

Las tecnologías digitales y el proceso creativo arquitectónico

TESIS DOCTORAL

Presentada para optar al título de Doctor por:

Hugo César Gómez Tone
Arquitecto/Magister

Madrid, 2024





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Bajo la dirección de:
Dr. Arq. Javier Francisco Raposo Grau

Madrid, 2024

Título: Las tecnologías digitales y el proceso creativo arquitectónico

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Revisores externos:

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Prefacio

A continuación, se detallan los artículos científicos derivados de la presente tesis doctoral y que ha permitido optar por la modalidad de compendio de publicaciones:

1. **Artículo Científico 1 publicado:**

   Gomez-Tone, H. C., & Raposo Grau, J. F. (2024). Characterization of conception drawing in architecture to face technological mediations. Frontiers of Architectural Research, 13(3), 425–438. https://doi.org/10.1016/j.foar.2023.12.013

2. **Artículo Científico 2 publicado:**

   Gomez-Tone, H., & Raposo Grau, J. (2024). The Architectural Conception Drawing in Immersive Virtual Environments. The Journal of Architecture. https://doi.org/10.1080/13602365.2024.2426169

3. **Artículo Científico 3 publicado:**

   Gomez-Tone, H., & Raposo Grau, J. F. (2024). The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator. Buildings, 14(8), Article 8. https://doi.org/10.3390/buildings14082334

Además, se han presentado las siguientes comunicaciones en congresos científicos derivadas de la investigación con actas publicadas en la base de datos científica SCOPUS:

1. **Ponencia en Congreso Internacional 1 sustentada y publicada**

   Gomez-Tone, H., Butron-Revilla, C. L., Manchego-Huaquipaco, E. G., & Dueñas Silva, M. K. (2023). Virtual Reality and 3D Printing in Architectural Design. Case study: The Conceptual Model. In Cardona-Reyes H., Lara-Alvarez C.A., Ortiz-Esparza M.A., & Villalba-Condori K.O. (Eds.), CEUR Workshop Proc. (Vol. 3691, pp. 415–425). CEUR-WS; Scopus. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85194728472&partnerID=40&md5=b5b70b33b82450c1a22c5a704ae6f054

2. **Ponencia en Congreso Internacional 2 sustentada y publicada**

   Gómez-Tone, H., Manchego-Huaquipaco, E. G., Butrón-Revilla, C., Bustamante-Escapa, J., & Anci, B. V. (2023b). Immersive Virtual Reality applied to Architectural Conception Drawing: Novices vs. Experts. ZEMCH. Int. Conf., 208–217. Scopus. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85194105528&partnerID=40&md5=597c592298a437e4c88b7609e4bba7d1

Dedicatoria

Dedico esta tesis a mis dos hijas, Camila y Renata que son el motivo de mis esfuerzos y que muchas veces han sufrido mi ausencia. A mi esposa, Lili cuyo amor incondicional y paciencia han sido mi sostén durante este largo camino. Y a mis estudiantes de arquitectura, cuyo entusiasmo y creatividad han sido mi inspiración constante, recordándome siempre el valor de seguir adelante. Gracias a todos por su apoyo y comprensión en este viaje en busca de conocimientos.

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Resumen

La introducción de tecnologías digitales en la arquitectura ha generado debates sobre su impacto en el proceso creativo. Se argumenta que estas tecnologías afectan negativamente la conexión entre imaginación, visión y mano, perjudicando la concepción inicial de las ideas arquitectónicas. Sin embargo, tecnologías emergentes como la Realidad Virtual Inmersiva (RVI) y la Impresión 3D (I3D) están cambiando esas percepciones. Por lo tanto, es necesario reexaminar el proceso creativo para evaluar cómo estas tecnologías pueden complementar los métodos tradicionales en la generación de ideas.

El objetivo de esta tesis es entender y documentar el proceso creativo inicial en arquitectura, especialmente en la generación de las primeras ideas, para evaluar cómo la RVI y la I3D pueden influir en este proceso sin alterar su esencia. Se plantearon tres hipótesis: 1) La revisión bibliográfica y el análisis de los dibujos de concepción de arquitectos contemporáneos y galardonados permitirá identificar las fases, características y condiciones esenciales del proceso creativo. 2) La RVI facilitará una creación más rápida y variada de ideas tridimensionales complejas a través de una experiencia inmersiva y corporal. 3) La I3D permitirá la materialización de ideas tridimensionales complejas y establecerá un vínculo háptico con la materialidad del objeto.

Para comprobar la primera hipótesis, se utilizó la metodología del estudio de caso, analizando los dibujos de concepción de Tadao Ando, Zaha Hadid y Frank Gehry, y revisando sus declaraciones sobre sus procesos creativos. Para verificar la segunda y tercera hipótesis, se llevó a cabo un estudio piloto experimental con una metodología de estudio de caso múltiple, involucrando a estudiantes de arquitectura.

Los resultados indican que el dibujo a mano requiere una condición fenomenológica que involucra cuerpo y sentidos.

Además, se desarrolla en cuatro momentos dentro de las fases de ideación y configuración del proceso creativo: la iniciación ambigua, la indagación y derivación, la reinterpretación y determinación, y la finalización figurada. De otro lado, la primera experimentación demostró que la RVI beneficia todos estos momentos. En la iniciación, permite una exploración rápida y variada de ideas. En la indagación, ofrece un espacio inmersivo sin distracciones, facilitando un flujo continuo de ideas y mayor concentración. Durante la reinterpretación, la visualización y manipulación de diseños en 3D desde diferentes ángulos y escalas brinda una comprensión espacial más rica. En la finalización, la RVI permite trabajar directamente en 3D, eliminando la necesidad de representaciones bidimensionales. La segunda experimentación, que combinó RVI e I3D, reafirmó los beneficios de la RVI y mostró que la I3D complementa la principal deficiencia de la primera que es la falta de vínculo háptico directo con los objetos creados.

La investigación concluye que el proceso creativo en arquitectura, especialmente en sus primeros momentos, es esencial y se puede beneficiar significativamente de la integración de tecnologías disruptivas como RVI e I3D. Estas herramientas complementan los métodos tradicionales, como el dibujo a mano y la creación de maquetas, ofreciendo ventajas únicas que potencian la percepción espacial y la materialización de ideas complejas. Superan limitaciones como la bidimensionalidad del dibujo y la complejidad de las maquetas físicas, facilitando una exploración tridimensional inmersiva y la rápida materialización física de ideas, lo que conduce a un proceso creativo arquitectónico más fluido.

Palabras clave: Proceso Creativo, Diseño Arquitectónico, Tecnologías Digitales, Primera Idea, Realidad Virtual, Impresión Tridimensional.

Abstract

The introduction of digital technologies in architecture has generated debates about their impact on the creative process. It is argued that these technologies negatively affect the connection between imagination, vision and hand, damaging the initial conception of architectural ideas. However, emerging technologies such as Immersive Virtual Reality (IVR) and 3D Printing (3DP) are changing those perceptions. Therefore, it is necessary to re-examine the creative process to evaluate how these technologies can complement traditional methods of idea generation.

The aim of this thesis is to understand and document the initial creative process in architecture, especially in the generation of the first ideas, to evaluate how IVR and 3DP can influence this process without altering its essence. Three hypotheses were proposed: 1) The literature review and analysis of conception drawings by contemporary and award-winning architects will identify the essential phases, characteristics and conditions of the creative process. 2) The IVR will facilitate faster and more varied creation of complex three-dimensional ideas through an immersive, bodily experience. 3) The 3DP will enable the materialisation of complex three-dimensional ideas and establish a haptic link to the materiality of the object.

To test the first hypothesis, a case study methodology was used, analysing the conception drawings of Tadao Ando, Zaha Hadid and Frank Gehry, and reviewing their statements about their creative processes. To verify the second and third hypotheses, an experimental pilot study was conducted using a multiple case study methodology, involving architecture students.

The results indicate that drawing by hand requires a phenomenological condition where the body and the senses play a crucial role. Furthermore, it develops in four moments within the ideation and configuration phases of the creative process: ambiguous initiation, enquiry and derivation, reinterpretation and determination, and figurative completion. On the other hand, the first experimentation showed that IVR benefits all these moments. In initiation, it allows for a rapid and varied exploration of ideas. In enquiry, it offers an immersive space without distractions, facilitating a continuous flow of ideas and increased concentration. During reinterpretation, viewing and manipulating 3D designs from different angles and scales provides a richer spatial understanding. In the finalisation, IVR allows working directly in 3D, eliminating the need for two-dimensional representations. The second experimentation, which combined IVR and 3DP, reaffirmed the benefits of IVR and showed that 3DP complements the main shortcoming of IVR, which is the lack of a direct haptic link to the created objects.

The research concludes that the creative process in architecture, especially in its early stages, is essential and can benefit significantly from the integration of disruptive technologies such as IVR and 3DP. These tools complement traditional methods, such as hand drawing and model making, by offering unique advantages that enhance spatial perception and the materialization of complex ideas. They overcome limitations such as the two-dimensionality of drawing and the complexity of physical models, facilitating immersive three-dimensional exploration and rapid physical materialization of ideas, leading to a more fluid architectural creative process.

Key words: Creative Process, Architectural Design, Digital Technologies, First Idea, Virtual Reality, Three-dimensional printing.

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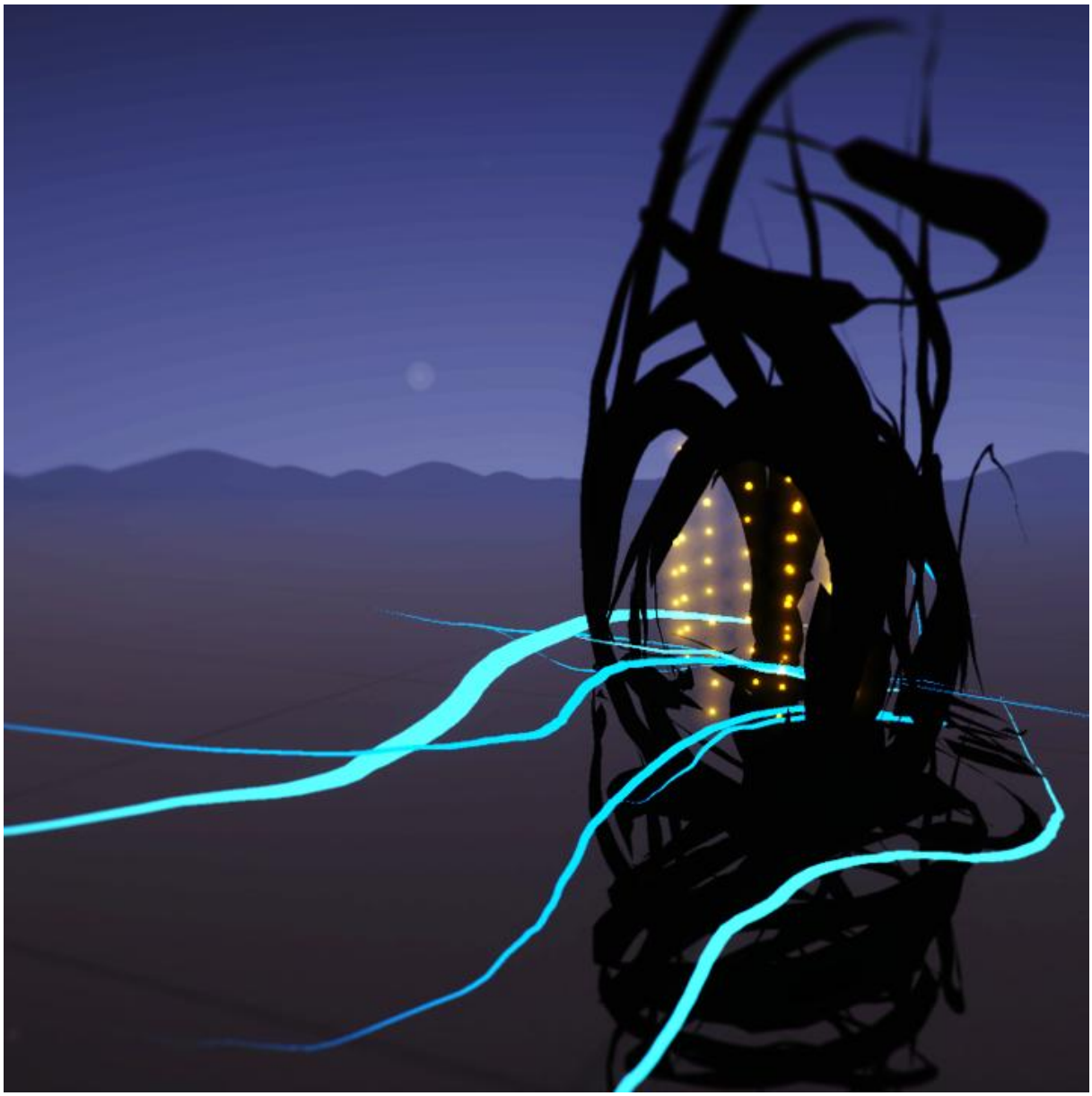
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Abreviaturas y Acrónimos

UPM	Universidad Politécnica de Madrid
RVI	Realidad Virtual Inmersiva
I3D	Impresión 3D
HMD	Head Mounted Display
Fab Lab	Fabrication Laboratory
IA	Inteligencia Artificial
CAD	Computer Aided Design
FDM	Modelado por Deposición Fundida
SLS	Sinterización Selectiva por Láser
SLA	Estereolitografía
BIM	Modelado de Información para la Construcción

El proceso creativo arquitectónico, tradicionalmente vinculado a dibujos y maquetas, está siendo transformado por las tecnologías digitales, que aportan dimensiones antes imposibles de pensar. Al fusionar lo digital con lo artesanal, se propone un equilibrio que conserva la esencia humana del diseño mientras explora y evoluciona con mayor libertad, enriqueciendo la práctica arquitectónica.

El autor

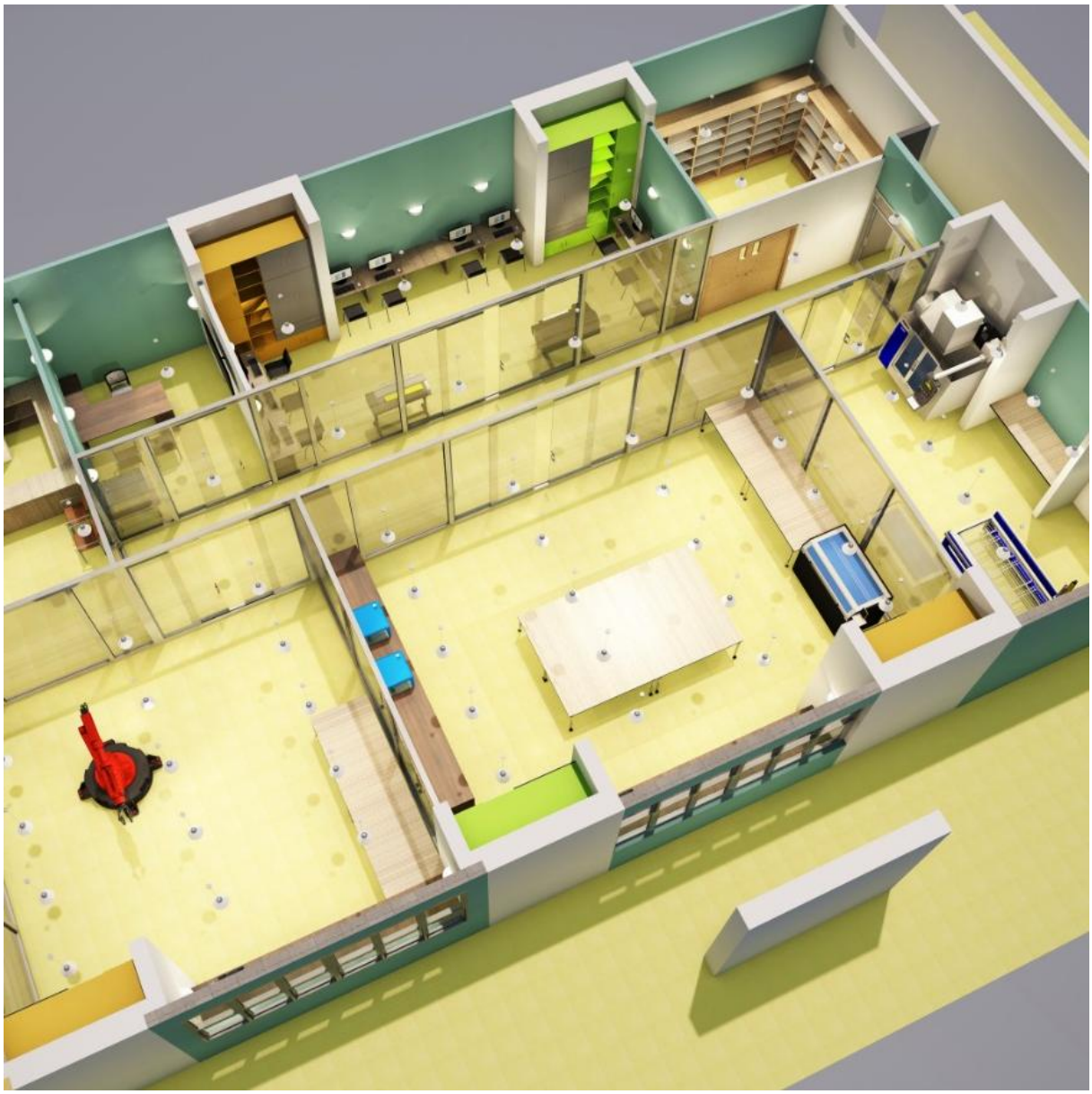


1. Introducción

Desde la década de los ochenta la introducción de la tecnología en el campo académico y profesional de la arquitectura ha establecido la polémica de si los nuevos medios y métodos podrían afectar al pensamiento del diseño (Meisenheimer, 1987). Existe un consenso casi absoluto que dicha intromisión tecnológica altera la conexión sensual y háptica entre la imaginación, la vista y la mano afectando negativamente los momentos iniciales de concepción de la esencia arquitectónica (Pallasmaa, 2017). La principal consecuencia de dicha intromisión ha sido una crisis de la experiencia sensible en la creación arquitectónica (Bizzotto, 2022). Cuarenta años después de aquellos primeros debates, el desarrollo de tecnologías emergentes y disruptivas como la Realidad Virtual Inmersiva (RVI) y la impresión 3D (I3D) entre otras, están terminando por colonizar todos los aspectos del campo profesional del arquitecto y cambiando la manera en que se conciben, diseñan, y construyen los espacios arquitectónicos.

Estas tecnologías adecuadamente usadas podrían estar muy lejos de generar tal crisis en la creatividad arquitectónica, por el contrario, podrían ampliar los horizontes creativos de los arquitectos, permitiéndoles innovar y experimentar de maneras que antes eran impensables. Ante la incorporación inexorable de las tecnologías, es necesario volver a darle una mirada académica a este proceso creativo. Esto implica una revisión de sus momentos, condiciones y características, aspectos esenciales para comprender cómo se gestan las ideas iniciales en arquitectura para preservarlas. A partir de esta revisión, se busca establecer, mediante experimentaciones directas con estudiantes de arquitectura, las posibilidades de su incorporación o complementariedad con los medios tradicionales de ideación y configuración de ideas para la conceptualización de proyectos arquitectónicos. enriquecer la práctica arquitectónica y expandir las herramientas disponibles.

Figura 1
Idea arquitectónica creada por un estudiante en un entorno de Realidad Virtual Inmersiva. Imagen fotografiada por el autor



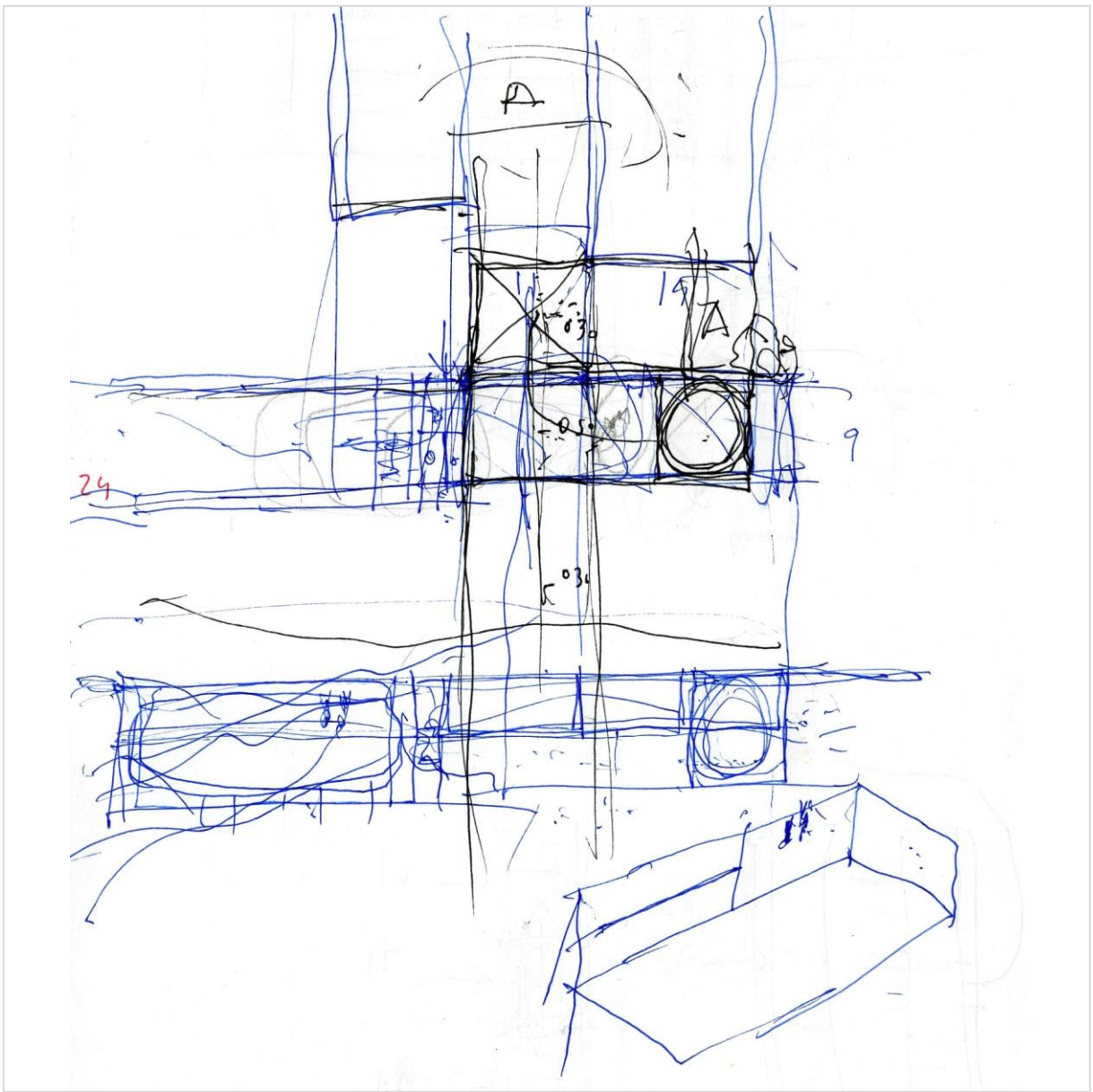
1.1. Motivación

La motivación para desarrollar esta tesis doctoral se origina en la experiencia docente universitaria en Perú, particularmente en la enseñanza del Taller de Diseño Arquitectónico del primer año. Esta labor ha permitido al autor observar de cerca los desafíos que enfrentan los estudiantes en las etapas iniciales del proceso creativo arquitectónico y cuestionarse cómo el aprendizaje del diseño arquitectónico se podría enriquecer al integrar nuevas herramientas tecnológicas.

Otra motivación importante surgió a partir de los fondos concursables universitarios para desarrollar investigaciones aplicadas que han permitido materializar iniciativas innovadoras aplicando tecnología. Un primer fondo, de 60 mil euros, estuvo destinado a explorar las ventajas y desventajas del uso de la Realidad Virtual Inmersiva y Aumentada en el dibujo y percepción de espacios arquitectónicos, permitiendo al investigador realizar experimentaciones y documentar el impacto de dicha tecnología. Un segundo fondo, de 450 mil euros, permitió la creación de un Laboratorio de Diseño y Fabricación Digital (Fab Lab) equipado con últimas tecnologías para la fabricación digital.

Ambos proyectos finalizados están brindando tanto a estudiantes como a docentes la posibilidad de experimentar con herramientas de realidad virtual y fabricación digital. Estos recursos ya culminados y disponibles han permitido avanzar hacia una fase de exploración y experimentación directa con los estudiantes, buscando la innovación educativa y la incorporación de metodologías contemporáneas en la enseñanza y aprendizaje de los procesos creativos que generan las primeras ideas arquitectónicas.

Figura 2
Modelo 3D del Laboratorio de Diseño y Fabricación Digital. Imagen fotografiada por el autor



1.2. Objetivos e hipótesis

Reconocer las fases, condiciones y características del proceso creativo en la generación de las primeras ideas del proyecto arquitectónico permitirá que la integración de tecnologías emergentes y disruptivas como la RVI y la I3D no altere los procesos creativos de generación de las primeras ideas del proyecto arquitectónico. Esto no solo preservará los procesos cognitivos fundamentales de la creatividad arquitectónica, sino que también extenderá su efectividad y eficiencia, proporcionando mayor profundidad y una perspectiva innovadora en la conceptualización arquitectónica.

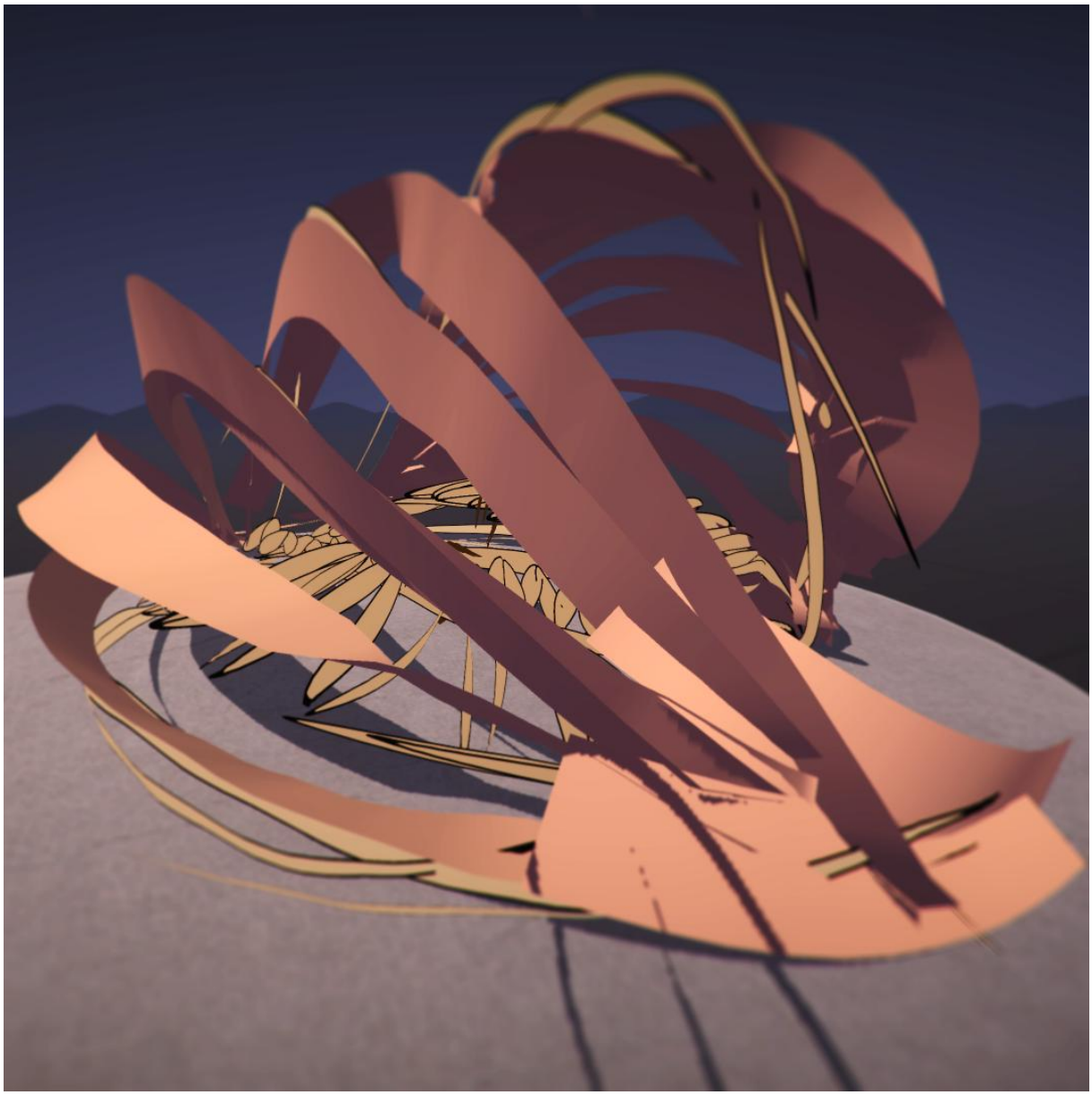
Se han planteado tres objetivos y tres hipótesis para el desarrollo de esta tesis.

Objetivo 1: Establecer los momentos, características y condiciones del proceso creativo en los momentos de generación de las primeras ideas arquitectónicas con la finalidad de afrontar las mediaciones tecnológicas.

Hipótesis 1: Dado que el proceso cognitivo para la creación de las primeras ideas arquitectónicas ha sido históricamente mediado a través del dibujo a mano alzada, esta tesis sostiene que la revisión bibliográfica y el análisis detallado de los dibujos de concepción realizados por arquitectos contemporáneos y galardonados con el Premio Pritzker permitirá reconocer y establecer con fines pedagógicos las fases, características y condiciones esenciales de este proceso creativo.

Figura 3
Bocetos de Alberto Campo Baeza para el Pabellón Robert Olnick de Nueva York. Imagen de www.campobaeza.com

Objetivo 2: Explorar las ventajas y desventajas de integrar la RVI en el proceso de generación de las primeras ideas arquitectónicas.

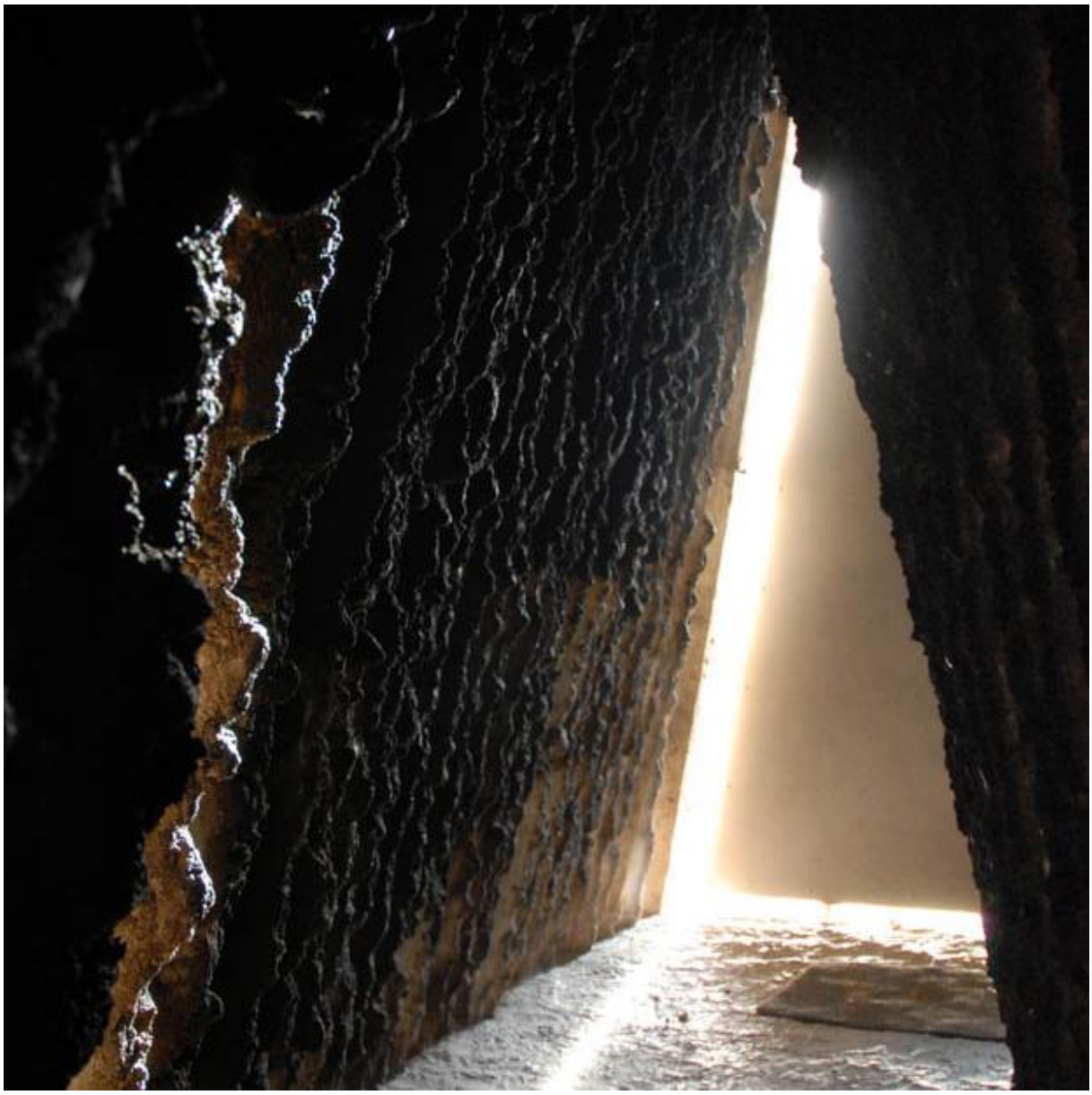


Hipótesis 2: Dada las cualidades que ofrece el uso de entornos de la RVI con visores montados sobre la cabeza (HMD del inglés Head Mounted Display), mandos hápticos y un software creado para el dibujo artístico a mano alzada, esta tesis sostiene que la incorporación de la RVI en las fases de ideación y configuración de las primeras ideas del proyecto arquitectónico no solo permitirá la creación de las primeras ideas del proyecto arquitectónico con las mismas características del dibujo de concepción realizado con lápiz sobre papel, sino que además, permitirá crear ideas más rápidas, variadas, tridimensionales y complejas a través de una experiencia intensa y corporal.

Objetivo 3: Explorar las ventajas y desventajas de integrar la I3D en el proceso de generación de las primeras ideas arquitectónicas.

Hipótesis 3: Dada la gran versatilidad y precisión de la I3D para fabricar de manera física objetos con cualquier geometría, esta tesis sostiene que la incorporación de la I3D en las fases de ideación y configuración de las primeras ideas del proyecto arquitectónico no solo ayudará a materializar de manera más rápida y precisa la idea tridimensional con respecto a las maquetas conceptuales fabricadas manualmente, sino que además, permitirá la materialización de ideas tridimensionales más complejas y la creación de un vínculo háptico con la materialidad del objeto, superando esta limitación de los modelos digitales y virtuales.

Figura 4
Idea arquitectónica creada por un estudiante en un entorno de Realidad Virtual Inmersiva. Imagen fotografiada por el autor



2. Estado de la cuestión

2.1. Arquitectura, cuerpo y creatividad

La arquitectura es mucho más que la simple construcción de estructuras; es una manifestación de la interacción profunda entre el entorno construido y la experiencia humana. Desde los primeros pasos de conceptualización hasta la materialización de una idea arquitectónica, el cuerpo humano juega un papel esencial en el proceso de diseño. La percepción arquitectónica involucra a todo el cuerpo, siendo esencial para comprender y experimentar el entorno circundante (Merleau-Ponty, 1957). Esta idea es reafirmada por Steven Holl (2018), quien destaca la importancia de la experiencia sensorial y fenomenológica en la arquitectura, haciendo hincapié en elementos como la luz, el color, el espacio y otros elementos sensoriales en la creación de experiencias arquitectónicas. El cuerpo y las manos no solo son herramientas para ejecutar acciones físicas necesarias en el diseño, como dibujar y modelar, sino que también sirven como marco y modelo para comprender tanto el mundo exterior como el interior de uno mismo (Hale, 2016). Permiten interpretar y sentir la tridimensionalidad del espacio desde la perspectiva del propio cuerpo tridimensional, así como concebir e idear dichos espacios.

Pallasmaa (2017) describe el estado creativo en la arquitectura como una condición de inmersión háptica en donde el cuerpo y la mano exploran, investigan y tocan de un modo parcialmente independiente ejemplificando el conocimiento existencial esencial. También se resalta la importancia de asumir el cuerpo en su totalidad y considerar todos los sentidos como punto de partida en el proceso creativo (Gomes et al., 2017). La creatividad involucra una colaboración entre la percepción visual, la destreza manual y el pensamiento cognitivo.

Figura 5
Capilla de Campo Bruder Klaus de Peter Zumthor. Imagen de www.zumthor.bjorkan.no



Como consecuencia de la transferencia mental desde la realidad del dibujo o de la maqueta a la realidad material del proyecto, las imágenes no son simples traducciones visuales, sino que constituyen una realidad de imaginación completamente háptica y multisensorial (Pallasmaa, 2017).

La creatividad en la arquitectura no se deriva únicamente de la capacidad técnica, sino que emerge de una profunda comprensión de cómo los humanos habitan y se mueven dentro de los espacios, reforzando la idea de que los ambientes arquitectónicos deben resonar con la experiencia humana (Zumthor, 2006). En la configuración arquitectónica, la implicación del cuerpo, los brazos y las manos es fundamental. Dibujar, modelar y proyectar la virtualidad envolvente de la arquitectura como espacio vivencial implica acciones y reacciones de alto contenido subjetivo, sensitivo y emocional. La relación háptica con el mundo ofrece información crucial sobre la importancia de los aspectos intuitivos, inconscientes y emocionales en el uso del espacio y en la comunicación conductual, fundamentales para el diseño de espacios culturalmente relevantes (Trachana, 2012).

Las actividades físicas y el movimiento corporal también influyen significativamente en la creatividad. Movimientos espontáneos y la manipulación de objetos físicos pueden mejorar el rendimiento creativo, sugiriendo una conexión mente-cuerpo que facilita perspectivas innovadoras en el diseño arquitectónico. La manipulación de objetos durante el proceso de diseño puede fomentar nuevas ideas y soluciones creativas, especialmente en la fase conceptual de proyectos arquitectónicos. Integrar prácticas físicas puede ser una herramienta útil para estimular la creatividad en disciplinas que tradicionalmente se consideran menos físicas, como el diseño arquitectónico (Frith et al., 2020).

Figura 6
Peter Zumthor diseñando a través del dibujo en su taller. Imagen de www.dezeen.com

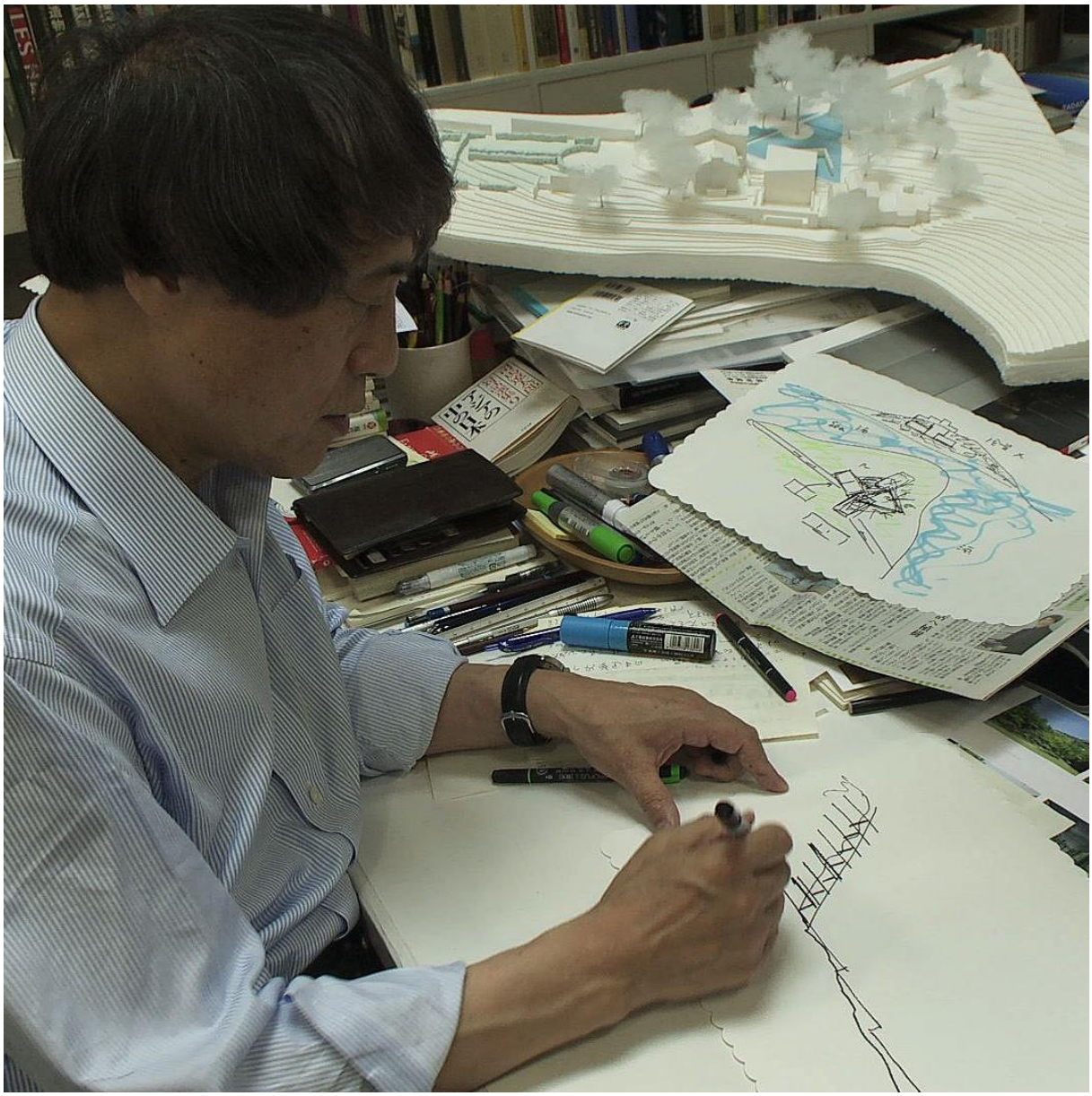




Esta relación entre el cuerpo y la creatividad se refleja también en la pedagogía del diseño arquitectónico. Promover el pensamiento creativo en el nivel inicial en arquitectura implica entrenar la conciencia de las sensibilidades corporales para captar lo fugazmente inteligible dentro del diseño y la composición. Los elementos esenciales del arte y la arquitectura se descubren a través del contacto con aquellas cualidades que, por su presencia, nos atraen y nos hablan. Esto permite a los estudiantes principiantes reivindicar su cuerpo sensitivo y sensible a través de la práctica de tocar la materia y crear cosas con las manos, como un puente hacia un mundo interior de sentimientos. Evocar el contacto ritual puede ser un proceso que activa la sensibilidad y los sentidos primarios (Urbina, 2018).

En conclusión, la arquitectura, más que una mera disciplina técnica, es una expresión de la interacción entre el cuerpo humano y el entorno construido. Desde la percepción sensorial hasta la materialización de una idea, el cuerpo y la creatividad están intrínsecamente vinculados en el proceso de diseño arquitectónico. Las manos no solo son herramientas para materializar ideas, sino que también son fundamentales en la formulación y evolución del pensamiento creativo. A través de la creación de bocetos, maquetas y otros medios de expresión manual, los arquitectos pueden explorar y comunicar ideas complejas, refinando continuamente sus proyectos a medida que avanzan en sus diseños. Esta relación entre el pensamiento y la acción física subraya la importancia de las habilidades manuales en la enseñanza y la práctica de la arquitectura, proporcionando una vía directa y táctil para el descubrimiento y la innovación arquitectónica (Dorado, 2013).

Figura 7
Frank Gehry diseñando con maquetas en su taller. Imagen del documental "Apuntes de Frank Gehry" www.youtube.com



2.2. La creación de la idea arquitectónica

La creación de la idea arquitectónica es un proceso que comienza con la imaginación y culmina en la materialización de una idea. Según Vygotsky (2004) la base real y la fuerza motriz de la creación es el impulso de la imaginación a encarnarse, es decir que todo producto de la imaginación, que ha surgido en respuesta a nuestra inspiración, intenta completar un círculo y encarnarse en la realidad. Esto explica la necesidad de traducir pensamientos abstractos en objetos tangibles en la arquitectura. La idea inicial arquitectónica actúa como un nexo entre la inspiración abstracta y su manifestación física, guiando todas las decisiones subsecuentes en el proceso de diseño (Ching, 2016). Este enfoque resalta que la arquitectura no es simplemente la construcción de edificios, sino la realización de conceptos que se originan en la mente del arquitecto.

Campo Baeza (2009) subraya que los arquitectos construyen ideas, concebidas con la cabeza y la razón, y que estas ideas deben entenderse como esquemas conceptuales mentales derivados de procesos cognitivos complejos, incluyendo el pensamiento crítico, la imaginación y la intuición. La intuición, en particular, juega un papel crucial en las fases iniciales de la ideación arquitectónica. Esta capacidad de percibir soluciones adecuadas sin una justificación racional completa es esencial para superar bloqueos creativos y desarrollar nuevas perspectivas y soluciones innovadoras (Jung, 1971). Es importante enfatizar la importancia de equilibrar el orden y el caos en el proceso creativo, utilizando la intuición y la percepción fenomenológica para desarrollar soluciones arquitectónicas innovadoras y sostenibles (Arnheim, 1969). Esta comprensión permite gestionar la complejidad del diseño y estructurar ideas efectivas.

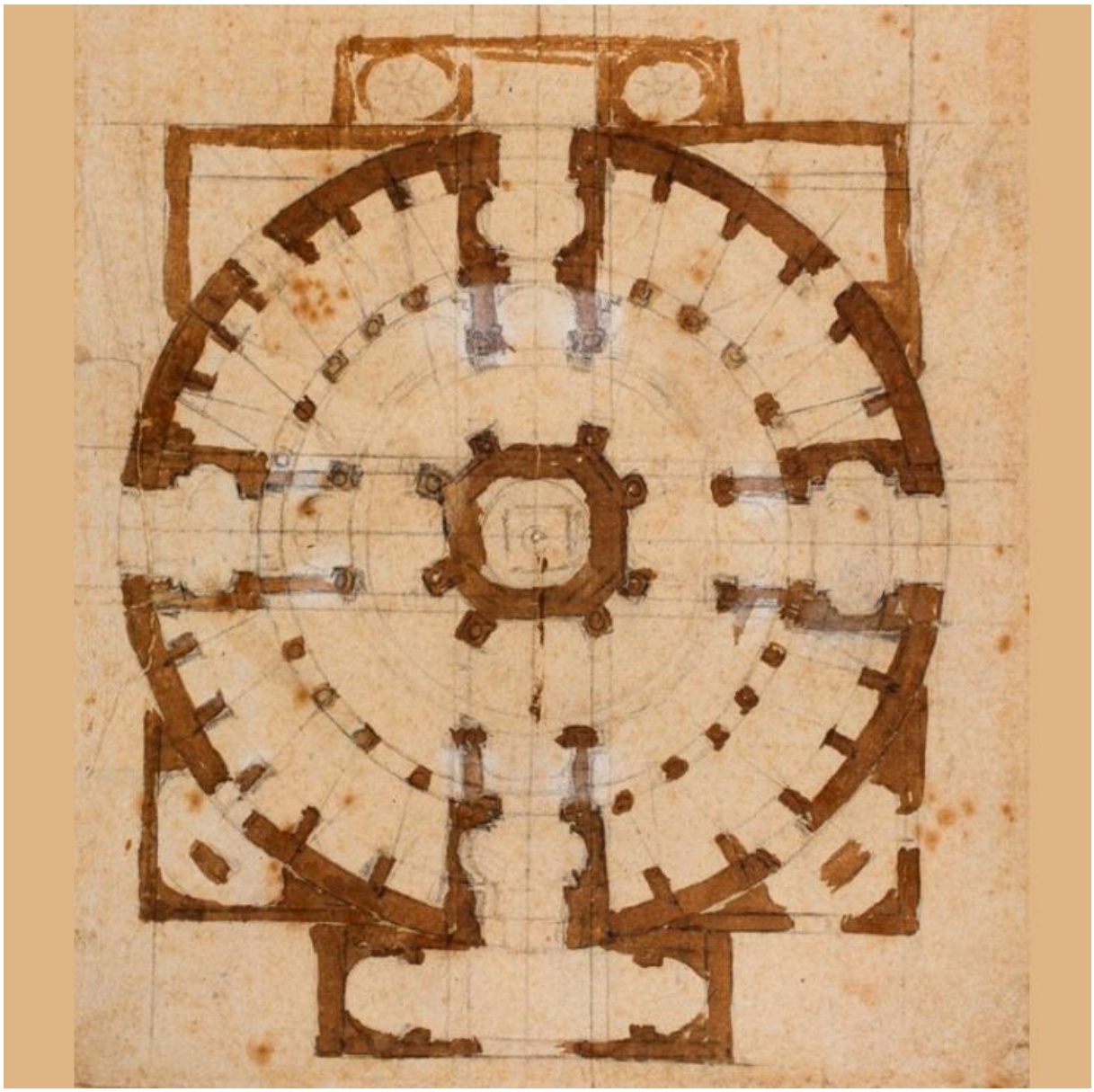
Figura 8
Tadao Ando diseñando a través de dibujos y maquetas. Imagen de www.neo2.com



En este proceso de concepción arquitectónica y de materialización de las ideas, éstas intervienen como imágenes y figuras y son procesadas por el pensamiento arquitectónico configurativo o gráfico-plástico (Seguí de la Riva, 1993). El pensamiento configurativo o figurativo, permite conferir imagen o figura a las ideas. Este proceso de la concepción arquitectónica por el que se da figura a las ideas tiene dos fases sucesivas denominadas ideación y configuración que son el núcleo de la creación de la arquitectura (Yanguas, 2019). En la ideación se generan las ideas aún abstractas en un proceso muy personal que no busca comunicar la idea. En la configuración, que sigue siendo un proceso muy personal, las ideas producidas en la ideación se transforman en figuraciones arquitectónicas, es decir se concretan y adquieren figura. Estas permiten la auto confrontación y la confrontación con otros, aunque sin intención comunicativa.

El proceso de ideación y configuración no es solo un ejercicio de intuición e inspiración espontánea, sino un proceso cíclico e iterativo donde el hacer práctico juega un papel fundamental. El ejercicio del proyecto arquitectónico se alimenta de un análisis crítico y de la experiencia previa, integrando continuamente nuevas percepciones y ajustes (Casado de Amezúa, 2003). Este enfoque resalta la importancia del dibujo y otras técnicas gráficas o del modelamiento como instrumentos esenciales para la ideación y la configuración de las ideas arquitectónicas, facilitando un diálogo continuo entre la mente y la materialidad del proyecto. Así, la teoría y la práctica se entrelazan en un proceso dinámico donde cada boceto y maqueta no solo representan, sino que también provocan y guían la evolución del pensamiento creativo, alineándose con la necesidad de materializar las ideas que buscan encarnarse en la realidad. Aunque la ideación se asocia al dibujo y la configuración a las maquetas, esto no es estricto.

Figura 9
Proceso de diseño iterativo a través de múltiples maquetas en la Oficina de Arquitectura SANAA. Imagen de www.arquitecturaviva.com



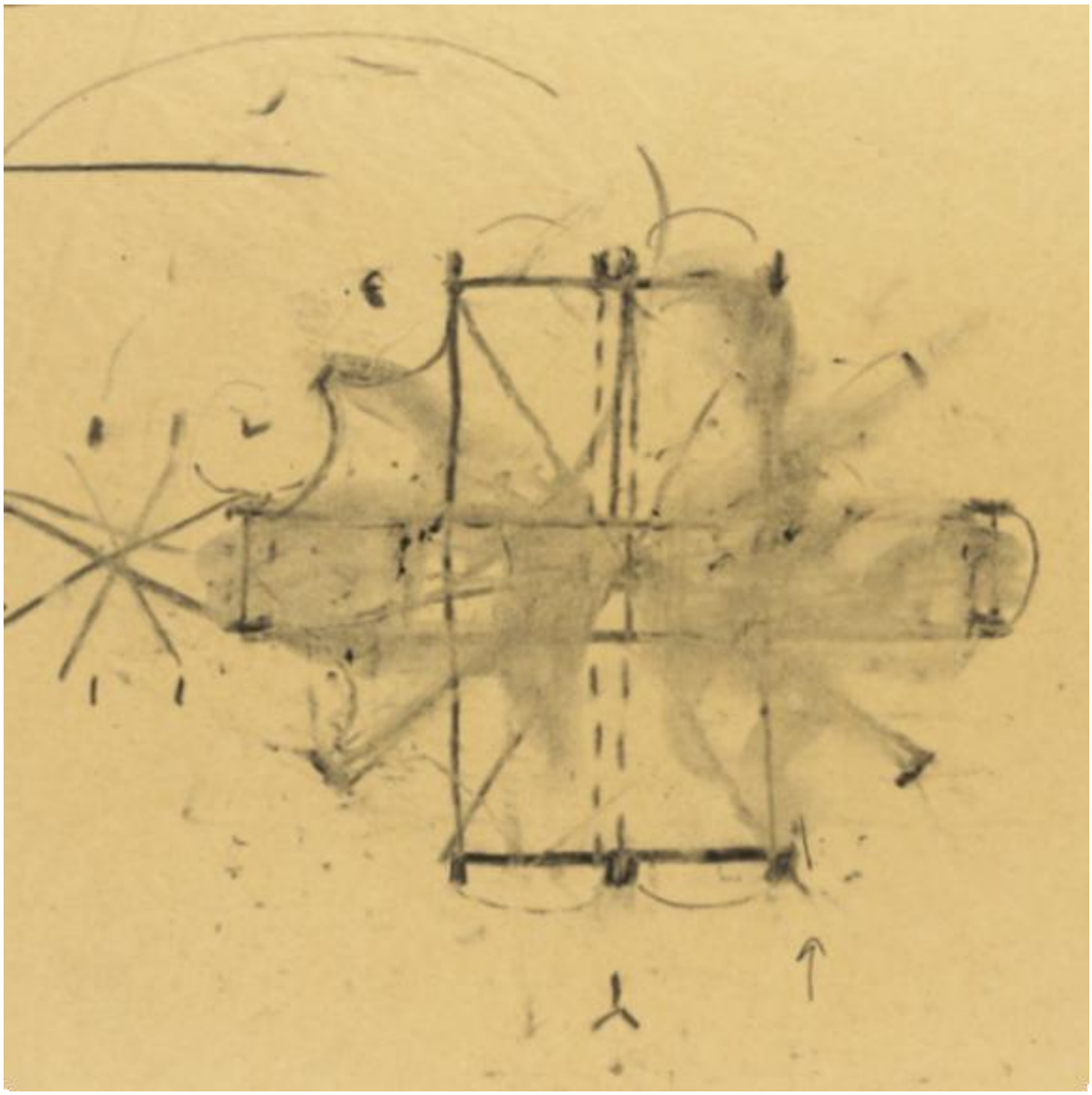
2.3. El dibujo en la creación de la idea

2.3.1. Antecedentes

El vínculo entre el dibujo como herramienta de la creatividad y el pensamiento arquitectónico se ha dado siempre, pero no se tiene certeza del momento exacto de su uso sistemático. Solo a partir del Renacimiento y del fácil acceso al papel es que se han encontrado evidencias del uso del dibujo en el proceso del diseño arquitectónico. Miguel Ángel Buonarroti es el precursor del uso del dibujo como medio de concepción e invención de la arquitectura de manera sistematizada. Los trazos de este escultor, pintor y arquitecto difieren notablemente de los de sus colegas y de quienes lo precedieron. Revelan un desarrollo gradual de ideas a lo largo de un proceso de dibujo meticuloso y continuado, realizado en distintos momentos repetidos. Este enfoque transformó la función y la estética de los dibujos arquitectónicos, demostrando que la arquitectura podía ser un medio para la expresión imaginativa, equiparándose así a la pintura o la escultura (Brothers, 2008).

Este tipo de dibujo especial vinculado al pensamiento arquitectónico recuperó su relevancia en la mitad del siglo XX, cuando se realizaron esfuerzos significativos para conceptualizar las acciones de producción arquitectónica y singularizar los procedimientos de investigación relacionados con el diseño arquitectónico y la materialización de la intuición constructiva (Vagnetti, 1958). Posteriormente, en las décadas de los sesenta y setenta, se estableció que el dibujo ya no debía considerarse únicamente como un medio preparatorio de la obra para construirse, sino también como una forma de ejecución en sí mismo.

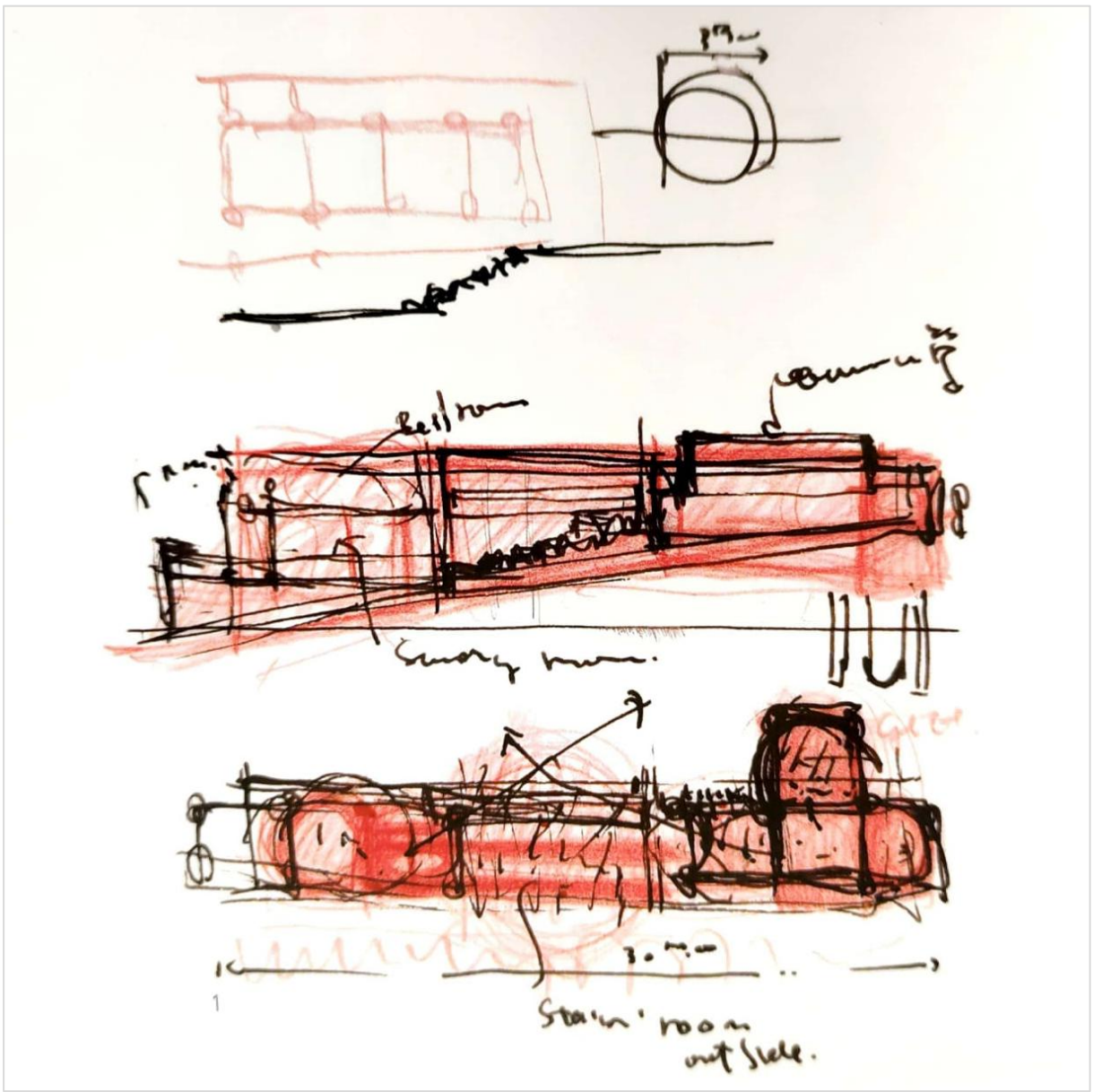
Figura 10
Dibujo de la planta de San Giovanni de Fiorentini realizada por Michelangelo Buonarroti. Imagen de www.meisterdrucke.es



El dibujo como producto y el acto de dibujar se fusionaron en un único proceso, ya que al dibujar también se ejecuta, logrando así armonía y precisión simultáneamente. El entendimiento teórico del dibujo culminó al reconocer que la traza era una abstracción conceptual generada por el gesto físico que expresaba la vitalidad de la mano y la energía involucrada en el acto mismo del trazado (Segui, 1986).

A partir de la década de los ochenta, las discusiones académicas sobre la importancia del dibujo en el diseño arquitectónico se centraron en su carácter especulativo y tentativo, así como en su estrecha relación con el proceso creativo en arquitectura (Graves, 1979). Surgió entonces un nuevo término, el "dibujo de concepción", introducido por primera vez en 1985 por Boudon y Deshayes (1985), quienes propusieron diferenciarlo del dibujo de presentación o comunicación, del dibujo retórico y del dibujo de obras acabadas. Este tipo de dibujo se enfocaba en concebir ideas, en los primeros esbozos y en los trabajos preparatorios. El dibujo de concepción se entendió como aquel que permitía concebir, explorar, ajustar y rectificar, siendo así un generador de realidad, un dibujo conjetural que moldeaba la forma del objeto arquitectónico, el cual aún solo existía de forma virtual (Segui, 1986). Recién desarrollada la argumentación teórica y la importancia de este tipo particular de dibujo, a mediados de la década de los ochenta, la introducción de la tecnología provocaba un debate sobre si la comprensión del dibujo, mediada por la tecnología, podría dar lugar a una comprensión diferente de la arquitectura. Surgió la pregunta de si los nuevos medios y métodos podrían influir en el pensamiento del diseño (Meisenheimer, 1987). Al finalizar los 80’s, ya se estaban llevando a cabo debates académicos sobre la supuesta "muerte" del dibujo tal como se conocía desde el Renacimiento (Mitchell, 1989).

Figura 11
Dibujos de concepción difuminados con los dedos de Louis Kahn para la Sinagoga Mikveh Israel en Pensilvania. Imagen de



2.3.2. Definiciones

Son muchas las aproximaciones teóricas relacionadas al dibujo conceptual o de concepción. Son de especial interés las siguientes aportaciones realizadas por los siguientes autores:

Según Pallasmaa (2017), cada vez que se realiza un boceto o se dibuja, se generan tres conjuntos distintos de imágenes, el dibujo plasmado en el papel, la imagen visual almacenada en la memoria cerebral y una memoria muscular del proceso de dibujar en sí. La imagen mental inicial puede adoptar diversas formas, puede ser una representación visual, una sensación táctil, muscular o corporal, o incluso una impresión difusa que la mano concreta en una serie de líneas que dan forma a una estructura o figura. Es imposible determinar si la imagen surge primero en la mente y luego se materializa a través del trazo de la mano, o si la mano produce la imagen de manera independiente, o si es el resultado de una colaboración fluida entre la mano y el espacio mental del dibujante.

De otro lado, Goldschmidt (2003) establece que el boceto actúa como una extensión de la imaginación mental, permitiendo una libertad total para evocar y manipular imágenes almacenadas previamente. Al mismo tiempo, al dejar una huella tangible de estas imágenes en una superficie visible mediante un proceso aditivo, el acto de bocetar conduce rápidamente a la creación de configuraciones y relaciones inesperadas entre los elementos gráficos. Las representaciones resultantes son susceptibles de nuevas interpretaciones y, si se buscan de manera consciente, pueden generarse con relativa facilidad utilizando información adicional de las estructuras de memoria del diseñador.

Figura 12
Dibujos de concepción de Tadao Ando para la casa Koshino en Japón. Imagen del libro "Tadao Ando, Process and Idea"


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Finalmente, Solana y Gutierrez (2015) resaltan que los bocetos son expresiones gráficas que concentran una carga conceptual abundante. Aunque tienen una codificación gráfica baja, exhiben una codificación simbólica elevada. Se trata de dibujos que poseen un lenguaje abierto y muestran escasa intención de síntesis. En su lugar, sostienen ideas extensas, exploran líneas de acción o realizan ensayos de verificación. Sirven como directrices para acciones posteriores y son capaces de generar discursos que pueden desembocar en acciones específicas y arquitectónicas. Aunque no logran establecer una solución definitiva en sí mismos, son lo suficientemente competentes como para guiar el desarrollo hacia resultados concretos.

Se propone una definición para el dibujo de concepción como proceso o acción. El dibujar es un acto de vinculación y colaboración de todo el cuerpo, pero fundamentalmente de las manos, la vista y la mente para que con ayuda de un instrumento y un soporte se hagan visibles las ideas provenientes del pensamiento creativo del arquitecto. Esta acción realizada en los momentos iniciales de la creación de la idea arquitectónica además busca reinterpretar, añadir y modificar aquellas primeras ideas visibles recurriendo a los datos almacenados en la memoria del arquitecto.

También se propone una definición para el dibujo de concepción como producto. El dibujo de concepción es el conjunto de trazos realizados rápida e intuitivamente que hacen visible y tangible las ideas dentro del proceso de pensamiento y de formalización de la arquitectura. Estos trazos inicialmente ambiguos no representan la respuesta final al problema a resolver, sino las directrices que tienen la capacidad por sí mismas de generar un diálogo con el arquitecto provocando nuevamente la acción de dibujar para establecer las primeras ideas arquitectónicas.

Figura 13
Dibujos conceptuales de Steven Holl para el Centro Cultural y Sanitario Cofco de Shanghái. Imagen de www.stevenholl.com


Noli me
tangere

2.4. La maqueta en la creación de la idea

2.4.1. Antecedentes

Se conoce que a lo largo de la historia la maqueta ha sido una compañera inseparable y competidora del dibujo en todos los aspectos de la producción y gestión arquitectónica (Carazo, 2011). Podría incluso haber desempeñado un papel similar al dibujo como primera impulsadora de la idea, si su creación hubiera sido tan fluida y espontánea como la elaboración de bocetos (Mills, 2010). Al igual que lo sucedido con el dibujo de concepción, no se conoce el momento exacto de la historia en que ésta se comenzó a usar como herramienta de creación arquitectónica. El primer reconocimiento del uso de la maqueta como tal lo sugiere Alberti (1991) en 1450 en su libro El Arte de Edificar cuando dice: "siempre elogiaré la antigua costumbre de los constructores, quienes no solo en bocetos y pinturas, sino también en maquetas reales de madera u otras sustancias, examinaron y pensaron una y otra vez, con el asesoramiento de los hombres de mayor experiencia". A pesar de reconocerle a la maqueta un valor semejante al del dibujo, esto no fue suficientes para conferirle a la maqueta un rol protagónico que la sostuviera como herramienta de diseño o por lo menos no existe evidencia posterior a ello. De lo que sí hay evidencia es que desde el nacimiento de la Escuela de Bellas Artes en el siglo XVII las maquetas fueron relegadas o prácticamente prohibidas debido a su asociación más con la escultura dejando que el dibujo se desarrolle estrechamente con la arquitectura (Morris, 2006).

Figura 14
Maqueta para la terminación de San Petronio de Bolonia, Arduino Arriguzzi. Imagen de www.riunet.upv.es

Recién en el siglo XX con la creación de la escuela de la Bauhaus se retoma el uso de la maqueta o modelo no solo como representación o comprobación, sino también como herramienta creativa.



De esta forma la maqueta comienza a tomar mayor importancia y aunque la exposición “Modern Architecture: International Exhibition” organizada por Philip Johnson y Henry-Russell Hitchcock en el Museo de Arte Moderno de Nueva York en 1932 no fuera de maquetas de ideación, se la reconoce como la exposición más relevante de maquetas arquitectónicas hasta ese entonces (Serrano & Rodríguez, 2018). Es solo en 1976 que el Instituto de Arquitectura y Estudios Urbanos de Nueva York organizó la primera exposición comisariada por Richard Pommer y Peter Eisenman dedicada exclusivamente a la maqueta como elemento de investigación proyectual. ‘Idea as Model’ publicó en 1980 su catálogo ampliando su contenido con algunas obras nuevas, que no estuvieron en la exposición inicial. Aunque la exposición no tuvo el resultado y efecto esperado, es una muestra clara de la inquietud teórica por usar las maquetas como herramientas de creación. Así lo establece el mismo Peter Eisenman (Institute for Architecture and Urban Studies, 1981) en el prólogo: “las maquetas, al igual que los dibujos arquitectónicos, pueden perfectamente tener una existencia artística o conceptual por sí solas […] como un elemento conceptual en contraposición a la herramienta narrativa, como parte de su proceso de diseño”. Posteriormente Eisenman agrega: “[…] la maqueta, como el dibujo, podía tener un casi inconsciente y no premeditado, incluso generativo, efecto en el proceso de diseño”.

En los 70’s y los 80’s los avances teóricos y críticos no solo se centraron en el dibujo, sino también en la maqueta. Por ejemplo, en 1987 se daba uno de los primeros puntos de referencia para la consideración de la maqueta arquitectónica en la revista Rasegna (Carazo, 2018) que con posteriores exposiciones en Venecia y Barcelona dieron cabida a mayores estudios monográficos de la maqueta y su importancia en el proceso del diseño arquitectónico.

Figura 15
Exposición de maquetas conceptuales de la oficina OMA/Koolhaas. Imagen de www.flickr.com

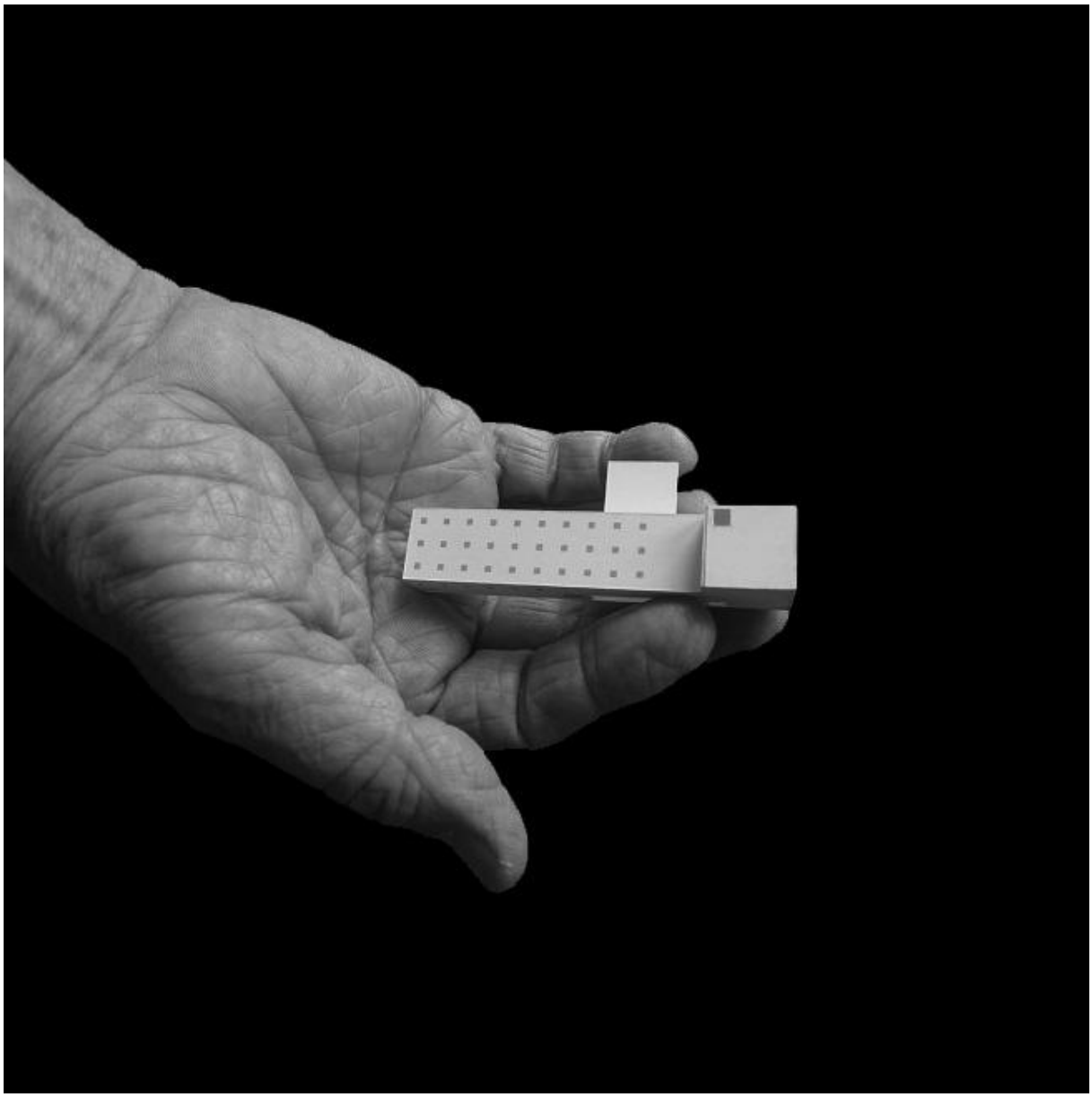


Recién a partir de la década de los noventa el uso de las maquetas conceptuales se dio como mecanismos de producción en algunas de las más prestigiosas oficinas de arquitectura mundiales como OMA o Gehry Partners (Carazo, 2011). Estas maquetas conceptuales no solo pusieron fuera de duda su necesidad, sino que además llegaron a ser consideradas un distintivo de la profesionalidad o la vanguardia en estos y otros estudios de arquitectura más prestigiosos (Morris, 2006).

2.4.2. Definiciones

Al igual que con el dibujo, se debe hacer una diferenciación de los diversos tipos de maquetas. En el desarrollo de la arquitectura se reconoce tres tipos de maquetas, la de presentación, la de trabajo y la conceptual (Schilling, 2018). (1) Las maquetas de presentación son las más conocidas y reúnen todo el contenido elaborado previamente para crear una expresión clara del diseño. Tienen un grado de precisión relativamente alto y una elección de materiales realista, así como una escala definida. (2) Las maquetas de trabajo son las que permiten trabajar sobre ellas para desarrollar las ideas, por ello son imperfectas buscando hacer reconocible la calidad de la idea y exponer los errores. Son fáciles de construir y reconstruir hasta encontrar la solución buscada. (3) Finalmente, las maquetas conceptuales o maquetas boceto son aquellas que permiten aprender, aprehender, comprender la exterioridad y asentar nuestra interioridad en los procesos creativos materializando el pensamiento creativo arquitectónico (Raposo Grau et al., 2020). A continuación, se revisan ideas importantes que permitirán establecer una definición de esta maqueta conceptual diferenciándola de las otras dos.

Figura 16
Maquetas conceptuales para el Nuevo Museo de Arte Contemporáneo de la oficina SANAA. Imagen de www.newmuseum.org



Las maquetas conceptuales son herramientas valiosas en los procesos de concepción y materialización de la arquitectura; más que elementos de comprobación final son mecanismos de ayuda en la búsqueda de la forma, la espacialidad, el funcionamiento y las soluciones constructivas (Ocampo, 2017). Tienen una capacidad analítica y diagramática poco difundida y comparten con el dibujo esa gran síntesis expresiva, que hace de ella un certero instrumento de conocimiento del entramado de ideas que subyacen bajo la forma arquitectónica. El esfuerzo de la abstracción, en busca de la idea rectora del proyecto arquitectónico, es el objetivo último de estos pequeños objetos analíticos nunca mayores de 15 x 15 cm. (Carazo & Galván, 2014).

Las maquetas conceptuales producidas en una fase temprana del trabajo de proyecto tienen su paralelo más cercano al pensamiento lateral de la teoría de la creatividad. Son modelos que se desmontan o reconstruyen en el proceso de desarrollo del proyecto y no son una solución en sí mismos, pero pueden llevar a una solución (Sachanowicz, 2019). Son herramientas de búsqueda de formas para la ideación espacial, así como para entrenar una concepción háptica y visual del espacio promoviendo la creatividad y la imaginación espacial (Domingo Gresa & Marcos Alba, 2016). Su fácil manipulación no solo propicia un eficaz anticipo para la indagación formal en el espacio sino que además permite la exploración háptica del espacio que no sólo es importante sino esencial para el arquitecto (Marcos Alba et al., 2024). Este vínculo fenomenológico significa que la maqueta tridimensional comunica al tacto y al cuerpo con la misma intensidad que al ojo (Pallasmaa, 2017). Su pequeña escala y la perspectiva externa del observador facilitan la identificación y evaluación de detalles hápticos que de otro modo podrían pasar desapercibidos.

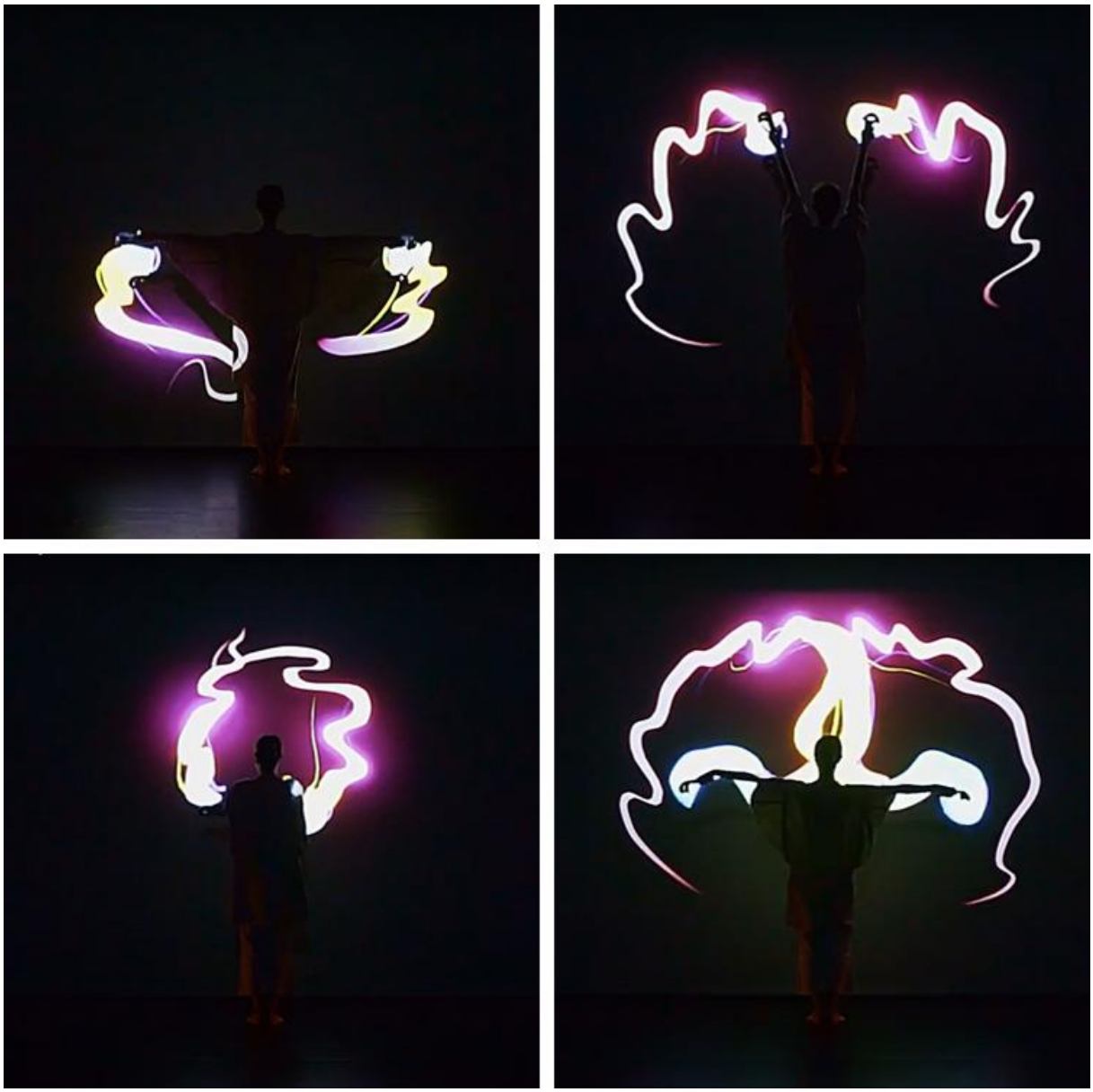
Figura 17
Maqueta conceptual de Campo Baeza para el Pabellón Robert Olnick de Nueva York. Imagen de www.campobaeza.com/es



Se puede concluir como definición que las maquetas conceptuales son pequeñas representaciones tridimensionales utilizadas en las fases de ideación y configuración de un proyecto arquitectónico para explorar y materializar las primeras ideas arquitectónicas. Estas maquetas sirven como herramientas analíticas y de síntesis expresiva que facilitan la exploración creativa y la investigación de las formas y espacios. Su pequeño tamaño y fácil manipulación las hacen ideales para experimentar con diferentes conceptos y promover una comprensión háptica y visual. No son soluciones definitivas, sino exploratorias y preliminares que deben ser evaluadas, discutidas, perfeccionadas y validades antes de continuar con las siguientes fases del proceso creativo.

De esta forma se admite la importancia de la maqueta en el proceso de creación de las primeras ideas arquitectónicas, pero no son las únicas herramientas. En el proceso de diseño como sucede en oficinas exitosas como OMA, además de la maqueta se emplean múltiples recursos visuales de manera simultánea como diagramas, fotografías, bocetos y collages informándose mutuamente. “Bocetos, diagramas, maquetas, dibujos, paneles y collages son componentes esenciales del entorno de trabajo en arquitectura, compartiendo la carga cognitiva del proceso creativo y colaborando en hacer tangible el proyecto arquitectónico” (Yaneva, 2007).

Figura 18
Maquetas conceptuales de Steven Holl para el Instituto de Arte Contemporáneo de VCU. Imagen de www.stevenholl.com

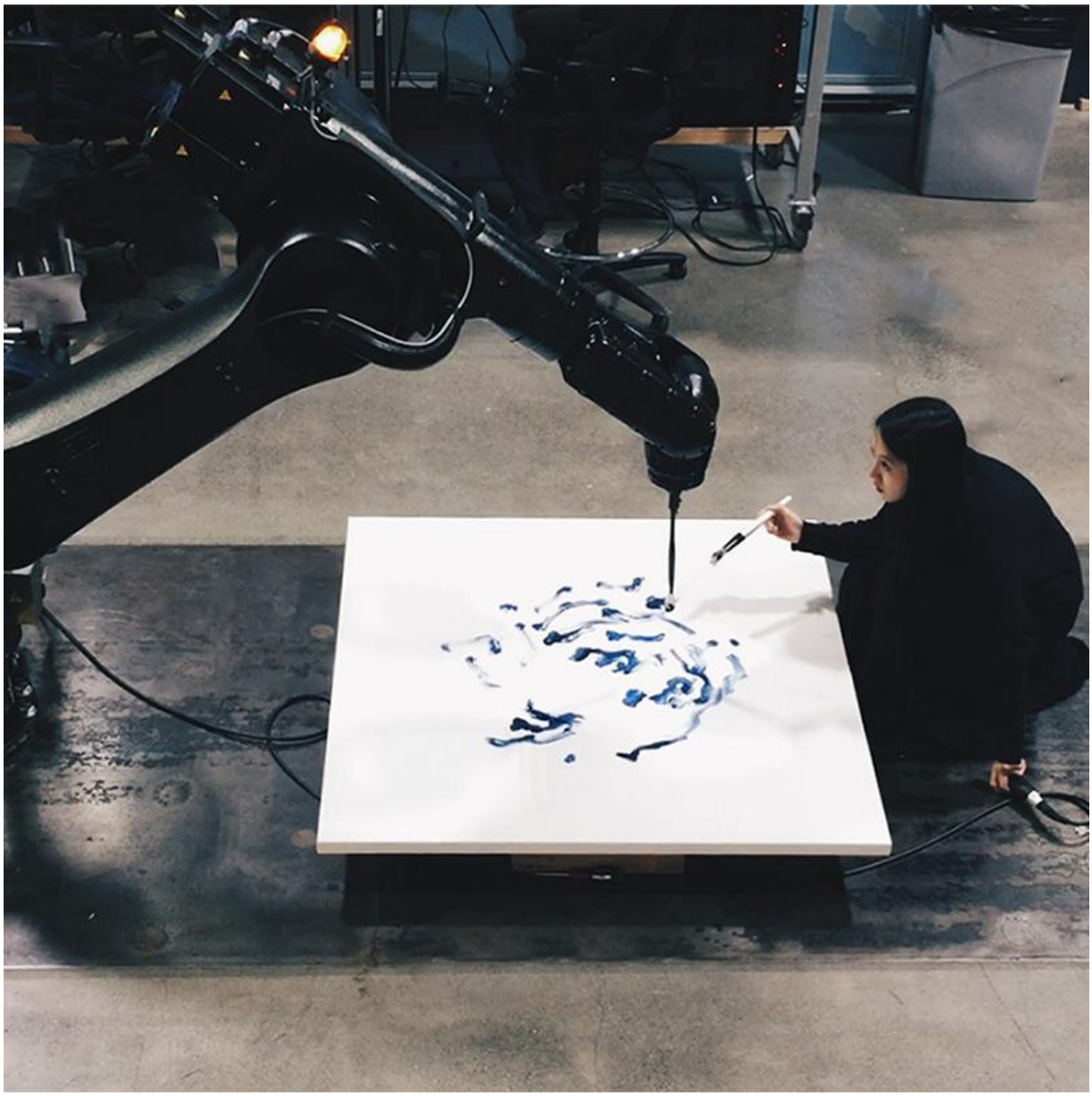


2.5. La tecnológica como mediadora de la creación de la idea

Desde inicios del nuevo milenio, las investigaciones han destacado cómo las tecnologías digitales pueden actuar como mediadoras tanto en el desarrollo del proyecto arquitectónico como en la ideación. Estas herramientas permiten una especulación más libre y creativa en las primeras fases del diseño, integrándose como elementos esenciales en un proceso creativo que fomenta la exploración y la innovación en arquitectura (Benton, 2007). Estos argumentos han seguido consolidándose de tal forma que en 2014 ya se tenía un número especial de CAADRIA (Computer Aided Architectural Design Research in Asia) que advertía sobre el impacto de la tecnología digital en el diseño arquitectónico destacando el diseño paramétrico y generativo, el BIM, la realidad virtual o mixta, la fabricación digital y los hogares inteligentes (Chang & Huang, 2014). Entre estas, el BIM destaca por transformar el diseño en un proceso de experimentación y simulación a través de maquetas virtuales, impulsando la innovación (Agustin Hernandez, 2011). Las herramientas CAD después de los bocetos y las maquetas, son las que potencian mejor la creatividad (Baghaei & Safari, 2018). Y la RVI es la tecnología que promueve la creatividad más que otras herramientas (Obeid & Demirkan, 2020).

Otros estudios han buscado argumentar la influencia de las herramientas digitales en las primeras fases de los procesos creativos arquitectónicos. Se ha argüido que con las herramientas tecnológicas se puede hacer lo mismo que se hace con el dibujo y las maquetas en la fase inicial del proceso de diseño para crear las primeras formas del diseño arquitectónico (Prawata, 2017)

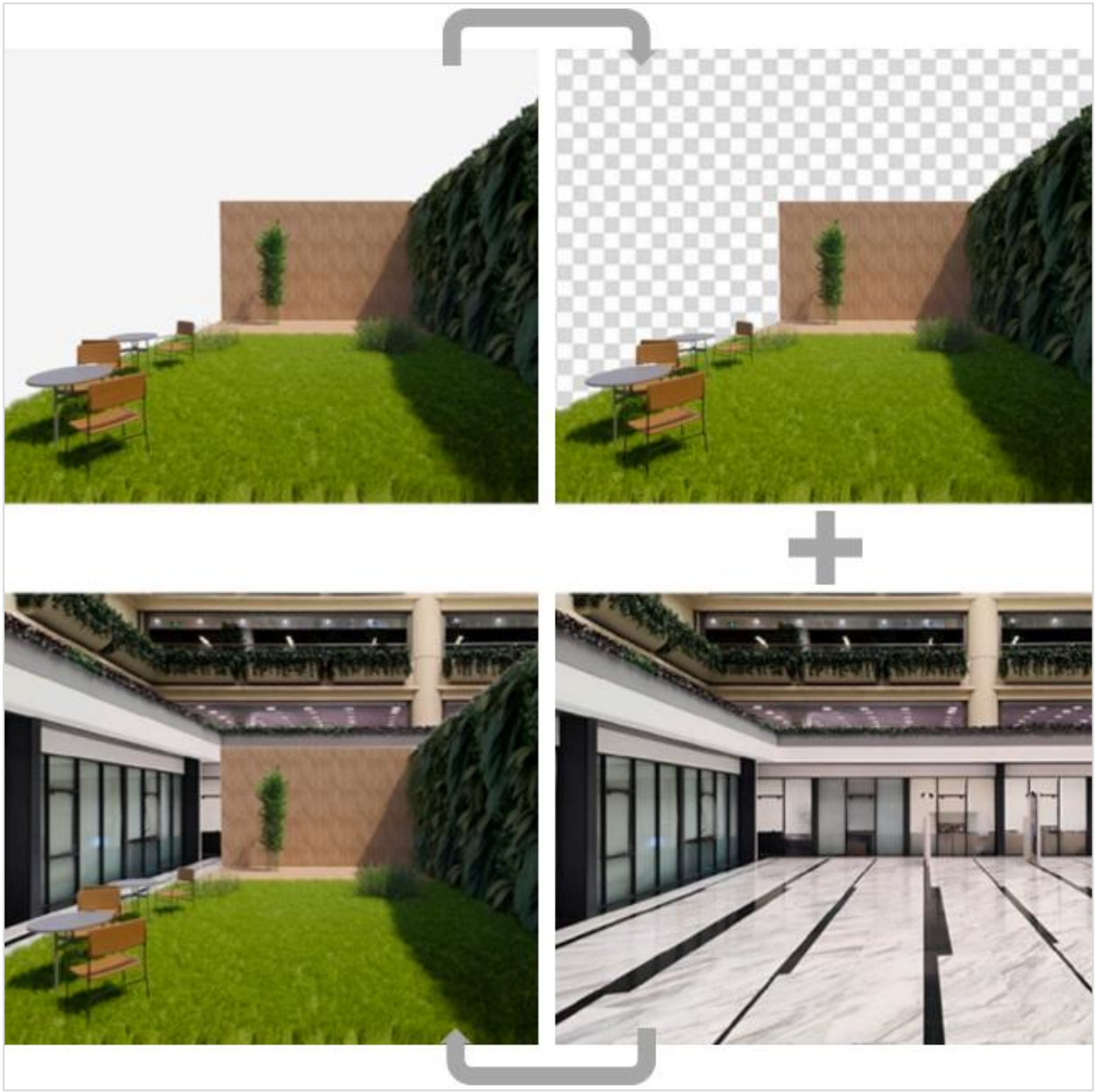
Figura 19
Danza y dibujo en movimiento con Realidad Virtual, Animitto 2.0. Imagen de www.mediacraft.video



El argumento enfatiza el uso de las tecnologías no solo como herramienta de presentación, sino como herramientas generadoras de información para acelerar el proceso de diseño aumentando el número de soluciones alternativas a los problemas de diseño generando mayores oportunidades de innovación. A pesar de estos esfuerzos por incorporar las herramientas tecnológicas en las fases iniciales del proceso creativo, la mayoría de las investigaciones se han concentrado más en el estudio de su impacto en la creatividad arquitectónica en fases más avanzadas del diseño. En estas fases, las tecnologías se utilizan principalmente para representar y comunicar ideas a través de técnicas como la animación y el modelado de información para la construcción (BIM) y en las simulaciones para explorar y comunicar las ideas de manera más efectiva y refinar los diseños antes de su ejecución final (Dash, 2021).

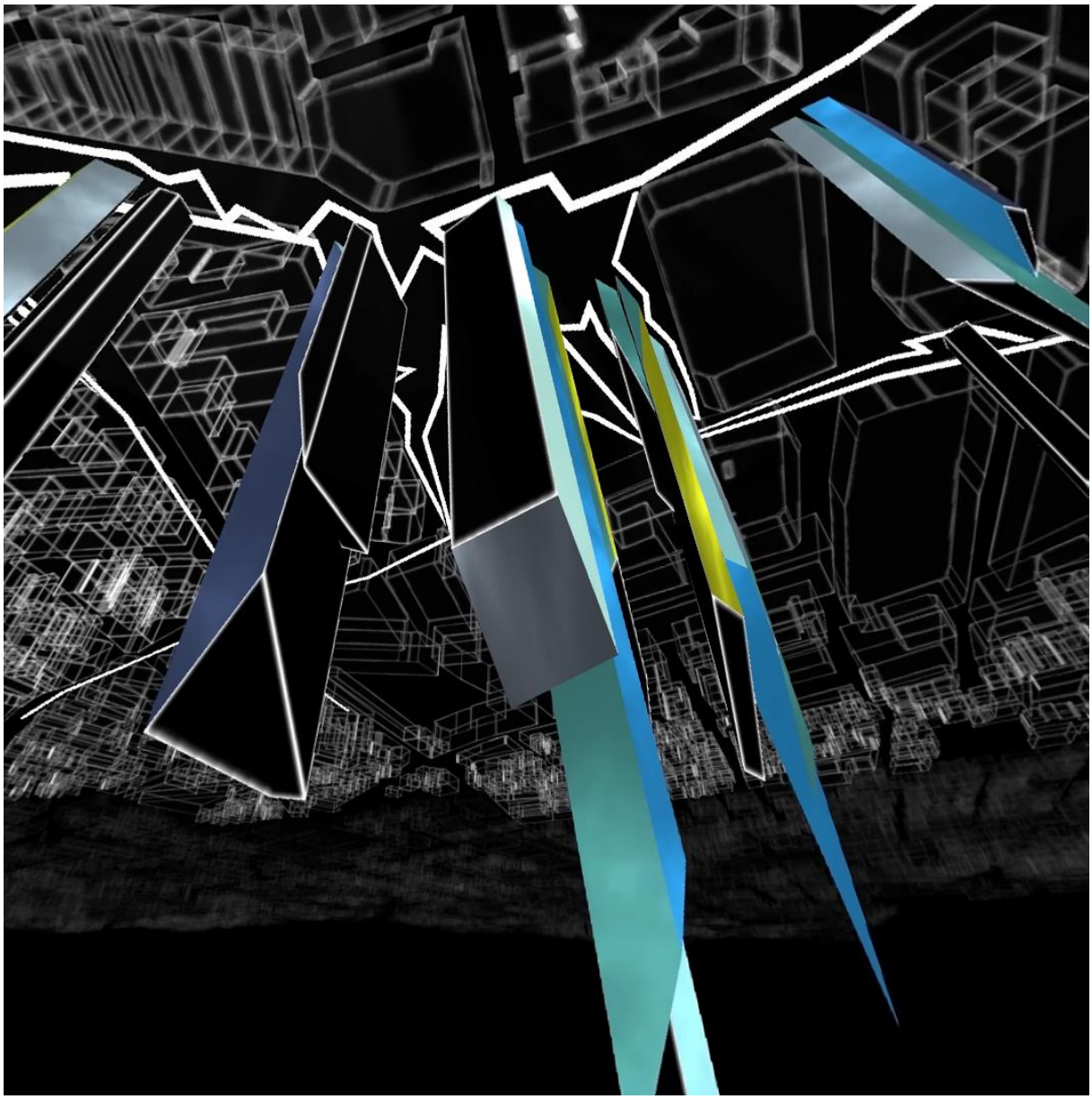
Existen pocas investigaciones que profundicen en los aspectos inherentes a la creatividad en las fases iniciales del diseño o en los elementos fenomenológicos de este proceso. Un ejemplo relevante es el uso del cuerpo para modelar el espacio mediante tecnologías avanzadas de modelado digital, que permite generar una experiencia multisensorial compleja tanto del espacio como del propio cuerpo. Este enfoque no solo enriquece las aplicaciones del diseño digital, sino que también favorece un retorno a una escala antropomórfica, donde la interacción humana con el diseño se vuelve más natural y comprensible (Patz et al., 2018). Otro ejemplo es el uso de los bocetos en entorno virtuales para potenciar la creatividad de los diseñadores en la fase de ideación, demostrando que estas herramientas permiten ampliar el espacio de soluciones de diseño, mejorar la transformación de las ideas y fomentar un enfoque holístico del diseño para la generación de conceptos (E. K. Yang & Lee, 2020).

Figura 20
Colaboración continua entre la artista y un brazo robótico. Drawing Operations. Imagen de www.sougwen.com/machinecollaboration



El avance vertiginoso de la tecnología está impactando el proceso cognitivo de ideación y configuración de las primeras ideas arquitectónicas. No se puede negar que la arquitectura contemporánea ha cambiado en estrecha relación con los cambios que la tecnología ha introducido en la metodología gráfica. En la actualidad se puede resumir que existen dos posturas enfrentadas. La que sostiene que hay una pérdida del humanismo y la creatividad debido fundamentalmente a la mediatización de la tecnología y la que sostiene que la tecnología incrementa las capacidades del arquitecto para idear, manipular, gestionar y materializar con amplia libertad y sin las limitaciones del dibujo manual bidimensional (Llopis, 2018). En cualquiera de las dos posturas parece que se reconoce que las tecnologías informáticas terminarán dominando y transformando todo el proceso creativo arquitectónico. Como muestra de ello, basta revisar algunas investigaciones recientes. La combinación de IA generativa y Realidad Virtual y Aumentada (Figura 21)facilita la interacción entre espacios virtuales y reales, permitiendo modificaciones en tiempo real y optimizando procesos como la modelación y el renderizado (Chen et al., 2024). Además, optimiza la calidad visual, la eficiencia energética y la sostenibilidad, al tiempo que mejora la interacción y accesibilidad en entornos diseñados (Arranz-Paraíso & Arranz-Paraíso, 2024). El diseño generativo, basado en algoritmos y modelado paramétrico, expande las opciones de diseño arquitectónico hacia soluciones más sostenibles y resilientes, promoviendo entornos inclusivos y adaptativos para generaciones futuras (Chew et al., 2024). Finalmente, la colaboración entre arquitectos e IA crea un "dueto creativo", en el que ambos interactúan activamente para especular sobre el espacio y generar soluciones innovadoras en las etapas iniciales del proyecto, potenciando la creatividad y eficiencia del proceso arquitectónico (Silva, 2024).

Figura 21
Combinación de IA y RVI para creación de espacios virtuales en tiempo real. Imagen de Chen et al., 2024



2.5.1. La realidad virtual inmersiva (RVI)

La realidad virtual inmersiva (RVI), para diferenciarla de las no inmersivas, es la tecnología digital que usa el modelado y la simulación por ordenador para permitir a una persona interactuar con un entorno artificial tridimensional mediante dispositivos como gafas, cascos, guantes o trajes corporales (Lowood, 2022). Su accesibilidad cada vez más creciente la está convirtiendo en una herramienta de aprendizaje independiente, aunque a menudo se utiliza sin una teoría del aprendizaje clara, lo que puede llevar a enfoques equivocados en la enseñanza del diseño arquitectónico (Nisha, 2019). En la enseñanza y aprendizaje de la arquitectura, las asignaturas de diseño suelen emplear la RVI como herramienta para la simulación, visualización y exploración, obteniendo resultados prometedores (Ummihusna & Zairul, 2021). Aunque la mayoría de las investigaciones se han centrado en estas capacidades, recientemente han comenzado a surgir estudios que exploran el impacto de la RVI en los momentos creativos iniciales arquitectónicos (Tastan & Tong, 2023).

El impacto de la RVI en la creatividad arquitectónica puede extenderse a factores como el flujo, la atención y la meditación. En una experimentación se encontró que los participantes en entornos de RVI produjeron trabajos creativos de mayor calidad en comparación con aquellos que usaron lápiz y papel (X. Yang et al., 2018). Además, el análisis de las ondas cerebrales de los participantes reveló que la RVI ayudó a mantener un enfoque más estable, mientras que los métodos tradicionales tendían a inducir un estado más relajado. Otro estudio comparó los efectos de entornos de diseño virtual inmersivos y no inmersivos en el estado de fluidez y motivación de la creatividad de estudiantes de primer año de diseño.

Figura 22
Zaha Hadid VR Experience: Plaza Leicester visualizada en imágenes 360°. Imagen de www.experiments.withgoogle.com/zaha-hadid



Los resultados mostraron que los entornos inmersivos favorecen un mayor estado de fluidez y motivación, lo que se traduce en una mayor creatividad (Obeid & Demirkan, 2023). La RVI también puede mejorar significativamente la creatividad en los procesos de ideación. Las tecnologías de RVI han revelado nuevos aspectos de los mecanismos cognitivos y conductuales que ayudan a superar bloqueos mentales, facilitando la exploración de ideas y la generación de soluciones innovadoras (Hu et al., 2021). En cuanto a la acción cognitiva en la generación de ideas, un estudio comparó la RVI con herramientas de diseño digital 2D, limitando el experimento a la fase inicial de boceto. Los resultados mostraron que la RVI activó la acción física y perceptiva en la cognición del diseño y mejoró la flexibilidad cognitiva en comparación con las herramientas de diseño 2D. Esta flexibilidad cognitiva fomentó un pensamiento de diseño divergente y se asoció con resultados creativos más innovadores (Lee et al., 2021).

En cuanto al proceso creativo en sus fases tempranas del proceso de diseño arquitectónico, un estudio previo realizado por el autor de esta tesis demostró que, gracias a la inmersión y la presencia, la RVI permite a los estudiantes comprender mejor lo que están diseñando, contrastar sus propuestas con el entorno construido donde se ubicará, y repensarlo de manera inmediata y sencilla a partir de la retroalimentación directa que reciben del diseño tridimensional virtual. En aquella experimentación con estudiantes del primer y último año de arquitectura se encontró como ventajas la mejor cualificación del espacio y la representación gráfica. La RVI permite experimentar y percibir el espacio diseñado a escala real y facilita una mejor comunicación del diseño. El diseño y creación en tres dimensiones es un proceso multimodal porque simultáneamente es un proceso de dibujo, de diseño y de construcción de los espacios.

Figura 23
Uso del Tilt Brush para el dibujo artístico virtual, The Lab at Google Cultural Institute. Imagen de www.artsandculture.google.com



Esto refuerza su eficacia en la enseñanza del diseño arquitectónico (H. C. Gomez-Tone et al., 2022).

La RVI se presenta como una herramienta poderosa para potenciar la creatividad y la innovación en la arquitectura, permitiendo una mayor exploración y experimentación en las fases iniciales del diseño. Sin embargo, es crucial que su implementación esté guiada por una comprensión clara de su papel en el aprendizaje y el proceso creativo para maximizar su impacto positivo.

2.5.2. La impresión 3D (I3D)

La impresión 3D (I3D) se puede definir como la fabricación aditiva de cualquier objeto tridimensional a partir de un modelo digital diseñado con programas CAD mediante la superposición secuencial de capas de material a una pieza física tridimensional (Žujović et al., 2022). Existen diversas tecnologías de I3D, cada una con sus propias características y aplicaciones. Las más difundidas y de fácil acceso son el Modelado por Deposición Fundida (FDM), la Sinterización Selectiva por Láser (SLS), la estereolitografía (SLA).

La I3D está revolucionando el diseño arquitectónico como una herramienta clave para potenciar la creatividad. Facilita la materialización de formas complejas antes imposibles, abriendo nuevas oportunidades para experimentar con materiales y técnicas constructivas (Moyano-Sanz et al., 2023). Además, permite explorar configuraciones innovadoras y reduce significativamente el tiempo entre la concepción de una idea y su realización física.

Figura 24
Proyecto TerraPerforma centrado en la impresión 3D con arcilla. Fab Lab Barcelona y IAAC. Imagen de www.youtube.com/watch?v=VdTwA5nEYk4&t=17s


KUKA
KUKA

Esto fomenta un ciclo de diseño iterativo y experimental que es crucial para la innovación, permitiendo la continua exploración y optimización de la forma y función arquitectónica (Žujović et al., 2022).

A pesar de sus muchas ventajas, la I3D también enfrenta desafíos que deben ser superados para maximizar su impacto en el diseño arquitectónico. El costo de la tecnología y la limitación en la selección de materiales adecuados son barreras significativas. Sin embargo, a medida que la tecnología evoluciona y se vuelve más accesible, se espera que estas limitaciones disminuyan, lo que permitirá una adopción más amplia y una exploración aún mayor de su potencial creativo. La I3D actúa como un catalizador para la creatividad en el diseño arquitectónico, proporcionando las herramientas para superar las limitaciones tradicionales y explorar nuevas posibilidades en la forma, la función y materialidad. A medida que los arquitectos continúan adoptando y adaptándose a esta tecnología, es probable que veamos una era de diseño arquitectónico aún más innovadora y personalizada potenciada aún más por los propios ambientes de fabricación digital (Fab Labs) y Maker Spaces que estimulan la experimentación, la innovación y el pensamiento creativo (Soomro et al., 2022).

El conocimiento de la fabricación aditiva también juega un papel crucial en la innovación arquitectónica. El I3D influye positivamente en la capacidad de reconfigurar diseños y explorar nuevas características, sin alterar los principios de funcionamiento subyacentes. Este enfoque facilita la innovación en la arquitectura, permitiendo a los diseñadores superar las limitaciones tradicionales y experimentar con nuevas posibilidades (S. Yang et al., 2019). Cuando esta tecnología se complementa con otras se multiplican los beneficios.

Figura 25
Impresión 3D mediante fabricación celular a gran escala. Imagen de www.youtube.com/watch?v=IRUcyRNqMCU



De otro lado, el uso de la RVI junto con la I3D ha demostrado incrementar la creatividad en proyectos de diseño. En el contexto educativo, estas tecnologías han demostrado aumentar el interés y el compromiso de los estudiantes, promoviendo la generación de ideas novedosas y mejorando la calidad estilística de los diseños. La incorporación de RVI y I3D en el proceso de diseño no solo estimula la creatividad, sino que también facilita una mejor comprensión y exploración de conceptos arquitectónicos complejos (Vo, 2022). La interacción de la I3D con otras tecnologías, como la inteligencia artificial (IA), aumenta aún más su potencial. La IA puede optimizar parámetros de diseño y fabricación en tiempo real, mejorando la precisión y eficiencia de las estructuras arquitectónicas.

Esta combinación permite a los arquitectos experimentar con formas y configuraciones arquitectónicas innovadoras, potenciando la creatividad en el proceso de diseño. La integración de IA en la I3D abre nuevas posibilidades para explorar formas arquitectónicas dinámicas y complejas, promoviendo un nuevo horizonte de expresión creativa (Živković et al., 2023).

La I3D es una herramienta poderosa que está transformado el diseño arquitectónico, ofreciendo nuevas oportunidades para la creatividad y la innovación (Valiente López et al., 2018). A medida que la tecnología continúa avanzando y se vuelve más accesible, es probable que su impacto en la arquitectura se expanda, permitiendo la creación de proyectos cada vez más personalizados y técnicamente sofisticados.

Figura 26
Instalación Serpenti de Zaha Hadid (2015), fabricada digitalmente. Imagen de www.designboom.com

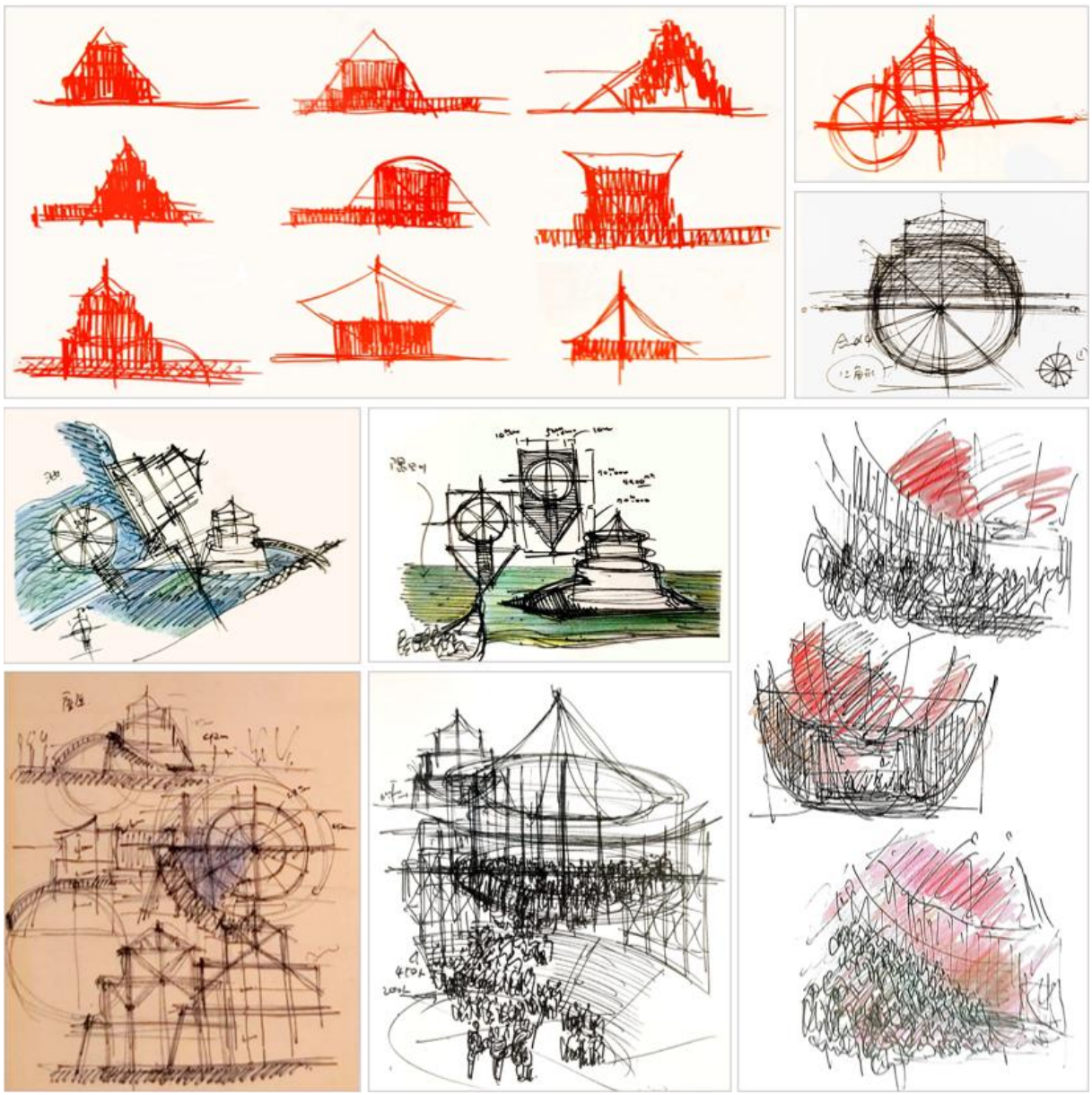


3. Metodología

3.1. Para la hipótesis 1

Para determinar las fases, características y condiciones del proceso creativo en los momentos de generación de las primeras ideas arquitectónicas se adoptó la metodología del estudio de caso. Se eligieron los dibujos de concepción de tres arquitectos, Tadao Ando, Zaha Hadid y Frank Gehry. Su elección para este estudio de caso múltiple responde a tres criterios. En primer lugar, los tres arquitectos son ganadores del Premio Pritzker, lo que asegura un nivel de excelencia y reconocimiento internacional en su producción arquitectónica. En segundo lugar, los arquitectos seleccionados representan enfoques distintos y complementarios en el proceso creativo, lo que enriquece el análisis comparativo. Tadao Ando se distingue por la integración de la materialidad y la espiritualidad en su trabajo; Zaha Hadid, por su exploración formal y la interpretación innovadora del espacio fluido, y Frank Gehry, por su uso expresivo de formas esculturales y materiales. Un tercer criterio fue la disponibilidad de documentación accesible en publicaciones de sus cuadernos de dibujo que permita una lectura consecutiva del argumento o del procedimiento del pensamiento creativo (Salgado de la Rosa et al., 2020). Este conjunto significativo de dibujos conceptuales permitió reconstruir la secuencia creativa, minimizando interpretaciones sesgadas por falta de continuidad en el material disponible. Además, la elección de proyectos arquitectónicos (no urbanísticos) de pequeña escala responde al interés por estudiar procesos más controlables y delimitados, donde las decisiones proyectuales sean más explícitas y evidentes en los dibujos. Finalmente, el análisis de los dibujos se enriqueció con entrevistas y declaraciones de los arquitectos, conectando los datos visuales con su visión personal y reforzando la validez de las conclusiones.

Figura 27
Arquitectos Tadao Ando, Zaha Hadid y Frank Gehry. Imágenes de la web



Para el análisis del proceso creativo de los tres arquitectos, se determinaron cinco categorías relacionadas con sus dibujos conceptuales que se muestran en la Tabla 1.

Tabla 1. Categorías para observar y analizar en cada conjunto de dibujos conceptuales.

Categorías	Descripción
Trazos e instrumentos	Se observó el tipo de trazos e instrumentos utilizados, los grosores del trazo, el uso de colores y efectos como rellenados, achurados, difuminados, etc. También se buscó reconocer el soporte físico en el cual fueron realizados.
Abstracción y forma	Se observó la forma de los primeros dibujos creados, tratando de determinar su ambigüedad, su determinación, su regularidad, su orden y su nivel de abstracción.
Tamaño y cantidad	Se observó el tamaño del dibujo y su rapidez de su ejecución at través de su complejidad y nivel de detalle. También se observó la cantidad de dibujos realizados en un mismo formato.
Transformación y determinación	Se observó las correcciones, adiciones o transformaciones de los dibujos, esto se determinó por las líneas remarcadas, repasadas y tachadas.
Figuración y representación	Se observó la forma de los últimos dibujos creados, tratando de reconocer el uso rudimentario de las técnicas de representación como plantas, cortes, axonométricas o perspectivas cónicas.

Figura 28
Conjunto de dibujos conceptuales de Tadao Ando para el Teatro Karaza. Imágenes del libro Tadao Ando 0, Process and Idea



Los dibujos escogidos de Tadao Ando fueron los realizado para el Teatro Kara-za, (Japón, 1985). Este proyecto está presentado en 13 páginas del libro "Tadao Ando 0, Process and Idea" (Ando, 2010). El mismo arquitecto muestra además de dibujos de detalles constructivos y fotografías, sus dibujos conceptuales que se ven en la figura 28.

En el caso de Zaha Hadid se escogieron los dibujos realizados para la Estación de Bomberos Vitra (Alemania, 1990-1994). Este proyecto está presentado por la misma arquitecta en 17 dobles páginas en el volumen "Process: sketches and drawings" del libro "Zaha Hadid, complete Works" (Schumacher & Fontana-Giusti, 2004). En el libro se muestra sin textos los dibujos conceptuales que se ven en la Figura 29.

Finalmente se escogieron los dibujos de concepción de Frank Gehry para el edifico del Banco DZ (Alemania, 1995-2001). En este proyecto el mismo autor muestra ocho láminas con sus dibujos de concepción, además de fotografías y algunos textos en el libro "Gehry Draws" (Bredekamp, 2004). Dichos dibujos pueden verse en la Figura 30.

Figura 29
Conjunto de dibujos conceptuales de Zaha Hadid para la Estación de Bomberos de Vitra. Imágenes del libro Zaha Hadid, complete Works



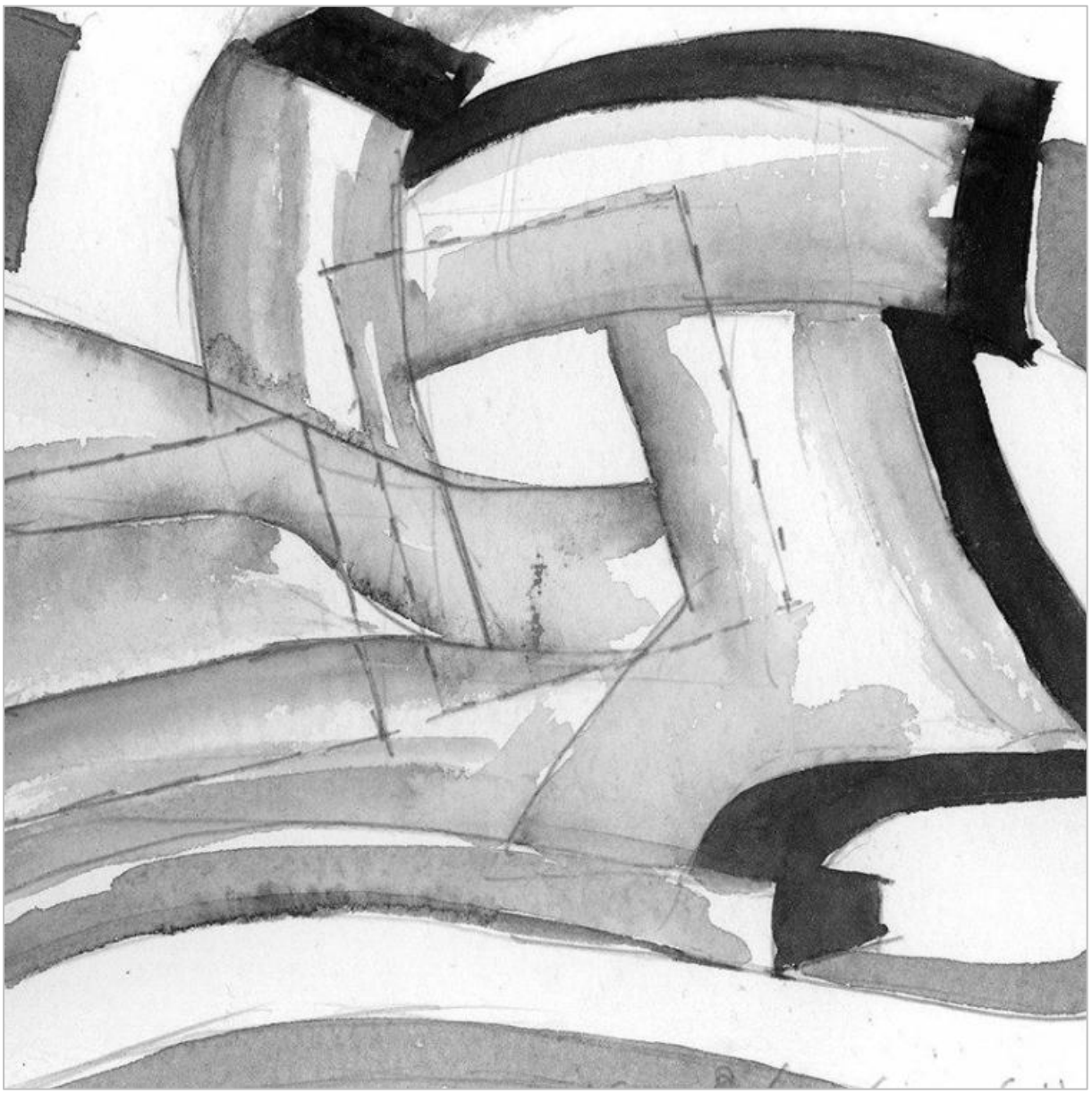
3.1.1. Evaluación de resultados 1

Los resultados se han compilado en la Tabla 2 que se muestra a continuación.

Tabla 2. Categorías analizadas en los dibujos de concepción de los tres arquitectos

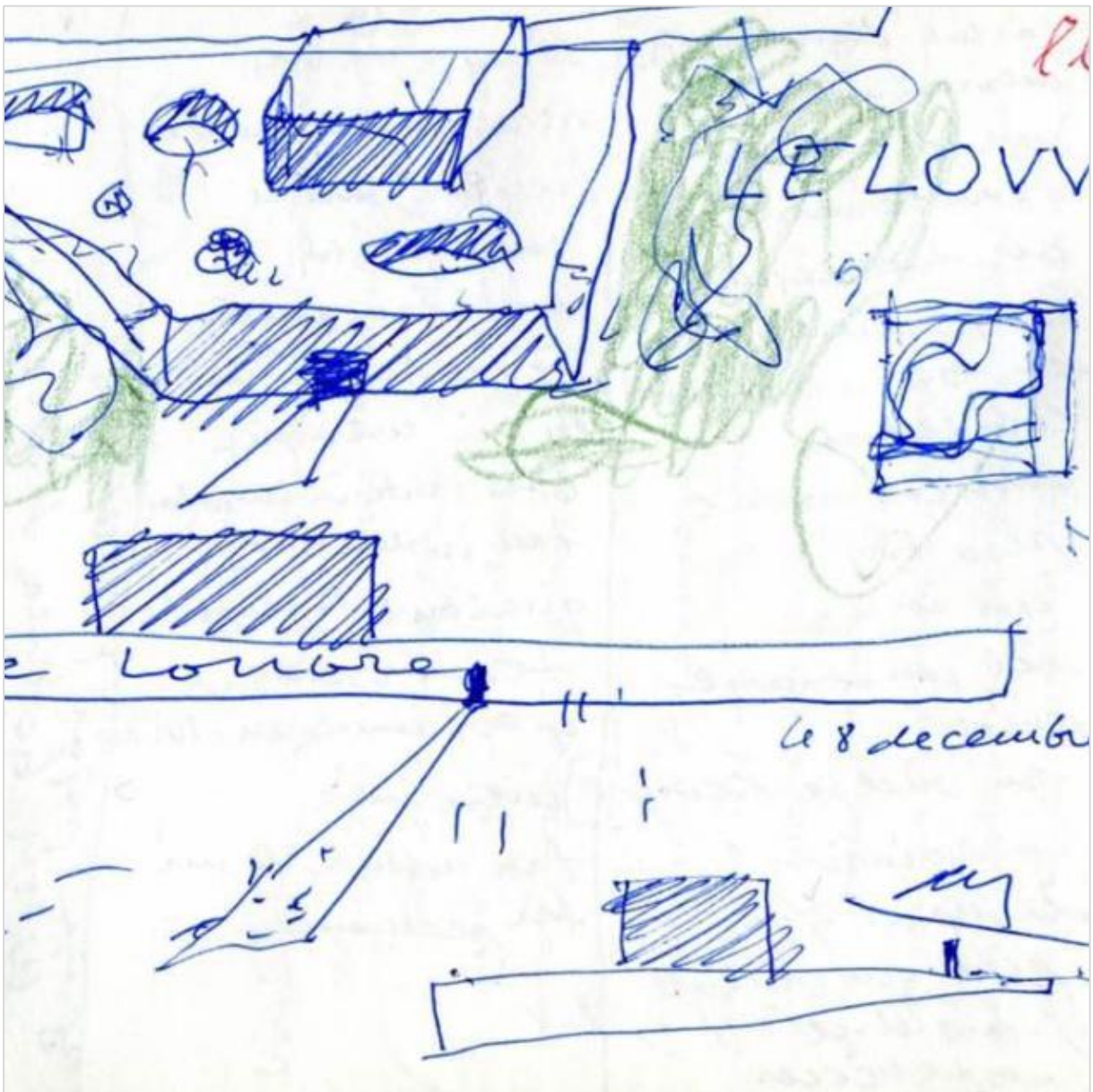
Categoría	Tadao Ando	Zaha Hadid	Frank Gehry
Trazos e instrumentos	Usa en general el lápiz de grafito complementado con lápices de color para resaltar ideas. Sus trazos son gruesos y poco precisos, pero expresan mucha fuerza e intensidad. Enfatiza la importancia del dibujo a mano como medio para comunicar la esencia de la idea.	Emplea la tinta negra sobre papel aprovechando sus propiedades para experimentar con trazos delgados y gruesos, difuminaciones y rellenos para crear contrastes visuales. Considera sus trazos como pequeños experimentos de investigación.	Usa tinta negra sobre papel con trazos de grosor uniforme. No usa tipos de línea o difuminados para valorizar trazos. Busca mantener un trazo continuo de principio a fin. Reconoce que sus dibujos parecen garabatos, pero los alienta porque allí encuentra lo intuitivo y la casual.
Forma y abstracción	Su nivel de abstracción no es tan profundo, sus dibujos son formas abstraídas de su interpretación de la realidad, pero todavía reconocibles. Dice que para dar forma a las imágenes vagas lo hace a través de bocetos y dibujos de líneas gruesas.	Sus dibujos son altamente abstractos, pero de una pulcritud que les confiere un estatus de pequeñas obras abstractas finalizadas. Declara que nadie entiende sus dibujos y debe entonces explicar qué significa y cómo quiere que progrese el dibujo.	Sus dibujos más que un nivel alto de abstracción, muestran características de inacabados o poco prolijos. Dice que no significan nada para nadie excepto para él, pero que finalmente se parecen asombrosamente al edificio terminado.

Figura 30
Conjunto de dibujos conceptuales de Frank Gehry para el edificio del Banco DZ. Imágenes del libro Gehry Draws



Tamaño y cantidad	Realiza dibujos pequeños y rápidos carentes de detalles buscando transmitir la esencia de la idea arquitectónica. Sostiene que través de repetidos intentos se clarifica sus intenciones del espacio arquitectónico que está gestando.	Realiza sus dibujos con mucha precisión y detalle lo que indica que no fueron realizados de manera rápida. Sí muestra una multiplicidad de formas derivadas de las primeras. Dice que empieza esbozando sus dibujos siempre en tamaño muy pequeño	Sus dibujos son de tamaño pequeño y aparentan ser realizados de manera rápida por su poco detalle y complejidad. Afirma que los dibujos no son importantes, que son solo escalones, pero que gracias a ellos sabe cuál es el paso siguiente que dar.
Transformación y determinación	Muestra muchas líneas repasadas, remarcadas y superpuestas. Además de zonas achuradas o rellenadas para dar mayor valor. Sus dibujos buscan la transformación de una idea con la intención de encontrar la forma ideal.	Explora formas mediante repeticiones, entrecruzamientos y derivaciones, sin realizar correcciones visibles en sus dibujos. Reconoce cómo fue elaborado de principio a fin cada dibujo y cuáles fueron los dibujos que se derivaron de él.	No corrige sus dibujos, sino que prefiere explorar nuevas formas en nuevos dibujos en vez de repasar o modificar trazos anteriores. Considera que se debería hacer y confiar en los dibujos y aprender lo que está saliendo de ahí
Figuración y representación	La mayoría de sus dibujos son vistas frontales o plantas esquemáticas. También usa axonométricas y perspectivas cónicas muy simples, de pocos detalles, pero con uso de algún color.	Sus dibujos son casi únicamente plantas. Hay poco uso de la isométrica y vista en corte. Usa medios digitales para la abstracción de plantas y cortes, pero esos dibujos no han sido analizados.	Sus primeros dibujos son casi siempre esquemas en planta. También utiliza axonométricas rudimentarias y perspectivas cónicas interiores muy esquemática

Figura 31
Dibujos Conceptuales de Steven Holl para el Museo de Arte Contemporáneo de Herningherning, Dinamarca. Imagen de www.stevenholl.com


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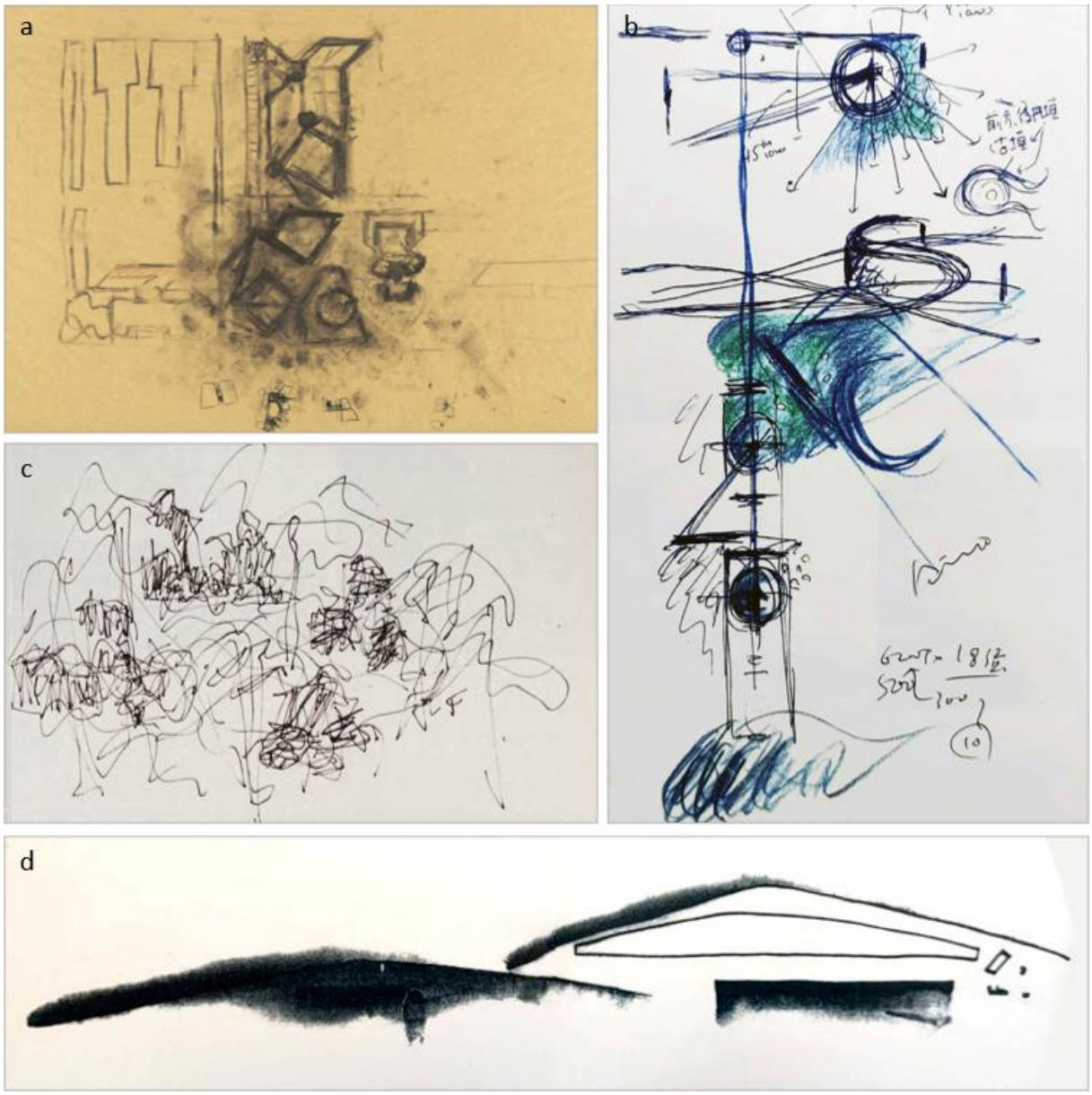
Del estudio de los tres casos se ha determinado que para que este proceso cognitivo suceda de manera óptima se debe dar una condición fenomenológica o háptica que permite vincular de manera ideal el pensamiento y la vista con el movimiento de las manos usando un instrumento dejando trazos sobre un soporte. También se ha determinado cuatro características del dibujo de concepción como proceso y como producto vinculadas a cuatro momentos más o menos secuenciales de este proceso cognitivo (Figura 33). La condición y las cuatro características no pretenden ser una sistematización absoluta. Se pretende buscar un proceso heurístico para efectos pedagógicos que permita sostenerlos como proceso del pensamiento arquitectónico sin importan el medio analógico o digital en el que se desarrolle.



Figura 33: La caracterización del dibujo como proceso y como producto

Figura 32
Dibujos conceptuales de Alberto Campo para el Museo del Louvre en Liévin. Imagen de www.campobaeza.com

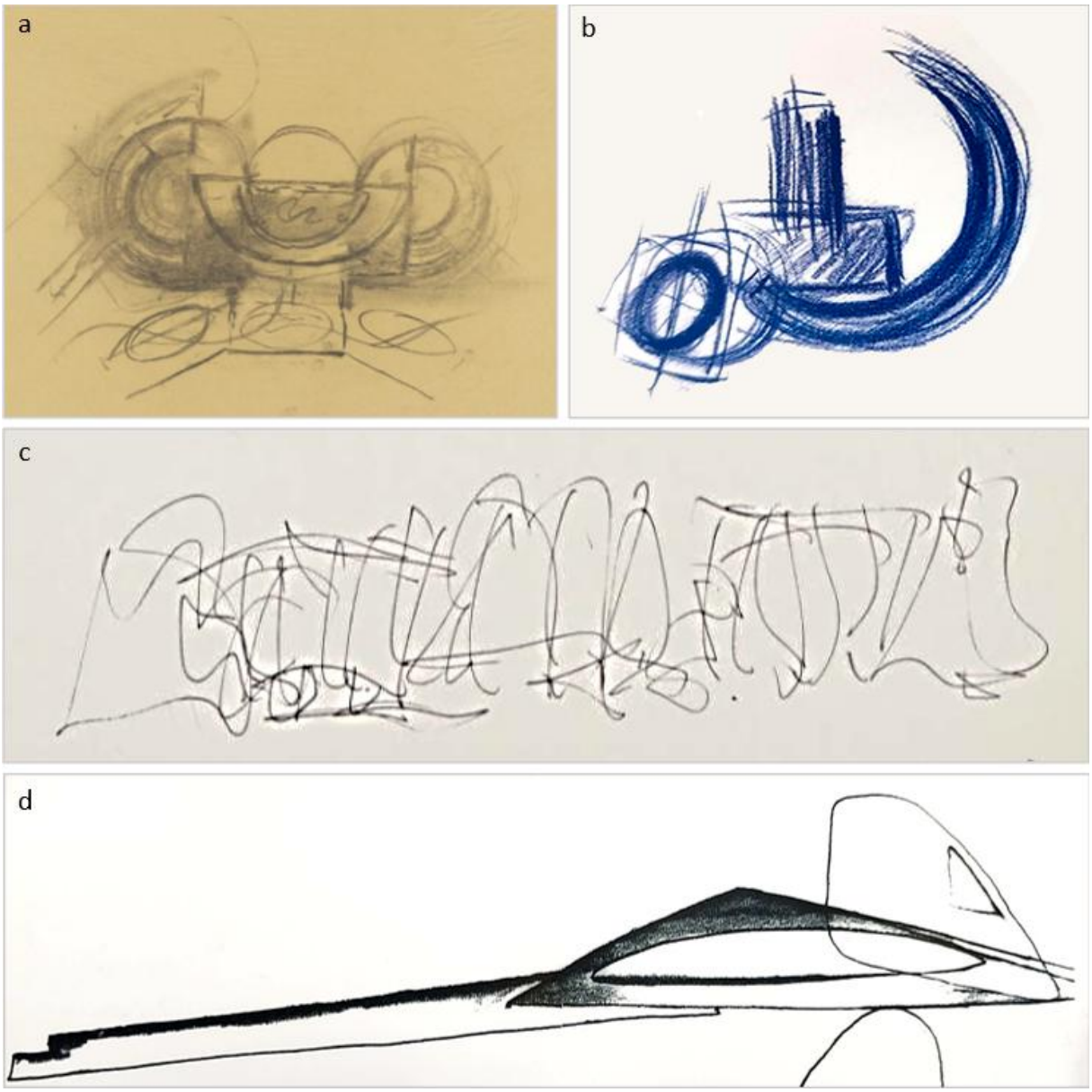
Condición: el dibujar fenomenológico y el dibujo háptico: Según (Pallasmaa, 2017), los dibujos son el resultado de la colaboración entre la mano y el pensamiento arquitectónico, destacando la autonomía del movimiento de la mano y su capacidad para registrar valores espaciales a través del trazo.


a
b
c
d

Dibujar implica una experiencia fenomenológica en la que el cuerpo del dibujante se convierte en el lugar del acto creativo, priorizando la vivencia sobre la comprensión (Pallasmaa, 2014). En este proceso inicial de diseño, los instrumentos, técnicas y soportes elegidos reflejan la esencia del acto creativo y su vínculo directo con el pensamiento (de Lapuerta, 1997). En la figura 34 se aprecia el uso del carboncillo difuminado con los dedos sobre papel vegetal en los dibujos de Louis Kahn para la Escuela de Arte de Filadelfia en Pensilvania (Kahn, 1965a). El segundo ejemplo muestra los dibujos de Tadao Ando para el Museo del Bosque de Tumbas en Kumamoto en Japón (Ando, 2010) en donde se aprecia el uso de la tinta azul con diferentes lápices de colores haciendo un rellenado rápido de zonas para darles un valor diferente. En tercer lugar está el dibujo de Frank Gehry para el Museo de Arte Ohr-O'Keefe de Biloxi, Mississippi (Bredekamp, 2004). A pesar de la falta de grosores, difuminados o colores, las líneas curvadas y repasadas sin un principio ni fin capturan el movimiento y la fluidez; por lo tanto, expresan el vínculo háptico. En la parte final, se ve el dibujo de Zaha Hadid para el proyecto Rheinauhafen en Colonia, Alemania (Schumacher & Fontana-Giusti, 2004). En este dibujo se muestra el uso de la tinta sobre un papel absorbente logrando trazos bien definidos y a su vez manchas controladas con la tinta corrida. La intencionalidad y la búsqueda por investigar muestran un íntimo vínculo entre la autora y el dibujo.

El dibujar indeciso y el dibujo sin forma: El proceso inicial de creación arquitectónica es lento y lleno de dudas, donde el acto de dibujar se convierte en una investigación crítica más que en una simple ilustración (Manolopoulou, 2005). En esta etapa, los trazos son gestos gráficos indefinidos y tentativos que acompañan al pensamiento sin requerir concreción (Llopis et al., 2013).

Figura 34
Los dibujos hápticos de Louis Kahn (a), Tadao Ando (b), Frank Gehry (c) y Zaha Hadid (d).


a
b
c
d

La ambigüedad deliberada de estos dibujos permite explorar alternativas y atrapar ideas en evolución (de Lapuerta, 1997). Este proceso genera dibujos abstractos y poco definidos, entendidos principalmente por el autor. Lejos de ser finales, son dinámicos, plantean preguntas y sugieren nuevas exploraciones (Manolopoulou, 2005).

Louis Kahn, en sus bocetos de la figura 35 para la Sala de oración Sher-e-Bangla Nagar en Bangladesh (Kahn, 1965b) deja espacios en blanco y difuminados, trazos inconclusos, líneas de contorno alternativas, grosores variados, borrones y marcas manuales, creando un dibujo abstracto. El segundo ejemplo de la figura muestra un dibujo con trazos firmes y determinados, pero igualmente repasados y rayados todo hecho con lápiz de color azul. Este es el dibujo de concepción de Tadao Ando para el Museo de la Villa Oyamasaki en Japón (Ando, 2010) que inicialmente solo tenía sentido para el autor por su abstracción. Frank Gehry en sus dibujos iniciales para el Aeropuerto Marco Polo, Venecia-Tessera, Italia 2001 (Bredekamp, 2004), muestra trazos tambaleantes, irregulares, enredados o desordenados a veces hechos sin levantar el lápiz, lo que se le ha denominado los garabatos de Gehry. Finalmente, los dibujos pueden tener misteriosas sombras oscuras y manchas como los ejecutados por Zaha Hadid para el proyecto Rheinauhafen en Colonia en Alemania (Schumacher & Fontana-Giusti, 2004).

El dibujar continuo y el dibujo pequeño multiplicado: El acto de dibujar es un proceso cognitivo continuo que busca mantener el flujo ininterrumpido del pensamiento y del diseño (Herbert, 1988). Para captar la rapidez de la imaginación, se recurre a dibujos pequeños, que permiten un circuito visual más concentrado y detallado, reduciendo distracciones (de Lapuerta, 1997).

Figura 35
Los dibujos sin forma de Louis Kahn (a), Tadao Ando (b), Frank Gehry (c) y Zaha Hadid (d)

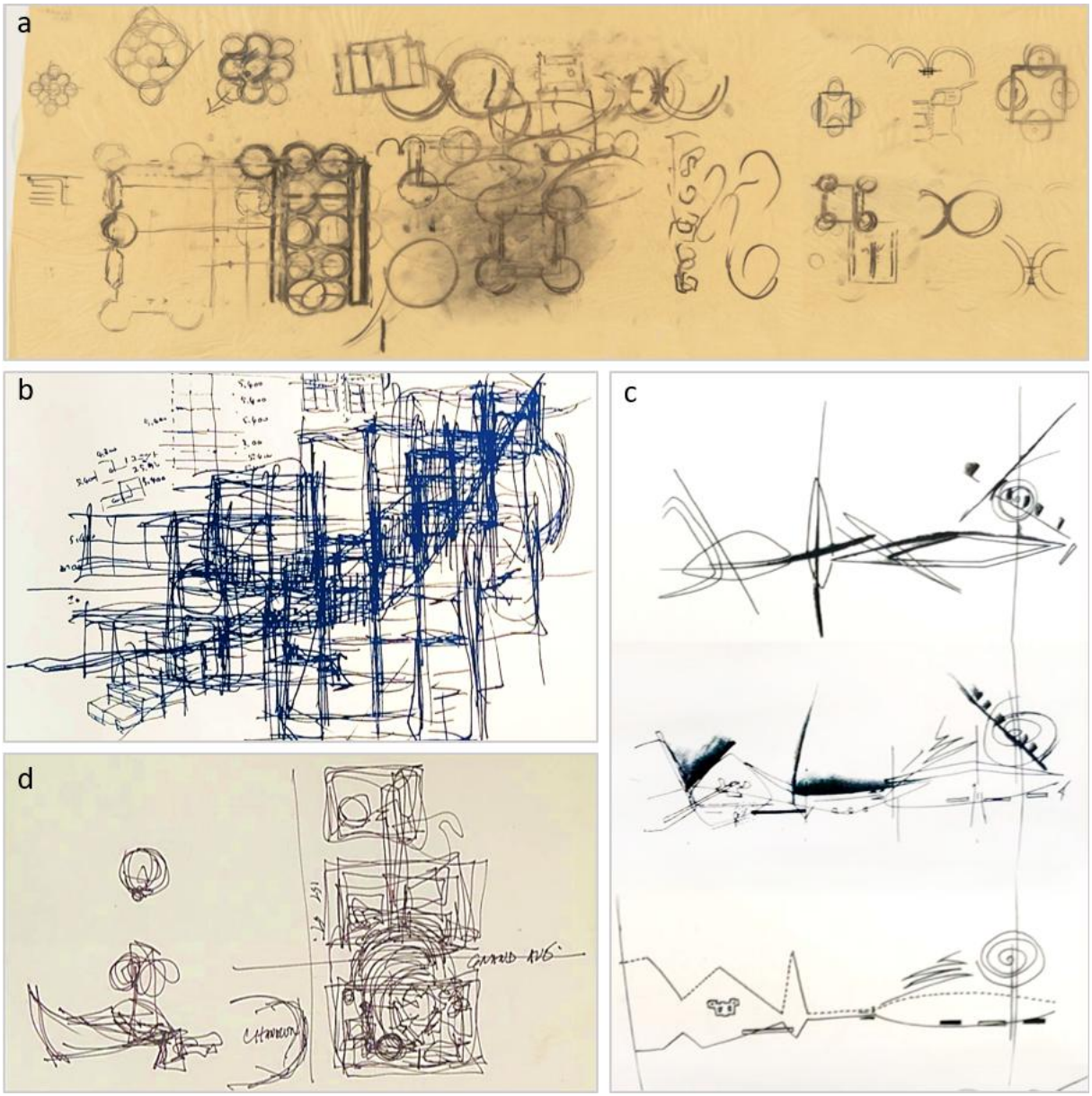

a
b
c
d
CINEMA

Estos dibujos, rápidos y fáciles de descartar, se multiplican, eliminando detalles innecesarios y favoreciendo la exploración ágil de ideas (Smith, 2006). Los soportes ideales son cuadernos de croquis portátiles, aunque también surgen en objetos cotidianos como servilletas o boletos, reflejando la urgencia de materializar el pensamiento arquitectónico.

En la figura 36 se puede apreciar la variedad de dibujos pequeños que logra Louis Kahn para la Sala Eleanor Donnelley Erdman, Bryn Mawr College en Pensilvania (Kahn, 1960) pero además se puede apreciar su poca prolijidad producto de la rapidez de ejecución y su facilidad para ser descartados con un simple tachado. La rapidez y multiplicidad también se reconocen en los dibujos de Frank Gehry para su propia residencia en Santa Mónica, California (Bredekamp, 2004). El tercer ejemplo muestra los dibujos de concepción de Zaha Hadid para el Parque multimedia Zollhof 3 en Alemania (Schumacher & Fontana-Giusti, 2004) en los que se aprecia una multiplicidad de pequeños dibujos poco detallados realizados con rapidez a diferencia de otros conocidos realizados con más tiempo y dedicación. Algunas veces, y debido a la condición fugaz e inesperada del pensamiento arquitectónico, los dibujos pequeños se realizan en insospechados soportes como las entradas al cine que usó Tadao Ando para las primeras ideas del Museo de Arte Chichu en Naoshima, Japón (Ando, 2010).

Figura 36
Los dibujos pequeños y multiplicados de Louis Kahn (a), Frank Gehry (b), Zaha Hadid (c) y Tadao Ando (d)

El dibujar perceptual y el dibujo redibujado: En el proceso creativo, dibujar se convierte en un acto perceptual que, a través del "ojo de la mente", interpreta o descubre nuevos significados basados en dibujos previos (Fish & Scrivener, 1990). Este proceso impulsa a completar, borrar o generar nuevos dibujos derivados del original (de Lapuerta, 1997).

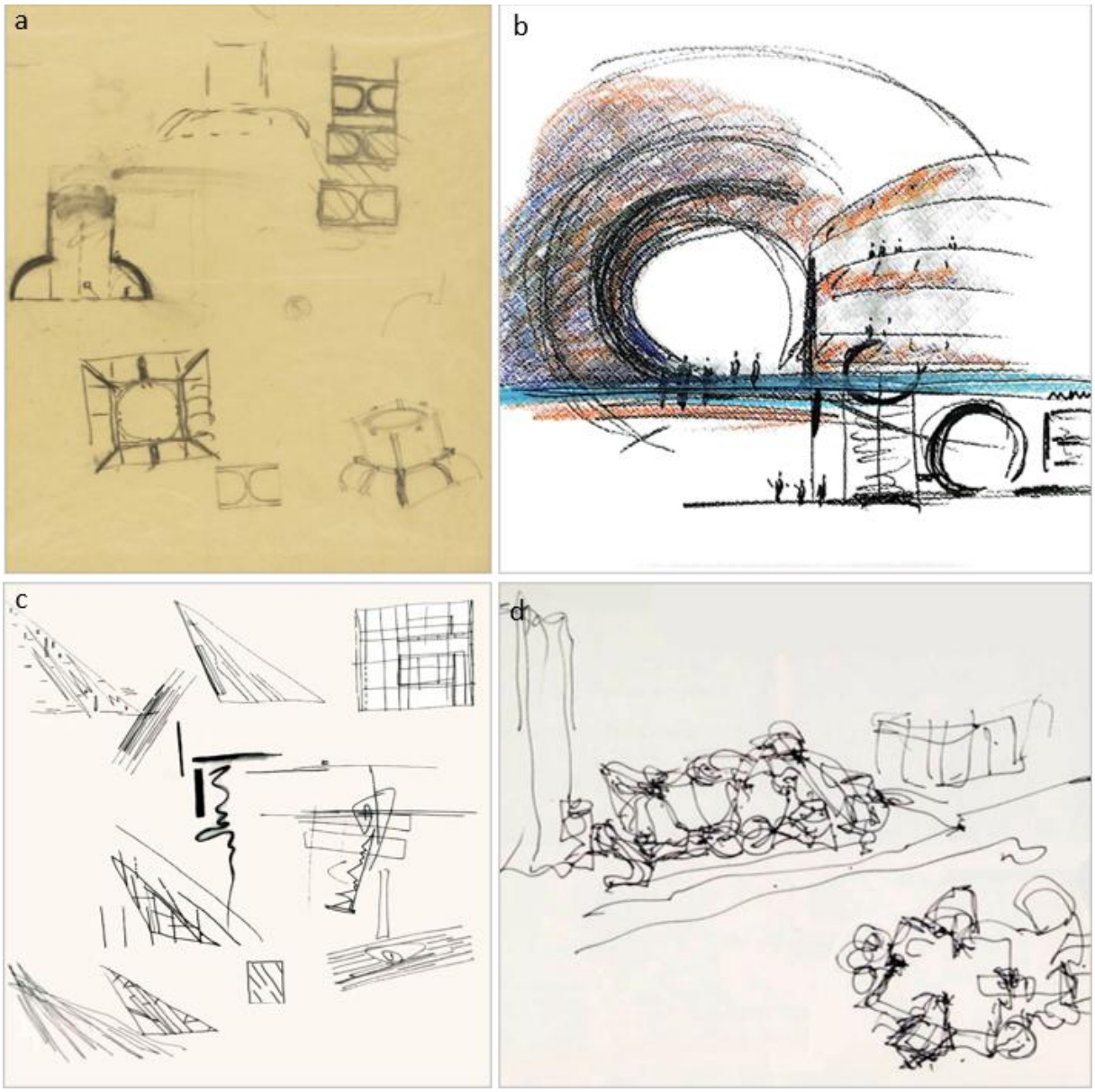

a
b
c
d

Los bocetos activan la memoria a largo plazo, conectando ideas no consideradas inicialmente y apoyándose en imágenes visibles en el área de trabajo (Goldschmidt, 1991; Herbert, 1988). El dibujo redibujado surge de este proceso perceptual, con trazos repasados, tachados o varios dibujos relacionados que reformulan ideas. Aunque desordenados y poco legibles para otros, son de gran valor perceptual para el autor.

En la figura 37 se muestra los dibujos de Kahn para la Sinagoga Mikveh Israel de Filadelfia, Pensilvania (Kahn, 1963) en los que se aprecia la derivación de las formas en búsqueda de la ideal. El segundo dibujo le pertenece a Tadao Ando para el Viviendas Rokko en Japón (Ando, 2010) con trazos repasados varias veces con el mismo lápiz de color azul para remarcar lo que perceptualmente se quiso poner en relieve. En otros casos como los dibujos de Zaha Hadid para el proyecto Rheinauhafen en Colonia en Alemania (Schumacher & Fontana-Giusti, 2004) se aprecia la intención de mantener más posibilidades de reinterpretación, por ello el dibujo es repetido uno al lado del otro buscando las transformaciones, modificaciones y refinamientos (Goldschmidt, 2003). Finalmente, el dibujo de Frank Gehry para la Sala de conciertos Walt Disney de Los Ángeles(Bredekamp, 2004) también es un ejemplo, aunque no muy frecuente, del repasado de trazos en la búsqueda y descubrimientos perceptivos de la idea reinterpretada más importante. Gehry en general hace nuevos dibujos rápidos.

El dibujar para recordar y el dibujo convencional rudimentario: En el proceso creativo, los arquitectos revisan sus dibujos previos para recordar y reactivar ideas, usando los bocetos como una extensión de la memoria (de Lapuerta, 1997). Dibujos preconfigurados, como axonométricos o vistas diédricas, aunque rudimentarios, facilitan esta función en comparación con los más abstractos (Goldschmidt, 2003).

Figura 37
Los dibujos redibujados de Louis Kahn (a), Tadao Ando (b), Zaha Hadid (c) y Rafael Moneo (d).


a
b
c
d

Estos dibujos contienen lo esencial del diseño y permiten tanto la autoevaluación como la discusión con otros (Herbert, 1988). Aunque los sistemas de representación pueden limitar o distorsionar ideas, dominarlos técnicamente es clave para evitar pérdidas de información (de Lapuerta, 1997). Al finalizar ciclos creativos, se emplean esquemas técnicos básicos que reactivan el proceso, siendo la planta uno de los más utilizados por su claridad en proporciones y distribución.

En la figura 38 se muestra los bocetos de Louis Kahn (Kahn, 1965b) para la Sala de oración de Sher-e-Bangla Nagar en Dhaka, Bangladesh. Es estos dibujos se puede ver el uso de las vistas en planta y corte además de una axonométrica, todos ellos realizados de manera muy simple y rudimentaria. El segundo ejemplo muestra los dibujos en perspectiva cónica, corte y planta muy esquemáticos, superpuestos y de diferentes tamaños realizados por Tadao Ando para el Teatro Politécnico de Shanghái en China (Ando, 2010). La planta siempre ha sido para Zaha Hadid el elemento más importante dentro de su proceso conceptual. En el tercer dibujo se aprecia las diversas vistas en planta triangulares y una elevación rectangular para el Parque multimedia Zollhof 3 en Alemania (Schumacher & Fontana-Giusti, 2004). El último dibujo muestra el uso de la vista en planta y una axonométrica de Frank Gehry para el Sala de Conciertos Walt Disney de Los Ángeles, California (Bredekamp, 2004). Estos dibujos tienen un carácter rudimentario y poco convencional.

Figura 38
Los dibujos convencionales dibujados rudimentariamente de Louis Kahn (a), Tadao Ando (b), Zaha Hadid (c) y Frank



3.2. Para la hipótesis 2

Para la comprobación de esta hipótesis se realizó un estudio piloto con la misma metodología de estudio de caso múltiple, es decir extendido a varios casos buscando la redundancia y la variedad para lograr un mejor entendimiento y formulación de las teorías (Denzin & Lincoln, 2013).

3.2.1. Participantes

La elección de los casos se dio a través de un muestreo por conveniencia seleccionando dos grupos de estudiantes de la Facultad de Arquitectura y Urbanismo de la Universidad Nacional de San Agustín de Arequipa en Perú. El primer grupo, denominado novatos, estuvo formado por estudiantes que habían terminado de cursar el primer año de estudios. El segundo grupo, denominado expertos, estuvo conformado por estudiantes del último año que ya habían cursado cuatro años de la carrera profesional. Para el reclutamiento se utilizó un cuestionario en Google Forms en el que además se recabó información en cuanto a condiciones específicas como daltonismo, epilepsia, y predisposición para mareos, náuseas y migraña. Estas condiciones restringieron la participación en el estudio. De los ochenta estudiantes del primer año se reclutó 14, de los sesenta estudiantes del último año también se reclutó 14. El promedio de edades de los participantes novatos y expertos fue de 20.08 y 23.43 años respectivamente. Los 28 participantes firmaron un consentimiento avalado por el Comité de Ética de la universidad para participar en la experimentación.

Figura 39
Estudiante de Arquitectura usando los equipos de RVI para dibujar en tres dimensiones. Imagen fotografiada por el autor


Brushes
Unlit Hull

3.2.2. Instrumentos

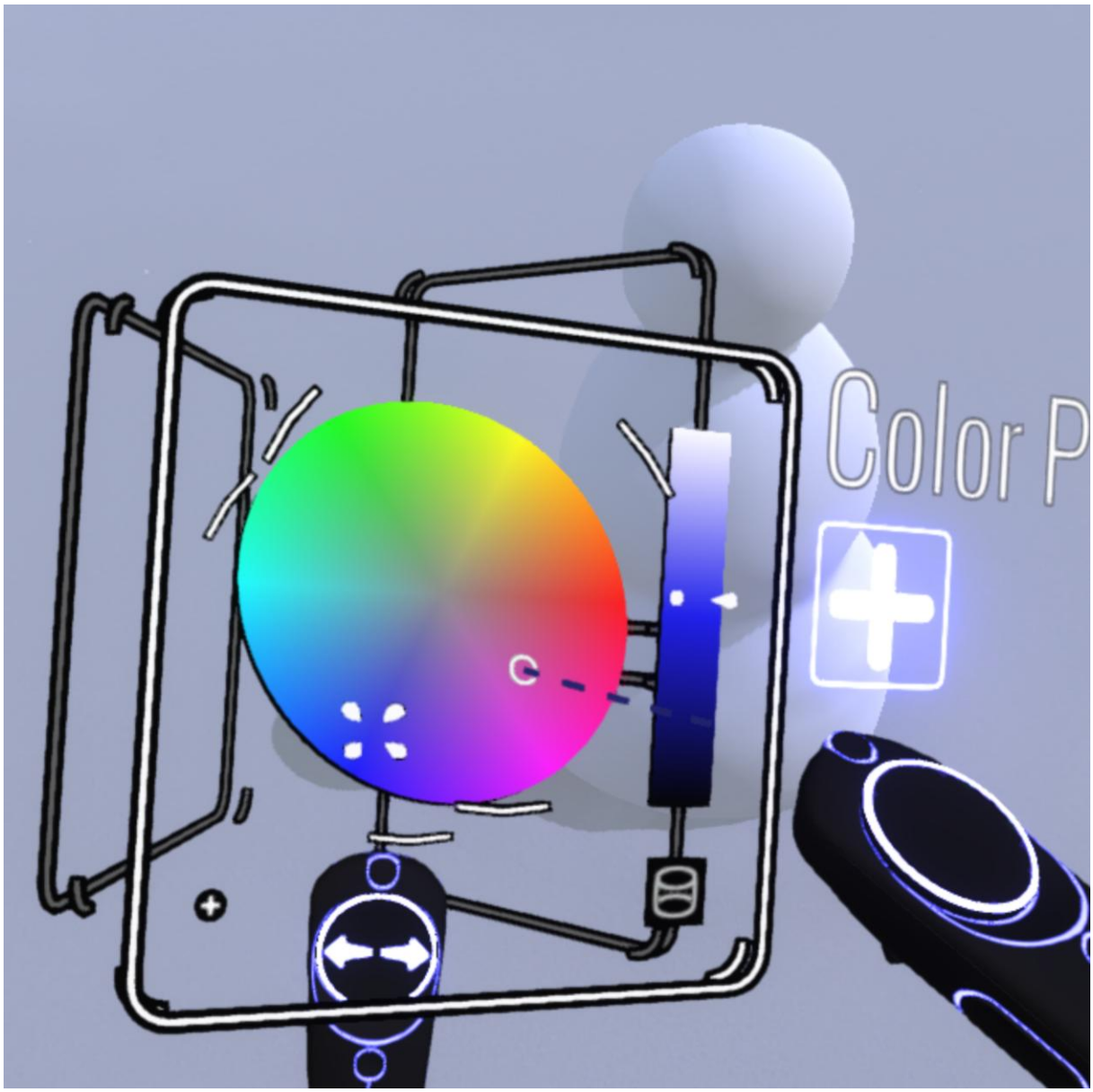
El diseño experimental consistió en la observación y entrevista de los participantes durante el proceso de creación de una idea arquitectónica a través del dibujo de concepción en RVI usando el software Tilt Brush (Figura 40). También se observó y analizó las ideas tridimensionales creadas y finalizadas dentro del entorno virtual. Para la recopilación de información se utilizaron tres instrumentos.

Ficha de observación 1: Esta ficha con una escala de Likert de 5 niveles (Tabla 3) permitió observar y registrar el comportamiento de los participantes durante todo su proceso de creación. Se observaron los movimientos del cuerpo, los gestos, la velocidad, la concentración, el desplazamiento y el uso del lenguaje para explicar lo creado.

Tabla 3. Ficha de Observación 1 y su escala de Likert.

	Frec. /intens. muy baja	Frec. /intens. baja	Frec. /intens. moderada	Frec. /intens. alta	Frec. /intens. muy alta
Muestra movim. intensos de manos, brazos y cuerpo	◯	◯	◯	◯	◯
Crea trazos y formas sólo para explorar opciones	◯	◯	◯	◯	◯
Crea múltiples trazos con facilidad y rapidez	◯	◯	◯	◯	◯
PAUSA					
Percibe el dibujo moviéndose y cambiando de escala	◯	◯	◯	◯	◯
Explica su propuesta final utilizando los dibujos	◯	◯	◯	◯	◯

Figura 40
Entorno virtual de Tilt Brush y herramientas para la elección de pinceles. Imagen fotografiada por el autor


Color P

Cuestionario: el cuestionario mixto (Tabla 4) de preguntas cerradas (con escala de Likert de 5 niveles) y de preguntas abiertas permitió conocer la percepción y opiniones del uso de la herramienta para la creación de ideas. Se aplicó a la mitad y al final de proceso creativo.

Tabla 4. Cuestionario de preguntas cerradas (escala de Likert) y de preguntas abiertas

	Frec. /intens. muy baja	Frec. /intens. baja	Frec. /intens. moderada	Frec. /intens. alta	Frec. /intens. muy alta
¿Cómo de intensa fue la experiencia de dibujar en IVR?	○	○	○	○	○
¿Qué hizo que la experiencia fuera especial o intensa?					
¿Qué utilidad tuvo probar trazos y formas al principio?	○	○	○	○	○
¿Qué ha resultado más interesante en la primera parte de la exploración?					
¿En qué medida ha sido útil crear trazos de forma sencilla y continua?	○	○	○	○	○
¿Qué impedimentos has encontrado durante el proceso de dibujo?					
PAUSA					
¿Qué utilidad ha tenido el cambio de escala para percibir el dibujo?	○	○	○	○	○
¿Qué fue lo más impactante en esta segunda parte del proceso de dibujo?					
¿Qué utilidad ha tenido dibujar en 3D en lugar de 2D?	○	○	○	○	○
¿Por qué no hizo dibujo s bidimensionales al final del proceso?					

Figura 41
Entorno virtual de Tilt Brush y herramientas para la elección de colores. Imagen fotografiada por el autor

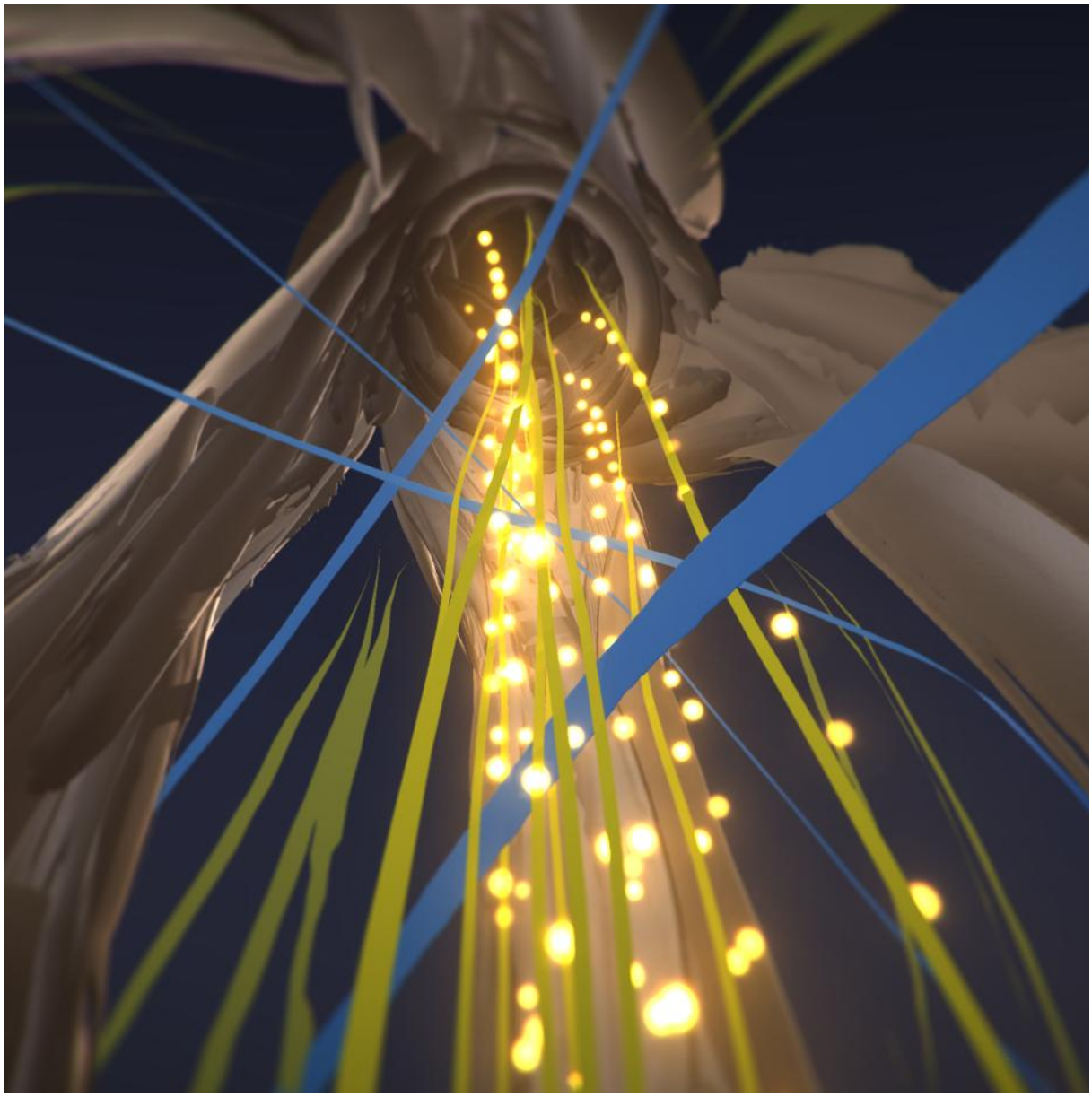

Color Picker

Ficha de observación 2: También con una escala de Likert de 5 niveles esta ficha que se observa en la Tabla 5 permitió observar y valorar las ideas creadas que quedaron registrados en el entorno virtual como respuesta final del proceso.

Tabla 5. Ficha de Observación 2 y su escala de Likert.

	Presenc. /cantid muy baja	Presenc. /cantid muy baja	Presenc. /cantid moderada	Presenc. /cantid alta	Presenc. /cantid muy alta
Trazos de diferentes tipos, grosores y colores que expresan un vínculo háptico	○	○	○	○	○
Dibujos abstractos e indeterminados sin forma o con una forma poco definida	○	○	○	○	○
Dibujos pequeños y multiplicados con pocas convenciones gráficas y detalles	○	○	○	○	○
Dibujos replanteados, repintados, tachados, desordenados y resaltados	○	○	○	○	○
Dibujos con convenciones de la representación gráfica rudimentarios	○	○	○	○	○

Figura 42
Estudiante de Arquitectura usando los equipos de RVI para materializar sus ideas a través del dibujo virtual. Imagen fotografiada por el autor



3.2.3. Procedimiento

La experimentación se dio en tres sesiones. En la primera sesión se hizo una presentación multimedia de diez minutos en la que se explicó la importancia del del proceso creativo a través del dibujo. En la misma sesión se realizó un entrenamiento grupal del uso de los visores montados sobre la cabeza de la marca HTC Vive, los mandos hápticos y del software Tilt Brush. La elección de este software se basó en tres criterios. Primero fue la alta libertad de trazos a mano alzada y baja precisión geométrica, para mantener la flexibilidad y fomentar la innovación; segundo fue la presencia de herramientas y pinceles creativos para experimentar con los mismos trazos y el tercer criterio fue la curva aprendizaje baja para facilitar el entrenamiento en su uso. En el uso del software se buscó el dominio de la mayoría de las herramientas como pincel, color, guías y otras como seleccionar, borrar, transportarse, además de grabar, exportar y fotografiar. Se restringió el uso de la herramienta trazo recto y simetría. La última parte de este entrenamiento permitió que cada participante utilice el hardware y software durante 20 minutos. Al finalizar esta sesión se le entregó a cada participante el poema "El Viento" del escritor peruano José María Eguren. No se les dio ninguna explicación más allá de leer, entender y reconocer los sentimientos y sensaciones que este texto generaba.

En la segunda sesión se explicó el tema de diseño a realizar que fue la creación de una idea arquitectónica para una "Escultura Habitable" que permita experimentar las sensaciones del poema estudiado. Se recalcó que no se buscaba el logro de una propuesta arquitectónica precisa y terminada, sino solo el logro de una primera idea que pueda luego continuar desarrollándose.

Figura 43
Dibujo virtual escalado para ser observado por estudiante desde su interior. Imagen fotografiada por el autor



La creación de la idea se hizo por completo en el entorno virtual (no se usó lápiz ni papel). También se les pidió dejar registrado todo el proceso de ideación, así como la idea terminada. Los participantes usaron durante 25 minutos el software y hardware y en el entorno virtual crearon los dibujos tridimensionales de las primeras ideas. Durante este tiempo se aplicó la ficha de observación 1. Para una adecuada observación se usó una pantalla de televisor de 65 pulgadas que mostraba lo creado por cada participante en tiempo real. Una pausa de cinco minutos sirvió para aplicar la primera parte del cuestionario. A continuación, dedicaron 25 minutos a observar lo creado previamente, completar la exploración y concretar una idea final. La idea final fue brevemente explicada por cada participante. Finalizada la actividad en el entorno virtual cada participante terminó de responder la segunda parte del cuestionario.

En la tercera sesión dos docentes expertos en diseño arquitectónico revisaron las creaciones finales exportadas a la plataforma Sketchfab en donde se puede ver, mover y rotar los objetos a través de la pantalla del ordenador. También se observó las ideas finales con el uso de los HMD y mandos hápticos Para recabar esta información se aplicó la Ficha de observación 2.

3.2.4. Evaluación de resultados 2

Figura 44
Primera idea finalizada y presentada sobre el pedestal del entorno virtual. Imagen fotografiada por el autor

Del dibujo de concepción como proceso.

La ficha de observación 1 (Tabla 3) y el cuestionario (Tabla 4) han proporcionado los siguientes resultados en cuanto al dibujo como acción y proceso creativo (ver Figuras 46 y 47).


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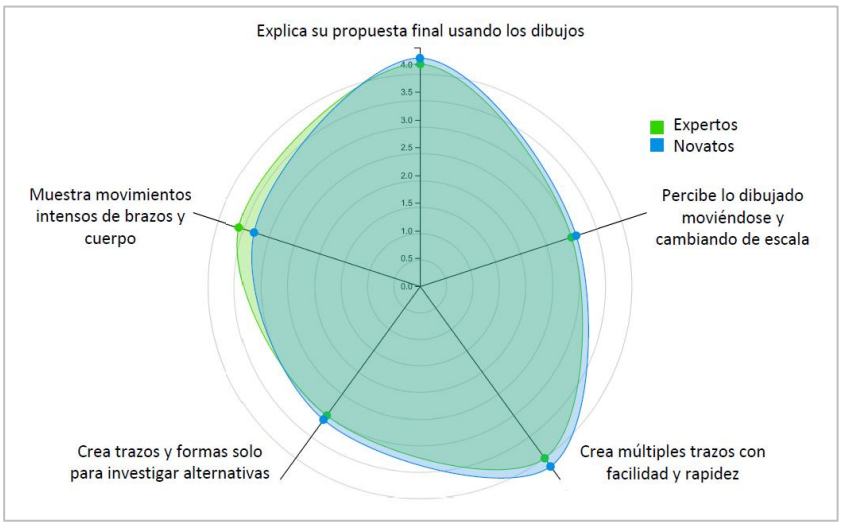


Figura 46. Gráfico con valores obtenidos de la Ficha de Observación 1

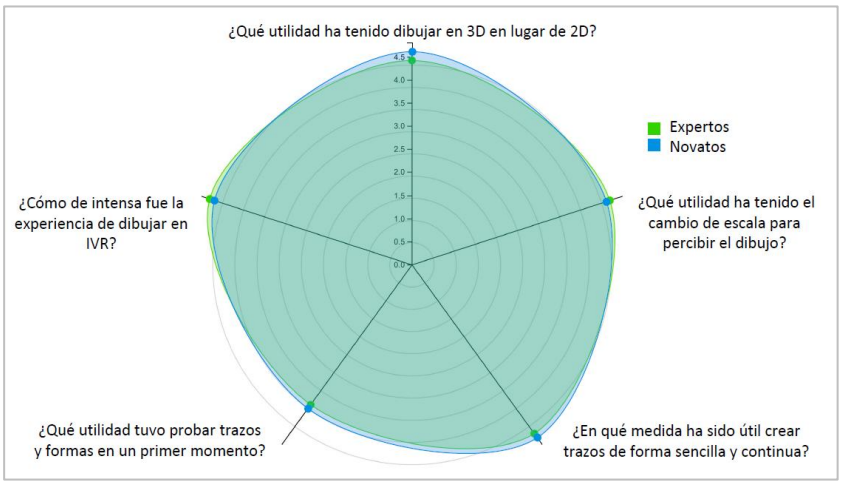
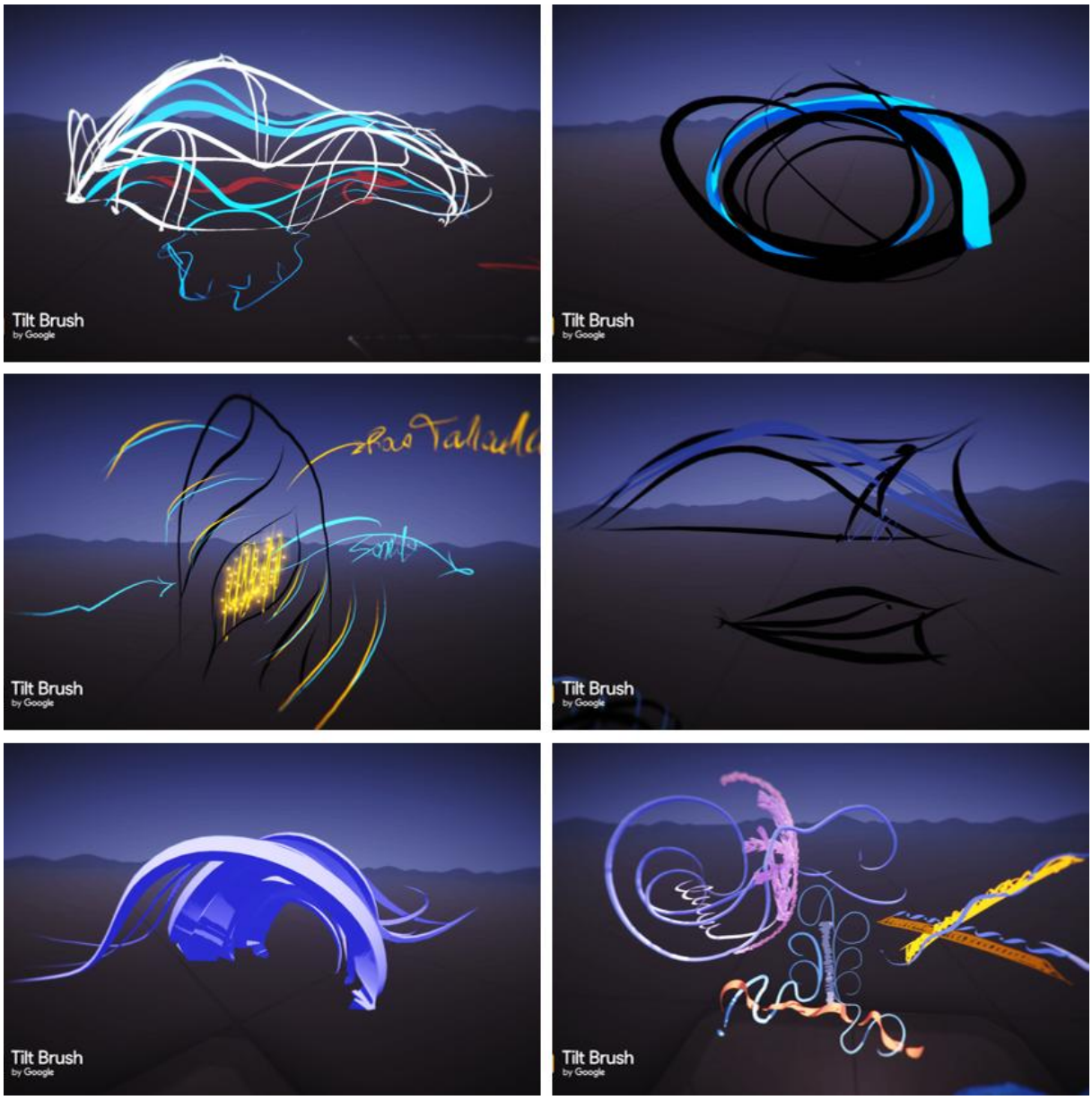


Figura 47. Gráfico con valores obtenidos del Cuestionario 1

Figura 45
Ejemplos de los dibujos hápticos creados con RVI. Imágenes fotografiadas por el autor

Respecto a la condición fenomenológica del acto de dibujar. La observación del movimiento corporal durante el proceso de dibujo en realidad virtual reveló que tanto novatos como expertos mostraron

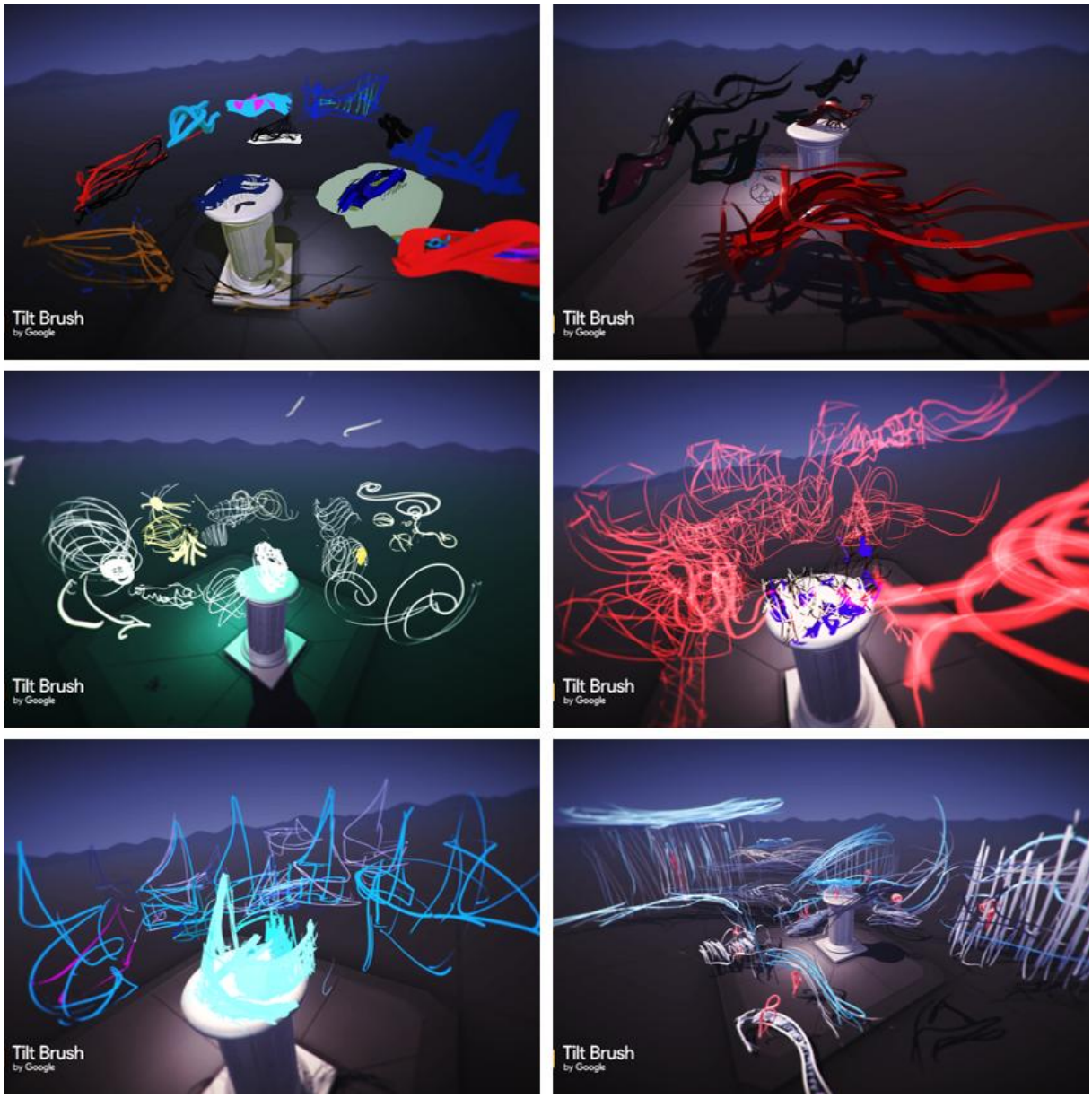

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movimientos moderados de manos y brazos, pero más pronunciados que los movimientos comunes de mano y muñeca que se realizan cuando se dibuja con lápiz sobre papel. Aunque los movimientos no fueron exagerados, fueron suficientes para indicar un mayor compromiso corporal. El cuestionario reveló una experiencia intensa al dibujar en un entorno virtual, con puntuaciones altas (4.7 para novatos y 4.8 para expertos). Los participantes describieron la experiencia como la entrada en un mundo diferente, paralelo y mágico, lo que demuestra un alto sentido de presencia y agencia en el entorno de realidad virtual.

Respecto a la característica 1: el acto de dibujar indeciso. La exploración inicial de trazos y formas por parte de los estudiantes fue moderada, con puntuaciones de 3.0 para novatos y 3.1 para expertos. Los estudiantes investigaron tipos de trazos, grosores y colores y aunque se restringió el uso de trazos fantasiosos algunos los indagaron. En el cuestionario, los estudiantes valoraron positivamente la utilidad de probar varios trazos y formas, con puntuaciones de 3.9 para novatos y 4.0 para expertos. Las respuestas más comunes destacaron la facilidad para crear diversos tipos de trazos y la sensación de estar en otro mundo como factores importantes que fomentan la creatividad.

Respecto a la característica 2: el acto de dibujar continuo. Los novatos produjeron muchos dibujos exploratorios, mientras que los expertos crearon menos dibujos, pero con más detalles. Ambos grupos tuvieron un proceso de dibujo intenso y continuo, con puntuaciones de 4.2 para novatos y 4.0 para expertos. Los estudiantes valoraron altamente la utilidad de poder crear dibujos de manera continua y fluida, con puntuaciones de 4.8 y 4.7 respectivamente.

Figura 48
Ejemplos de los dibujos sin forma creados con RVI. Imágenes fotografiadas por el autor

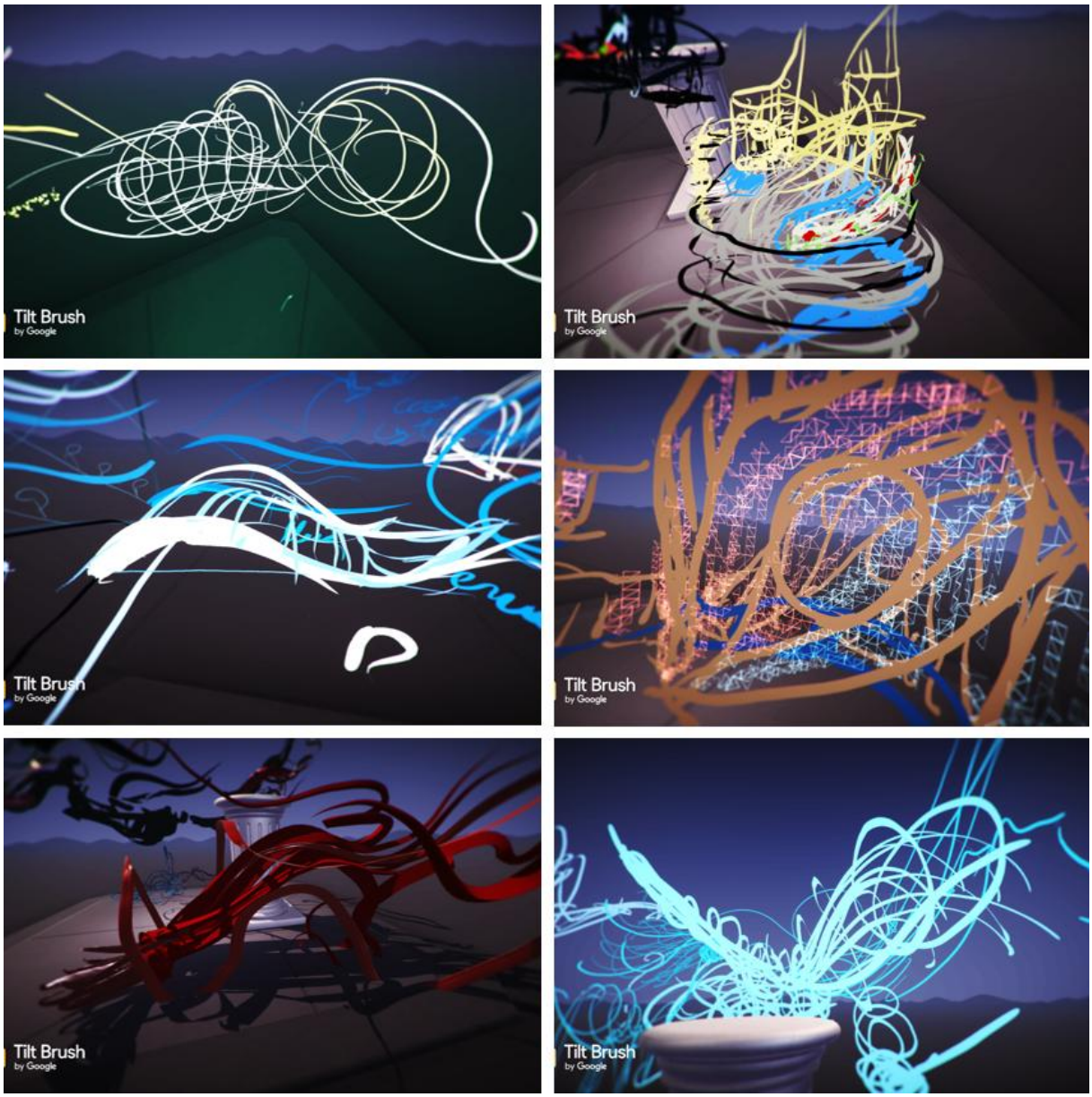

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La falta de tiempo para dibujar fue mencionada como un impedimento, junto con la dificultad de dibujar la profundidad, aunque esta se podía superar de alguna manera utilizando la herramienta “guía” que permite crear un sólido para dibujar sobre este.

Respecto a la característica 3: el acto de dibujar perceptivo. Después de una pausa de 5 minutos, se pidió a los estudiantes que observaran sus dibujos y cambiaran de escala para entender y percibir mejor lo creado. Los estudiantes utilizaron moderadamente el cambio de escala, con puntuaciones de 3.1 para novatos y 3.0 para expertos. No realizaron correcciones, pero hicieron nuevos dibujos derivados de los anteriores. La capacidad de cambiar de escala y experimentar los dibujos desde el interior fue altamente valorada, con puntuaciones de 4.6 para novatos y 4.7 para expertos. Las respuestas indicaron que la posibilidad de meterse dentro de sus creaciones y percibir la tridimensionalidad fue lo más impactante.

Respecto a la característica 4: el acto de dibujar para recordar. Los estudiantes movieron y rotaron sus dibujos tridimensionales para explicar sus ideas, con puntuaciones de 4.3 para novatos y 4.2 para expertos. Solo tres estudiantes escribieron textos cortos en el entorno virtual para apoyar sus explicaciones. Todos los estudiantes dibujaron en tres dimensiones, prescindiendo del dominio técnico de dibujar axonométricas, vistas diédricas o perspectivas cónicas. La utilidad del dibujo en 3D para continuar desarrollando ideas fue altamente valorada, con puntuaciones de 4.8 para novatos y 4.6 para expertos. La preferencia por el dibujo en 3D sobre el bidimensional se debió a su claridad y suficiencia para ser entendido en cualquier momento posterior.

Figura 49
Ejemplos de los dibujos inquisitivos multiplicados que puede verse alrededor del pedestal creados con RVI. Imágenes fotografiadas por el autor


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Del Dibujo de Concepción como Producto.

La ficha de observación 2 que se muestra en la Figura 51 ha proporcionado los siguientes resultados en cuanto al dibujo como producto finalizado. También se usó una escala de Likert de 5 niveles.

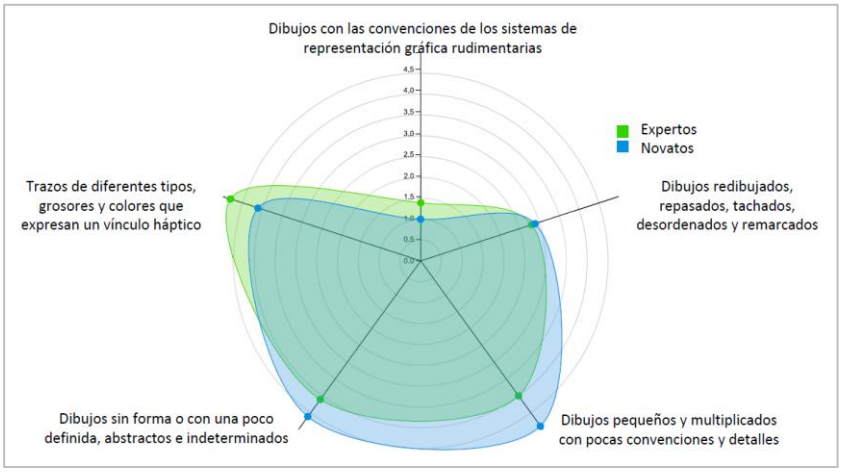
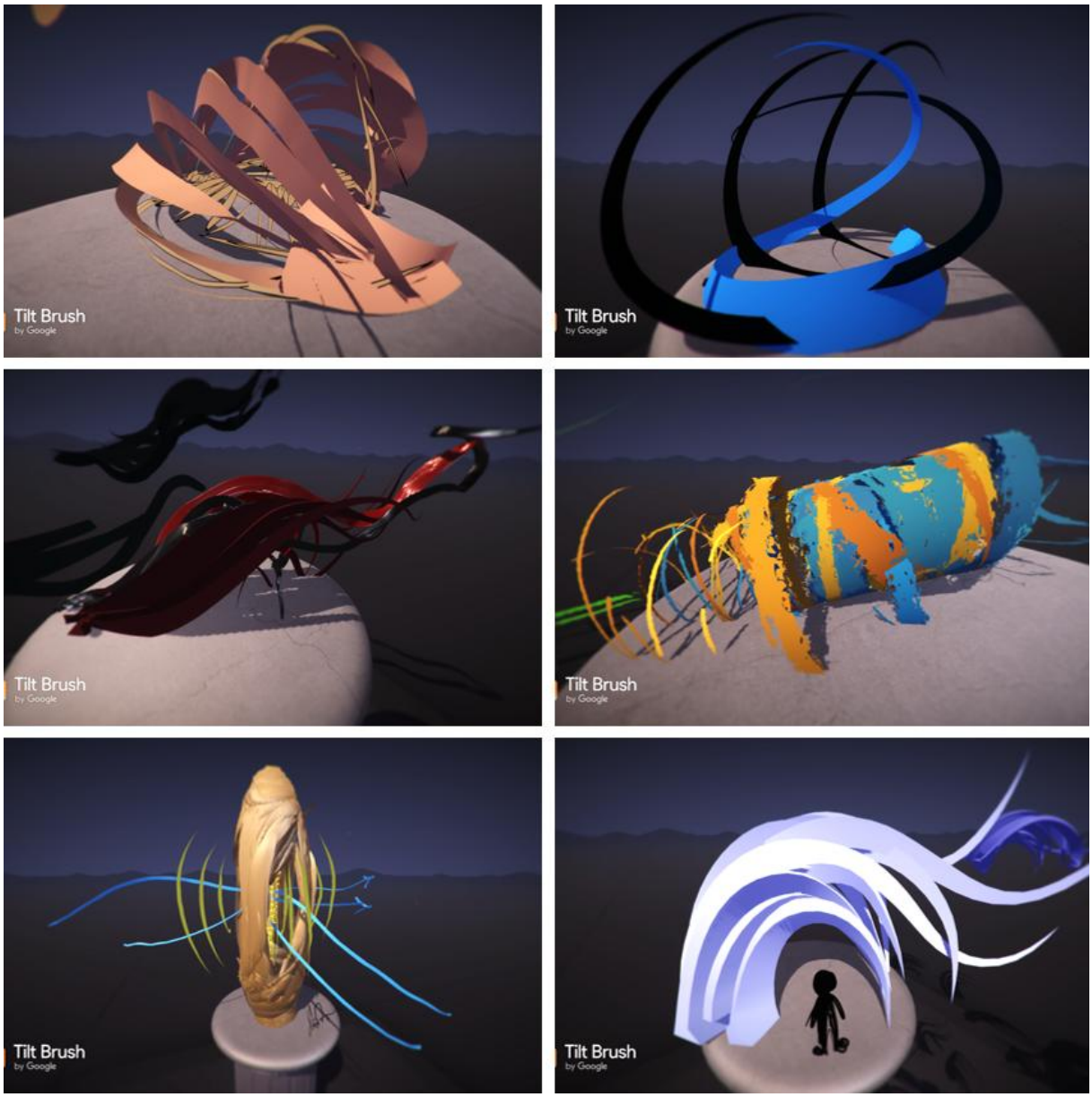


Figura 51. Gráfico con los valores obtenidos de la Ficha de Observación 2

Respecto a la condición fenomenológica. Los estudiantes expertos usaron una mayor variedad de trazos, colores y grosores, mostrando un vínculo háptico más fuerte con sus dibujos comparado con los novatos, con puntuaciones de 4.8 frente a 4.1. Algunos expertos utilizaron trazos fantasiosos a pesar de haber sido restringidos (parte derecha de la Figura 45). Sin embargo, esto ha evidenciado un compromiso sensorial más profundo con el proceso de dibujo.

Respecto a la característica 1: el dibujo sin forma. Los dibujos iniciales exploratorios que se pueden observar en la Figura 48 mostraron un alto nivel de abstracción, especialmente entre los novatos, con puntuaciones de 4.6 frente a 4.1 para los expertos.

Figura 50
Ejemplos de los dibujos redibujados creados con RVI. Imágenes fotografiadas por el autor


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La restricción del uso de la herramienta escuadra llevó a la creación de trazos más libres y los dibujos finales fueron más configurados y menos abstractos, reflejando una respuesta final del proceso cognitivo.

Respecto a la característica 2: el dibujo pequeño y multiplicado. Los novatos produjeron muchos dibujos exploratorios, mostrando una alta iteración y multiplicidad en sus dibujos, con puntuaciones de 4.9 frente a 4.0 para los expertos. La diversidad de tamaños de los dibujos se debió a las diferentes escalas en las que fueron creados, adaptándose al movimiento de la mano y el brazo en un entorno sin muchas referencias de escala. Ver Figura 49.

Respecto a la característica 3: el dibujo redibujado. La eliminación de trazos en el entorno de RVI es rápida y no deja rastros. No ha sido posible reconocer los trazos eliminados, borroneados, o tachados lo que ha resultado en puntuaciones moderadas de 2.9 para novatos y 2.8 para expertos. En la Figura 50 se puede observar ejemplos de algunos trazos superpuestos y acompañantes que remarcaron ideas, generando dibujos desordenados pero detallados. Los estudiantes prefirieron crear nuevos dibujos en lugar de corregir los existentes.

Respecto a la característica 4: el dibujo rudimentario convencional. Los dibujos finales fueron tridimensionales en su totalidad. Al no necesitarse del uso de plantas, cortes, axonométricas o perspectivas cónicas han resultado puntuaciones bajas de 1.0 para novatos y 1.4 para expertos. La restricción de herramientas de precisión generó que todos los trazos sean imprecisos dándole al producto final un acabado rudimentario, pero al ser tridimensional suficiente para ser entendido y recordado de manera clara en cualquier otro momento posterior en el mismo entorno virtual o a través de la pantalla de un ordenador o teléfono móvil. Obsérvese algunos ejemplos en la Figura 52.

Figura 52
Ejemplos del uso del dibujo tridimensional virtual en lugar del dibujo bidimensional convencional rudimentario. Imágenes fotografiadas por el autor


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3.3. Para la hipótesis 2 y 3

Debido a que la materialización de una idea a través de la I3D implica crear previamente el modelo en entornos digitales, se decidió realizar un estudio piloto experimental en el que se vincule la creación de una idea tridimensional en RVI y su posterior materialización usando la I3D. Esta experimentación se realizó con un grupo de estudiantes aplicando la metodología de estudio de caso múltiple.

3.3.1. Participantes

La elección de los casos se dio a través de un muestreo por conveniencia seleccionando dos grupos de estudiantes matriculados en la asignatura "Taller de Diseño Arquitectónico 1" de la Facultad de Arquitectura y Urbanismo de la Universidad Nacional de San Agustín de Arequipa en Perú. Se dividieron los 33 alumnos del grupo B de dicha asignatura en dos subgrupos. La división fue aleatoria, pero manteniendo equidad en cuanto a su desempeño académico reflejado en sus calificaciones de la primera parte de la asignatura. De esta forma se garantizó que la desigualdad de los aprendizajes previos no distorsione los resultados de la experimentación. Se utilizó un cuestionario Google Forms para recabar información en cuanto a condiciones específicas como daltonismo, epilepsia, mareos, náuseas y migraña. Estas condiciones restringieron la participación en el estudio. El grupo experimental quedó conformado por 15 estudiantes, 7 mujeres y 8 varones con un promedio de edad de 17.8 años. El grupo control quedó conformado por 18 estudiantes, 13 mujeres y 5 varones con un promedio de edad de 18.1 años. Para su participación, los estudiantes firmaron un consentimiento avalado por el Comité de Ética de la universidad.

Figura 53
Estudiante entrenando con el equipo de RVI y Google Blocks. Imagen fotografiada por el autor.



3.3.2. Instrumentos

Para la recolección de información se usaron dos fichas de observación. La Ficha de Observación 1a que se observa en la Tabla 6 fue semejante a la usada en el caso anterior.

Tabla 6. Ficha de Observación 1a y su escala de Likert.

	Frec. /intens. muy baja	Frec. /intens. muy baja	Frec. /intens. muy baja	Frec. /intens. muy baja	Frec. /intens. muy baja
Muestra movimientos intensos de manos, brazos y cuerpo	○	○	○	○	○
Crea formas y volúmenes sólo para explorar opciones	○	○	○	○	○
Crea múltiples formas y volúmenes con facilidad y rapidez	○	○	○	○	○
PAUSA					
Observa las formas y volúmenes para reorganizarlos	○	○	○	○	○
Explica la idea conceptual mostrando el modelo	○	○	○	○	○

La segunda ficha de observación se diseñó para observar y evaluar la presentación de la idea impresa en 3D como producto final en ambos grupos. Se observaron los tres aspectos referidos a las tres características de la maqueta de concepción. La valoración también fue con una escala de Likert de cinco niveles como se observa en la Tabla 7.

Figura 54
Entorno virtual de Google Blocks y herramientas para la creación de formas. Imagen fotografiada por el autor

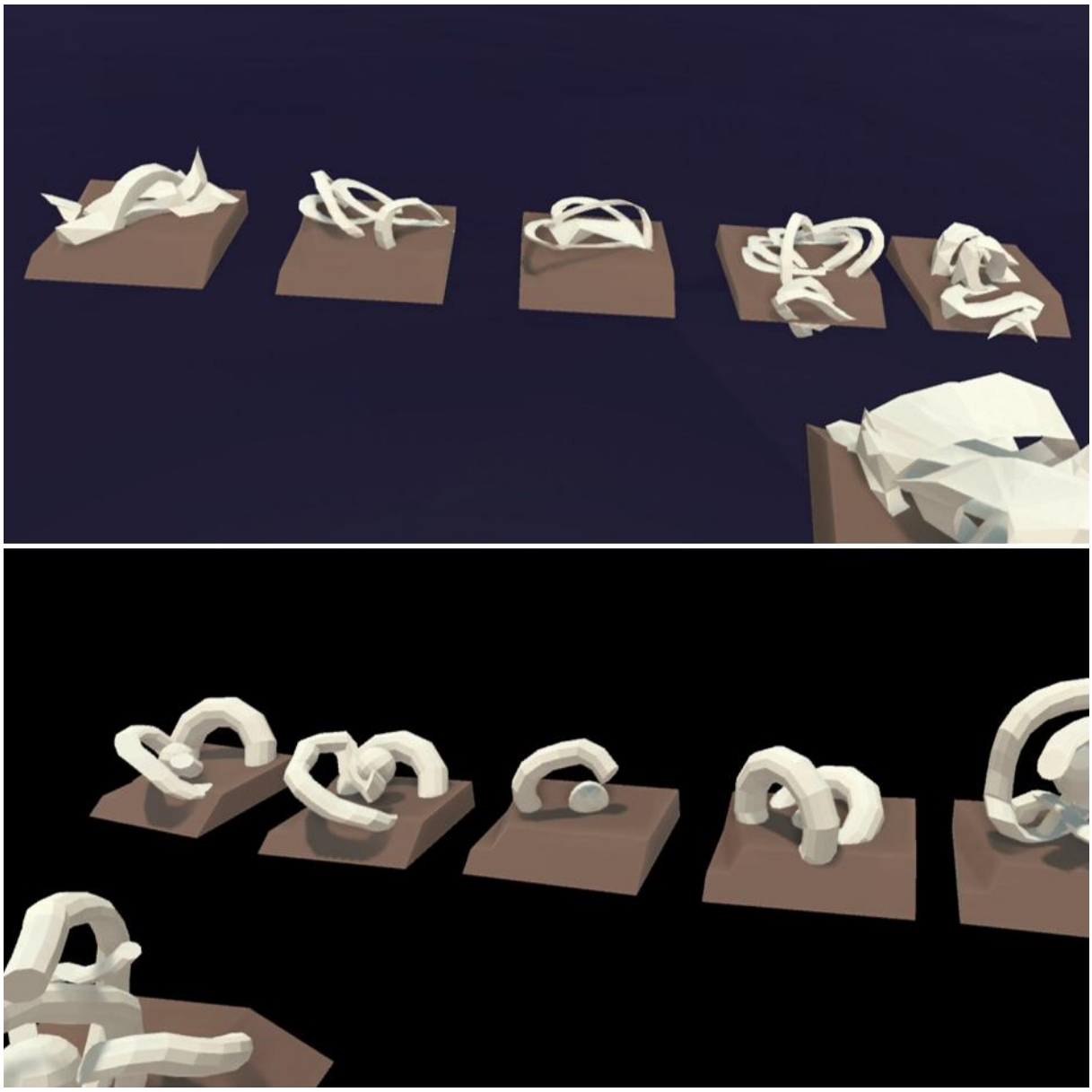


Tabla 7. Ficha de Observación 2a y su escala de Likert.

	Presen. /cantid. muy baja	Presen. /cantid. baja	Presen. /cantid. moderada	Presen. /cantid. alta	Presen. /cantid. muy alta
Muestra una complejidad tridim. apreciable solo al mover y observar el objeto	○	○	○	○	○
Muestra una materialidad que induce a tocar el objeto y a estudiarlo bajo la luz del sol	○	○	○	○	○
Muestra una abstracción conceptual que le confiere autonomía de objeto bello	○	○	○	○	○

3.3.3. Procedimiento

La experimentación consistió en la creación y materialización de la primera idea para un embarcadero y mirador turístico a orillas del rio Chili en la ciudad de Arequipa a través de la construcción de una maqueta conceptual. Los 33 estudiantes, terminada la fase de análisis o prediseño, propusieron en un trabajo de taller la primera idea del proyecto. Dicha idea fue ejecutada a través de dibujos a mano alzada sobre una lámina de papel A3. Terminada la retroalimentación de los docentes se les convocó tres días después para terminar la ideación y configuración de dicha primera idea a través de una maqueta conceptual. En esos tres días se trabajó de forma diferenciada con el grupo experimental de la siguiente forma.

Figura 55
Iteraciones y pruebas en el proceso de crear la maqueta conceptual. Virtual Imagen fotografiada por el autor



En la primera sesión el grupo experimental tuvo un entrenamiento en el manejo de los HMD de la marca HTC Vive con mandos hápticos y del software “Google Blocks” (Fig. 53 y 54). Se eligió esta aplicación debido a que ha sido creada exclusivamente para el modelado de objetos 3D a mano alzada usando los mandos hápticos con un moderado control geométrico y precisión matemática. Aunque su naturaleza modular podría limitar la libertad creativa, han influido en su elección otros dos aspectos. Primero porque es una herramienta cuya curva de aprendizaje es muy baja lo que facilita su integración en una experimentación corta. Segundo, y a diferencia de otras aplicaciones como Tilt Brush, Gravity Sketch o Quill, los modelos exportados de Blocks en formato .obj son aceptados por aplicaciones para la I3D. Los estudiantes aprendieron a crear objetos tridimensionales en un entorno virtual utilizando solo las seis herramientas disponibles del software: Shape, Stroke, Eraser, Grab, Paint and Modify. Con la herramienta Shape crearon diversos tipos de poliedros y superficies curvadas como conos, cilindros y esferas. Con la herramienta Stroke crearon trazos libres a mano alzada y con la herramienta Modify transformaron los objetos construidos. Esta aplicación es muy sencilla, sin efectos de texturas o iluminación especial, pero suficiente para los objetivos de la experimentación. Cada estudiante usó los equipos de RVI y el software por 20 minutos garantizando su dominio.

En la segunda sesión como se muestra en la Figura 54 cada estudiante usó el hardware y software durante 60 minutos con una pausa intermedia de 5 minutos. Se comenzó retomando la ideación y configuración de aquella primera idea realizada dos días antes. El terreno idealizado y modelado en 3D se introdujo al entorno virtual para generar sobre él las ideas. La indicación para la primera parte de la sesión fue comenzar con la indagación de formas tridimensionales.

Figura 56
Maquetas en proceso de impresión 3D. Imagen fotografiada por el autor



También se indicó dejar registrado todo el proceso y no borrar los trazos o formas iniciales como se observa en la Figura 55. Tras una pausa de cinco minutos, la segunda parte de la sesión se centró en observar las formas creadas, ajustar su escala, corregir, agregar o eliminar elementos y finalizar la mejor idea. Durante esta sesión se aplicó la Ficha de Observación 1a. El archivo grabado del modelo virtual de extensión .obj fue exportado al software Ultimaker Cura para configurar la I3D en las cuatro impresoras de filamentos Creality disponibles. El tiempo de impresión de cada archivo en promedio fue de 2 horas lo que tardó 7 horas en total. En la Figura 56 se puede observar algunos ejemplos de las piezas impresas en 3D.

En la tercera sesión se convocó a los estudiantes del grupo control para la creación de su maqueta conceptual usando cartulinas, cartón, palitos de madera, micas de acetato, etc. Durante 90 minutos ejecutaron dicha tarea y el Investigador Principal aplicó la Ficha de Observación 1a. Luego de ello, los estudiantes del grupo experimental se unieron al grupo control para entregarles las piezas impresas en 3D. En ese momento se indicó a ambos grupos que debían terminar y presentar las maquetas en 30 minutos adicionales. En ese tiempo el grupo experimental se encargó de disponer y fijar las piezas impresas en 3D sobre la maqueta del terreno que fue previamente cortada con láser sobre cartulina y fotografiar bajo la luz del sol (Figura 57).

Para la evaluación de las maquetas conceptuales se pidió a cada estudiante que exponga su idea conceptual durante 3 minutos. Para ello debían usar la maqueta física final (manual o impresa en 3D) para explicar la elección de las formas y emplazamiento. Durante las exposiciones, el docente experto aplicó la Ficha de Observación 2a. Se puede observar la entrega de las maquetas de ambos grupos en la Figura 58.

Figura 57
Estudiantes fotografiando sus maquetas antes de la presentación final. Imagen fotografiada por el autor



3.3.4. Evaluación de resultados 3

La Ficha de Observación 1a ha dado los resultados que se ven en la Figura 58.

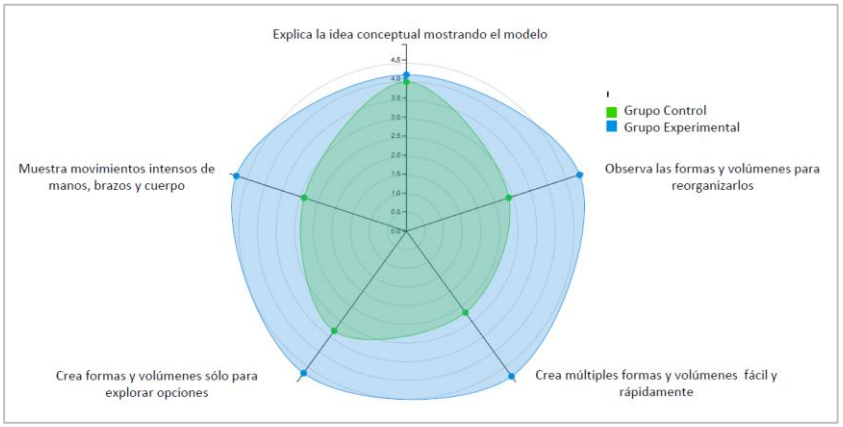
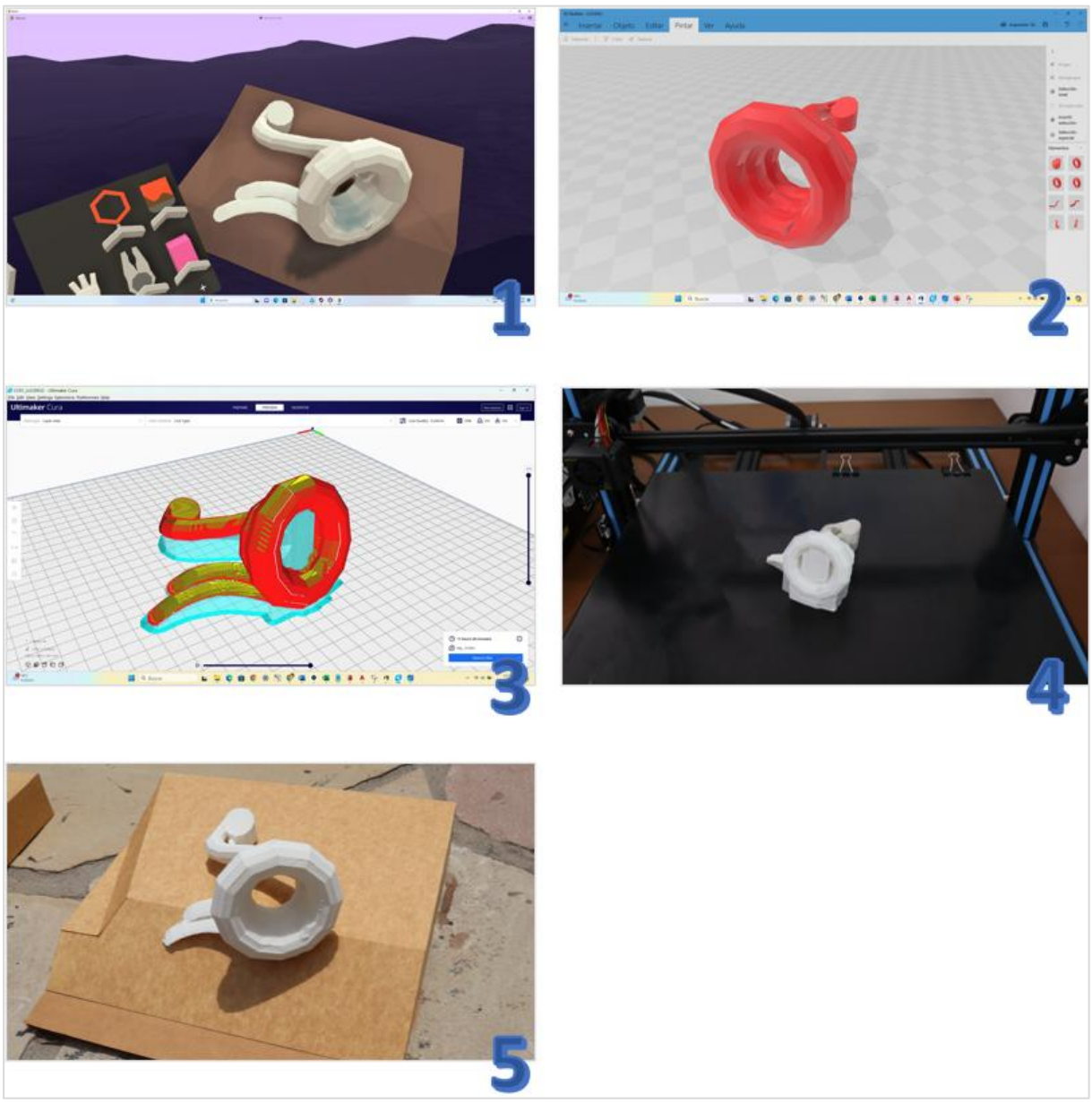


Figura 59. Valores obtenidos en ambos grupos con la aplicación de la Ficha de Observación 1a.

Los resultados revelaron que el grupo experimental mostró un nivel muy alto en cuanto al movimiento intenso de manos, brazos y cuerpo durante la creación del modelo (4.8), en comparación con el grupo control que fue moderado (2.9). La creación de formas y volúmenes para indagar resultó en niveles muy altos para el grupo experimental (4.7) frente al grupo control (3.3). En cuanto a la tercera observación, que buscaba determinar la facilidad para crear múltiples formas y volúmenes, se encontró la diferencia más notable entre ambos grupos. El grupo experimental logró este objetivo a un nivel muy alto (4.8), en contraste con el grupo control, que alcanzó solo un nivel moderado (2.7).

Figura 58
Entrega de maquetas conceptuales manuales e impresas en 3D en el Taller de Diseño. Imagen fotografiada por el autor


1
2
3
4
5

La observación y percepción inicial para reorganizar y ajustar tuvo una valoración de 4.9 para el grupo experimental, comparado con 2.9 del grupo control. La confrontación verbal del modelo con el docente mostró valores similares entre ambos grupos (4.2 vs 4.0).

La Ficha de Observación 2a, centrada en el modelo final como producto (Figura 61), mostró que los modelos impresos del grupo experimental eran más complejos y requerían mayor manipulación y observación (4.7) que las maquetas manuales del grupo control (3.5). En cuanto a la materialidad, los modelos experimentales inducían más a ser tocados y observados bajo los efectos de la luz y sombra (4.5 vs 4.1). Finalmente, los modelos impresos presentaron mayor abstracción y belleza como objetos autónomos (4.3) en comparación con las maquetas manuales (3.9).

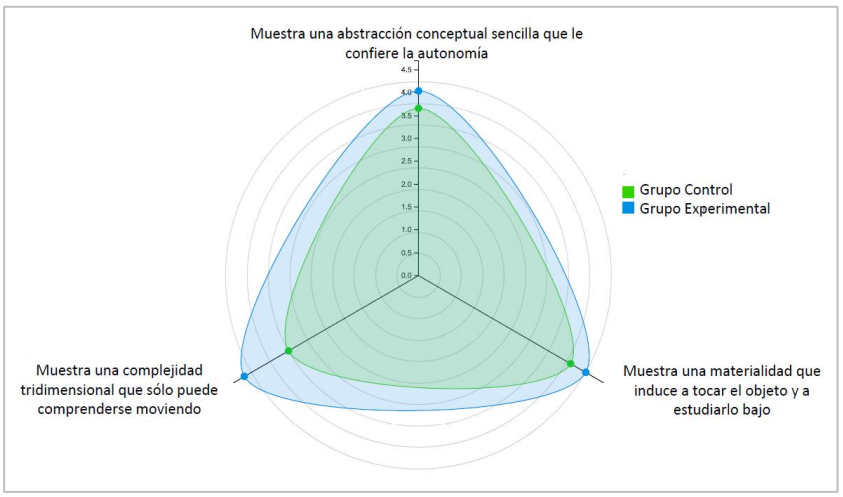


Figura 61. Valores obtenidos en ambos grupos con la aplicación de la Ficha de Observación 2a.

Figura 60
Proceso de la experimentación: 1.El modelo creado en Google Blocks, 2.El modelo exportado para visualización, 3.El modelo configurado en Ultimaker Cura para I3D, 4.El modelo impreso en 3D y 5.El modelo presentado sobre terreno.. Imagen fotografiada por el autor

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RESEARCH ARTICLE

Characterization of conception drawing in architecture to face technological mediations

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KEYWORDS
Conception drawing;
Architectural thinking;
Graphic ideation;
Concept;
Creativity

Abstract The conception drawing in architecture is that allows to initiate the architectural thinking, visualizing, and discovering the first ideas. This drawing has traditionally been given as an act of linking and collaboration between thought, sight, and the movement of the hands with a tool. Identifying and recognizing its characteristics will make it possible to deal with any mediation of information technologies. To establish such characteristics, three case studies were carried out. An analysis was made of the conception drawings and interviews by the Pritzker Prize laureates: Ando, Hadid and Gehry. One condition and four characteristics have been determined: drawing is a phenomenological action that produces haptic drawings; it is an undecided process that originates unformed drawings; it is a fast action that results in small and multiplied drawings; it is a perceptual act that generates redrawn and remarked drawings; and finally, it is an action that seeks to remember to resume the creative process at another moment, which produces rudimentary conventional drawings. Knowing these before any technological mediation will be an important pedagogical contribution that will allow future architects not to alter the cognitive processes that generate the first ideas in the initial moments of the architectural project.
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4. Publicaciones derivadas de la investigación

4.1. Artículo Científico 1

Título: Characterization of conception drawing in architecture to face technological mediations.

La publicación se centra en identificar y reconocer las características y condiciones del dibujo de concepción como mediador del pensamiento arquitectónico que permite visualizar y descubrir las primeras ideas del proyecto arquitectónico para afrontar cualquier mediación tecnológica.

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Figura 62
Portada del artículo 1: "Characterization of conception drawing in architecture to face technological mediations"

The architectural conception drawing in immersive virtual environments

Cognitive processes involved in initiating architectural ideas can be affected by technological incursion. Moreover, technological development of emergent and disruptive tools, such as immersive virtual reality, can further foster these processes. This research argues that the use of a virtual reality environment with HMD, haptic controls, and software created for artistic freehand drawing can generate the necessary phenomenological condition to facilitate the cognitive process of creating the first ideas of the architectural project; furthermore, the creation of such ideas would have the same characteristics of the traditional conception drawing made with pencil on paper. To verify this, experiments were carried out as part of a multiple case study methodology with 28 students in their first and last year of studies in a professionally accredited course of architecture and three instruments. The experimentation involved virtual creation of conceptual drawings of a small architectural project. The results showed insignificant differences in terms of the condition and characteristics of the cognitive creative process, and showed larger, but not significant, differences in terms of the drawing as a final product. While the process of virtual drawing presents some significant advantages that can make this technology an effective complement when creating the first architectural ideas, it cannot fully substitute the creative process.

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Introduction

The first ideas of an architectural project have traditionally been created through the close link between thought, sight, and the movement of the hands that leaving traces by means of a drawing instrument on a sheet of paper.[1] This special type of drawing is known as conception drawing and has remained unscathed by technological incursions, such as the evolution of digital design tools in visualising and developing architectural ideas. Such technological mediations are believed to alter the natural cognitive process, provoking a sensual and haptic disconnection between thought, imagination, the hand, and drawing, thus obstructing the immediacy of hand drawing in conceiving architecture.[2] However, given the development and evolution of emergent and disruptive technologies, such as Immersive Virtual Reality (IVR), technology has begun to be seen as a promising alternative that not only would not affect the creative process but could also overcome some of the limitations of the traditional method of conceiving and developing design with pencil and paper. The aim of this study is to explore how three-dimen-

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4.2. Artículo Científico 2

Título: The Architectural Conception Drawing in Immersive Virtual Environments

La publicación se centra en demostrar experimentalmente que la utilización de un entorno de realidad virtual con cascos montados sobre la cabeza, mandos hápticos y un software creado para el dibujo artístico a mano alzada generan las condiciones y características necesaria para que el proceso cognitivo de creación de las primeras ideas del proyecto arquitectónico no se altere y se dé adecuadamente.

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Figura 63
Portada del artículo 2: "The Architectural Conception Drawing in Immersive Virtual Environments"

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Article

The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator

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Abstract: The first ideas generation of the architectural project has traditionally been carried out through sketches. Even though in recent decades models have also gained importance, their use is still restricted due to the time required to make them and their difficulty of realization when it comes to complex forms. This research argues that the use of concept models mediated by two disruptive technologies such as Immersive Virtual Reality and 3D Printing can foster the cognitive process of the ideation and configuration of the first architectural ideas. To demonstrate the hypothesis, a pilot study was conducted with 32 architecture students; 17 students created models manually and 15 used IVR and 3DP. Two observation sheets were used to collect information. The results show that in the process of generating ideas, the group that used the two technologies developed three of the four characteristics of the cognitive process better, being an undecided and slow process, then fast and continuous, and finally perceptual for reinterpretation. Also, both technologies complemented each other and favored the development of an intense, tactile, and phenomenological experience. Finally, regarding the model as a product, a better result was found in 3D-printed models in terms of two of the three characteristics, three-dimensionality complexity and materiality. It is concluded that these two technologies ideally complement each other as mediating tools for three-dimensional architectural thinking, making it possible to use the conceptual models as the first generators of the architectural idea.

Keywords: architectural modeling; ideation; configuration; creativity; technologies; mock-up

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1. Introduction

The conception of the first architectural idea occurs in two successive phases, ideation and configuration. In the ideation phase, the first ideas are generated, and in the configuration phase, such ideas are concretized in architectural figurations [1]. This process has traditionally occurred through drawing. Models could also have been used as the first generators of the idea if their construction occurred with the same naturalness and ease with which sketches are made [2]. These special feature models are called concept models, and only in the last decades have they started to be used more frequently, becoming even a sign of professional or vanguard credentials of the most prestigious architectural firms [3]. However, when it concerns ideas involving complex forms, the construction of a model becomes a difficult task to execute, which may require the mastery of some special fabrication technique or simply require a lot of execution time. This research seeks to recognize the advantages and disadvantages of the use of a conceptual model mediated by Immersive Virtual Reality (IVR) and 3D Printing (3DP). For this purpose, an empirical study was designed with architecture students divided into two groups: one using traditional manual modeling techniques and the other using IVR and 3DP. Observation sheets were used to record the creative process and the characteristics of the final models to allow for a comprehensive comparative analysis between the two methodologies.

4.3. Artículo Científico 3

Título: The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator.

La publicación se centra en demostrar experimentalmente que el uso de maquetas conceptuales mediadas por dos tecnologías disruptivas como la Realidad Virtual Inmersiva y la Impresión 3D pueden favorecer el proceso cognitivo de la ideación y configuración de las primeras ideas arquitectónicas. Ambas tecnologías mejoran dicho proceso, haciéndolo más fluido, perceptual y táctil.

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Figura 64
Portada del artículo 3: "The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator".


CARACTERISTICAS
CUALIDADES
CONNOTACION
RECTANGULAR
OVALO
ANGULOSA
UNION
PROFUNDIDAD
TRANSPARENCIA
ELEGANCIA
ENVOLVENTE
DESAFIO
ELEGANCIA
INTRIGANTE
DINÁMICA
ORGÁNICA
AUDAZ
EXPERIENCIAL
IMPRESIONANTE
Zaha Hadid

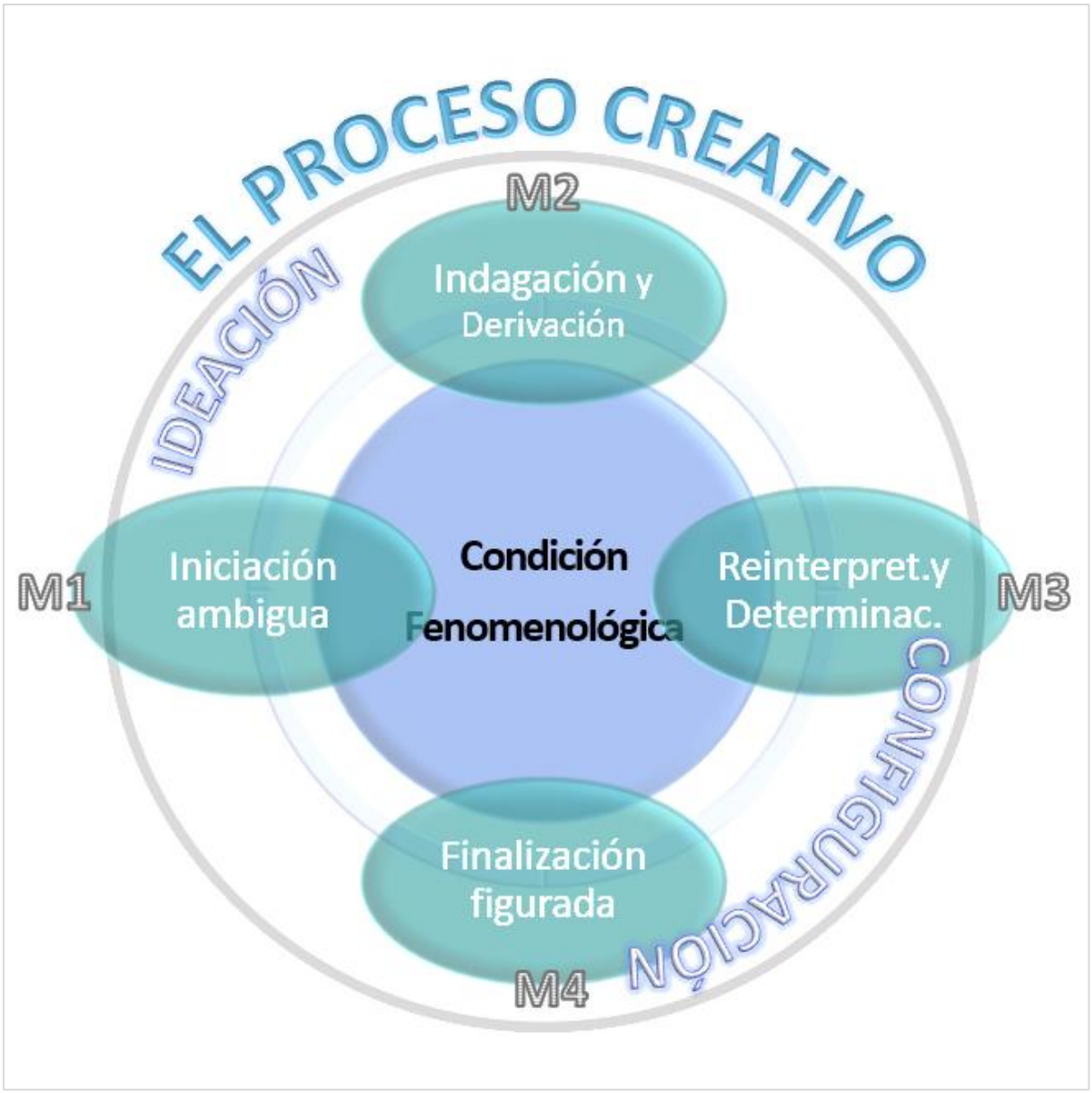
5. Discusión

5.1. El proceso creativo en la generación de la primera idea

El proceso creativo arquitectónico que permite materializar las primeras ideas de un proyecto se ha dado natural e históricamente a través del vínculo estrecho entre el pensamiento, la vista y el movimiento de las manos manejando un instrumento y dejando rastros sobre un soporte como el papel. El artículo 1 titulado "Characterization of conception drawing in architecture to face technological mediations" (H. C. Gomez-Tone & Raposo Grau, 2024a) ha permitido estudiar dicho proceso creativo a través del análisis de los dibujos de concepción de tres arquitectos reconocidos con los Premios Pritzker. Este estudio ha permitido abordar el primer objetivo e hipótesis de la tesis que se discute a continuación.

El proceso creativo que genera las primeras ideas de un proyecto arquitectónico involucra el pensamiento, la vista y la acción de las manos, ya sea a través del uso de un lápiz sobre un soporte plano o mediante la manipulación de materiales para crear formas tridimensionales. La intervención de las manos y el cuerpo es crucial, ya que permiten explorar e investigar de manera parcial e independiente, manifestando un conocimiento existencial esencial (Pallasmaa, 2017). Es fundamental considerar el cuerpo en su totalidad y utilizar todos los sentidos como punto de partida en el proceso creativo (Gomes et al., 2017). La percepción sensorial y el uso del cuerpo no solo son herramientas de exploración y percepción de los espacios, sino también de creación (Campo, 2009), funcionando como marco para comprender tanto el mundo exterior como el interior de uno mismo (Hale, 2016).

Figura 65
Dibujos a mano de los estudiantes del Taller de Diseño 1 como resultado de sus primeras ideas. Imagen fotografiada por el autor


EL PROCESO CREATIVO
IDEACIÓN
M2
Indagación y Derivación
M1
Iniciación ambigua
Condición Fenomenológica
Reinterpret.y Determinac.
M3
CONFIGURACIÓN
Finalización figurada
M4

La intervención del cuerpo y las manos es una condición insustituible en el proceso creativo arquitectónico, constituyéndose en una experiencia fenomenológica. Esta condición resalta el papel crucial del cuerpo humano no solo en la ejecución de acciones físicas, como dibujar o construir maquetas, sino también en la interpretación y concepción creativa. El proceso creativo en la arquitectura es una inmersión háptica, donde el cuerpo y las manos interactúan casi de manera autónoma, reflejando un conocimiento experiencial profundo, característico de la fenomenología (Pallasmaa, 2017). Este enfoque sostiene que la comprensión del espacio es multisensorial, abarcando más allá de lo visual o intelectual. Son necesarios e importantes todos los sentidos en el proceso creativo, pero fundamentalmente la interacción entre la percepción visual, la habilidad manual y el pensamiento cognitivo (Gomes et al., 2017). La creatividad, y por ende el proceso creativo arquitectónico, implica una colaboración multisensorial que convierte representaciones como dibujos o maquetas en una realidad imaginativa esencialmente fenomenológica y háptica.

Además de esta condición crucial para que se dé el proceso creativo arquitectónico se ha confirmado que dicho proceso tiene dos fases sucesivas denominadas ideación y configuración y que ambas son el núcleo de la creación de la arquitectura (Yanguas, 2019). El límite divisorio entre ambas fases es difícil de determinar, sin embargo, los momentos que suceden en ambas fases de este proceso creativo han sido más fáciles de establecer. Estos momentos no suceden de forma lineal, en lugar de seguir una secuencia rígida de pasos tienden a ser más cíclicos o en bucle e incluso desordenados y explosivos, ya que en ellos se aúnan componentes racionales y sensibles para materializar las primeras ideas (Figura 66).

Figura 66
Las dos fases, los cuatro momentos y la condición del proceso creativo arquitectónico. Imagen creada por el autor.



El primer momento ha sido denominado “iniciación ambigua”. Es el momento que da inicio al proceso creativo y es de mucha indecisión. Es ambiguo y abierto a todas las posibilidades y es cuando las ideas son todavía muy abstractas y no tienen una forma definida. Es un momento de investigación crítica más que de concreción específica (Manolopoulou, 2005). En este momento indeciso la gestualidad manual es imprescindible y esencialmente “propositiva” porque acompaña al pensamiento mediante gestos y manipulaciones indefinidos y tentativos. La intuición juega un papel crucial, guiando la mano del arquitecto de manera casi subconsciente. La incertidumbre inherente en este momento permite una exploración libre y sin restricciones, donde las ideas pueden evolucionar sin presiones ni expectativas definidas. Las primeras manifestaciones suelen ser ligeras y efímeras, reflejando un estado mental de constante cambio y ajuste. La indeterminación que define este momento genera signos que no se limitan a un único significante; son interpretables e incluso crípticos para el propio autor (Martín San Cristobal et al., 2022). Los dibujos o maquetas que se derivan de este momento son en su mayoría casi solo entendidos por el autor. No tienen forma definida, pero están vivos, son cambiantes y plantean más preguntas que respuestas.

Luego sucede el momento denominado “indagación y derivación”. Este segundo momento sucede cuando se destraba el inicio lento e indeciso. Sucede porque se busca dar respuestas a las primeras preguntas planteadas y es necesario mantener un flujo del pensamiento y del diseño ininterrumpido que es más eficaz que uno interrumpido o impedido (Herbert, 1988). Es un periodo de intensa actividad cognitiva donde la mente y las manos deben trabajar en armonía para capturar y materializar rápidamente las ideas emergentes.

Figura 67
Estudiantes del Taller de Diseño 1 iniciando sus procesos creativos. Imagen fotografiada por el autor



En este momento la parte cognitiva de la actividad de diseño suele ir más rápida que cualquier otra actividad, por este motivo se busca ejecutar con las manos a gran velocidad para captar los rápidos destellos de la estimulación mental (Smith, 2006). Esto permite tener un circuito de cognición corto que evita la distracción. Las herramientas y materiales deben estar al alcance y ser de fácil acceso, permitiendo cambios y ajustes rápidos. Los dibujos o maquetas que se derivan de este momento son pequeños, multiplicados y deben ser fáciles de realizar minimizando las convenciones innecesarias y reduciendo los detalles. Deben ser tan fáciles de hacer como tan fáciles de descartar (Herbert, 1988).

El tercer momento es la "reinterpretación y determinación". Este momento sucede cuando se han creado algunas ideas previamente. El proceso creativo se convierte en este momento en un acto perceptual que busca interpretar o descubrir a través del "ojo de la mente" nuevos significados en función de lo previamente ejecutado (Fish & Scrivener, 1990). En las imágenes y formas imprecisas y ambiguas se gesta la necesidad y el impulso de completarlas, de suprimir o agregar algo que no encaja (de Lapuerta, 1997). Estos descubrimientos perceptivos, intencionados o no, provocan que una idea creada se reafirme o se derive otra (Schon & Wiggins, 1992). Para que estos procesos sucedan es importante que los dibujos o maquetas previas estén a la mano y visibles (Herbert, 1988). La información que puede estar escondida en una idea debe percibirse, extraerse para alimentar nuevas órdenes motoras que impulsan el dibujar y modelar. Los dibujos o maquetas que se derivan de este momento están remarcados, repasados, tachados, parchados y reconstruidos. Son ideas que enfatizan o descartan los aspectos que la percepción permite reinterpretar para luego fijarlas como ideas prometedoras.

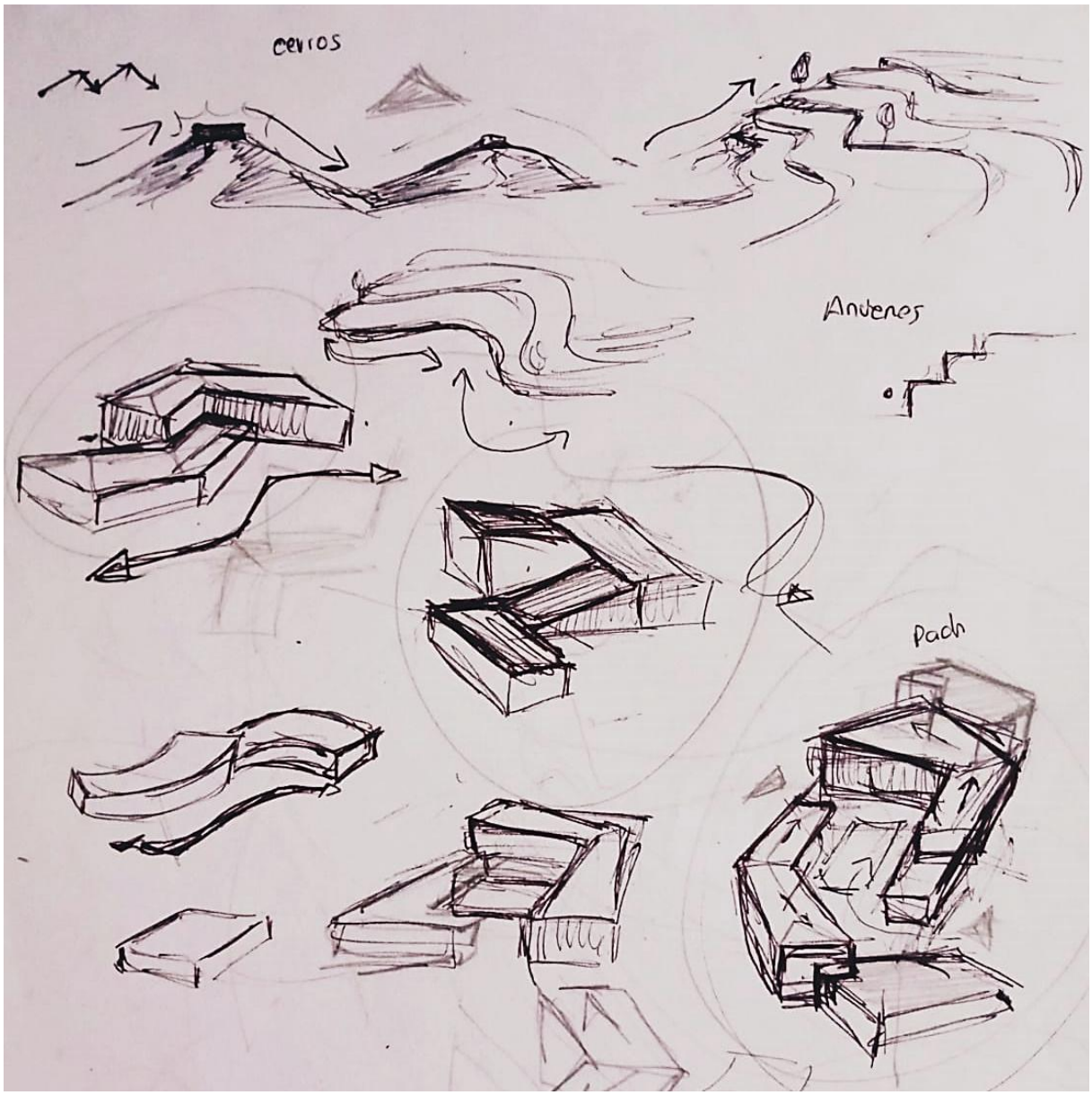
Figura 68
Estudiantes del Taller de Diseño 1 presentando sus primeros dibujo y maquetas conceptuales. Imagen fotografiada por el autor



Un ciclo corto del proceso creativo termina con el momento denominado la “finalización figurada”. El proceso de creación de las primeras ideas sucede muchas veces en tiempos diferentes y distantes. Para reactivar el proceso creativo en otro ciclo es necesario recordar las ideas trabajadas previamente. Para ello cada ciclo del proceso creativo se debe terminar con la o las ideas mejor configuradas que las del momento inicial ambiguo. Es más fácil recordar a partir de ideas configuradas que de ideas muy abstractas y sin forma. Esa idea finalizada debe permitir la auto confrontación, pero también la confrontación con otros apoyado con el discurso hablado (Herbert, 1988; Rey, 1985). Esto último es de mucha importancia cuando se está aprendiendo a crear ideas y se debe confrontarlas con los docentes arquitectos. Puesto que la idea arquitectónica es tridimensional los dibujos y maquetas que se derivan de este momento muestran comportamientos diferentes. Los dibujos terminan ejecutados bajo los criterios técnicos de las axonométricas, vistas diédricas o perspectivas cónicas, pero todos ellos realizados de manera muy esquemática o rudimentaria suficiente para expresar la tridimensionalidad de la idea. De otro lado, la maqueta al ser desde un principio tridimensional tiene una figuración clara y solo requiere ser terminada de forma que se le dé un estatus de pequeña escultura.

Estas fases y momentos no pretenden ser una sistematización absoluta del proceso creativo inicial. Lo que se pretende es determinar un proceso heurístico pedagógico que permita sostenerlo como proceso del pensamiento arquitectónico sin importar el medio en el que se desarrolle. Comprender las condiciones y características del proceso creativo es crucial para preservar los procesos cognitivos esenciales que facilitan la materialización del pensamiento creativo en las etapas tempranas del diseño arquitectónico.

Figura 69
Estudiantes del Taller de Diseño 1 configurando las primeras ideas. Imagen fotografiada por el autor


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5.2. El proceso creativo mediado por el dibujo de concepción

El dibujo de concepción es el tipo de dibujo fundamental usado por el arquitecto para iniciar el pensamiento arquitectónico, para contar y contarse a sí mismo, mediante un proceso personal, la argumentación de una nueva realidad (Raposo, 2014). El acto de dibujar es una herramienta esencial para transmitir teorías a través de la imagen (Vallespín Muniesa et al., 2019), para explorar ideas de manera fluida y dinámica, permitiendo un proceso de reflexión continua. La importancia de esta práctica se evidencia en cómo los dibujos a mano capturan el gesto y la intención del arquitecto, facilitando un tipo de pensamiento exploratorio que es esencial en las etapas iniciales del diseño (Smith, 2006; Llopis, 2018). Sin embargo, cuando el arquitecto está iniciando su formación universitaria puede no reconocer en el dibujo su importancia en el proceso creativo y encontrarle más desventajas en su bidimensionalidad y su dificultad de ejecución. El artículo 1 titulado “Characterization of conception drawing in architecture to face technological mediations” (H. C. Gomez-Tone & Raposo Grau, 2024a) ha permitido caracterizar esta forma de generar las primeras ideas arquitectónicas para preservarlas.

La condición fenomenológica: al ser el dibujo un mediador del proceso creativo, se identifica esta condición clave para que la ideación y configuración arquitectónica sea exitosa. El dibujar debe ser una experiencia fenomenológica o háptica, donde el pensamiento, la vista, el movimiento de las manos y el instrumento de dibujo estén íntimamente vinculados. Esta condición permite una conexión profunda entre el dibujante y el dibujo, haciendo que la experiencia de dibujar sea más importante que la comprensión del dibujo en sí.

Figura 70
Dibujos de concepción de la estudiante Valery Arias del Taller de Diseño 2
Imagen fotografiada por el autor


FUSIÓN
RESISTENCIA
Escogemos como
lugar de acción
esta pequeña
isla de roca
llevarla a
volumenes
orgánicos
con diferentes jerarquias y
elevaciones, destacando las
formas básicas.
Adoptar una forma del
paisaje

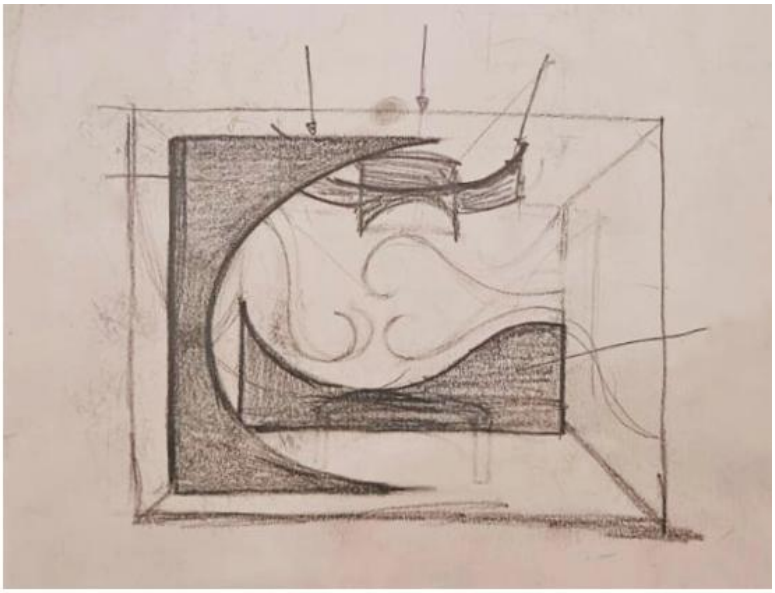
En arquitectura, el acto de dibujar es una colaboración íntima entre la mano y el pensamiento, donde el movimiento de la mano registra valores espaciales en las líneas dibujadas, creando una experiencia fenomenológica (Pallasmaa, 2017). Esta experiencia se caracteriza por la conexión háptica entre el dibujante y el dibujo, con cada trazo reflejando una intención perceptual. Los dibujos hápticos, que utilizan diversas técnicas y materiales, capturan esta experiencia a través de su textura y estilo, manifestando un conocimiento corporal profundo (Bizzotto, 2022). Además, se determinan los cuatro momentos y características fundamentales del dibujo de concepción.

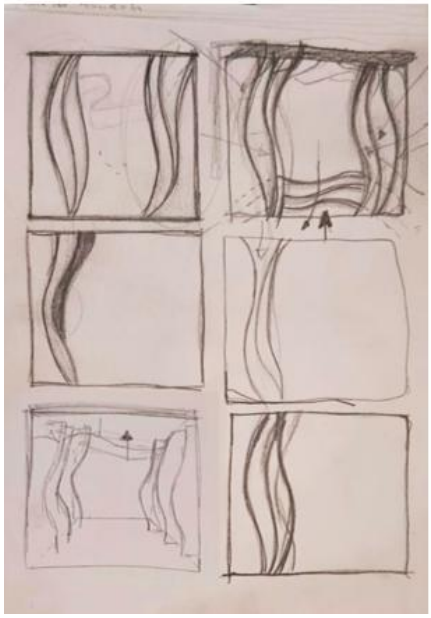
Momento 1: el dibujar indeciso y el dibujo sin forma. En las etapas iniciales del diseño arquitectónico, el proceso de dibujar es indeciso y exploratorio, lo que resulta en dibujos abstractos y poco determinados. Estos dibujos, a menudo entendidos solo por el autor, preservan alternativas y reflejan la naturaleza ambigua del pensamiento creativo. La ambigüedad deliberada de estos dibujos permite una exploración continua de ideas, manteniéndolas abiertas a reinterpretaciones futuras (Manolopoulou, 2005; de Lapuerta, 1997).

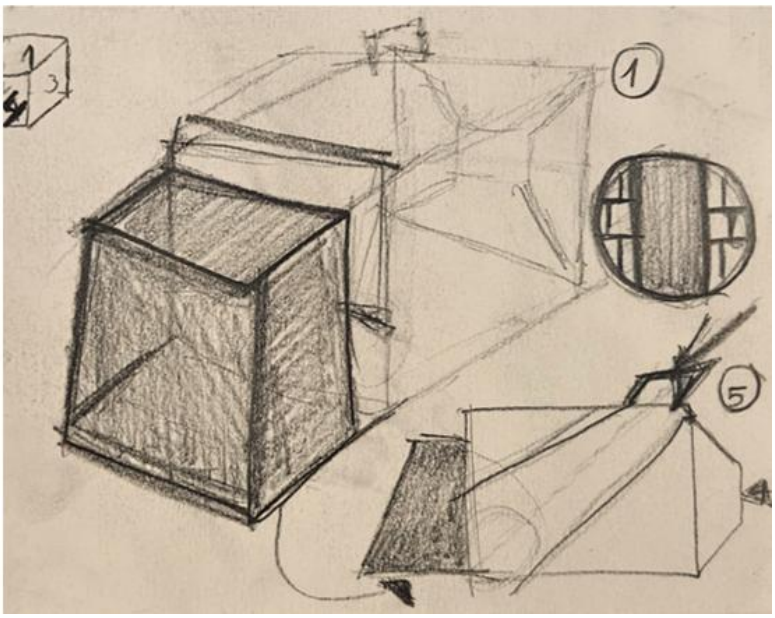
Momento 2: el dibujar continuo y el dibujo pequeño multiplicado. El acto de dibujar en el diseño arquitectónico es un proceso continuo que busca capturar rápidamente las ideas emergentes (Herbert, 1988). Dibujar de manera rápida y continua, especialmente en tamaños pequeños, facilita un flujo de pensamiento ininterrumpido y evita distracciones. Los dibujos pequeños y multiplicados son fáciles de realizar y descartar, permitiendo una rápida iteración y experimentación con diferentes ideas (Smith, 2006; de Lapuerta, 1997).

Figura 71
Dibujos de concepción del estudiante Carlos García del Taller de Diseño 2. Imagen fotografiada por el autor







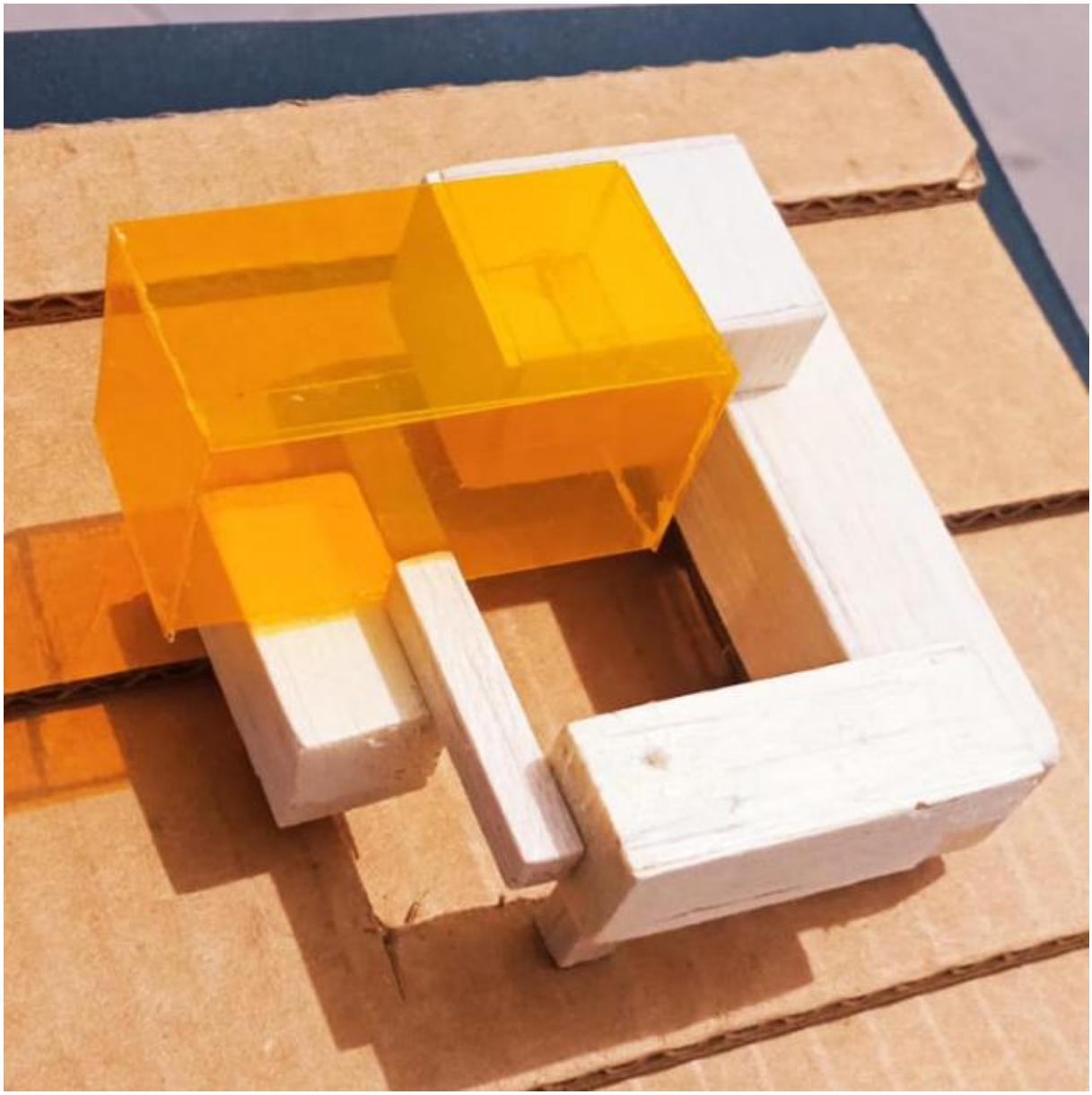

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Momento 3: el dibujar perceptual y el dibujo redibujado. A medida que avanza el proceso creativo, el acto de dibujar se convierte en un acto perceptual, donde el diseñador busca descubrir nuevos significados en los dibujos previamente realizados (Fish & Scrivener, 1990). Esto da lugar a dibujos redibujados, repasados, remarcados o con nuevos elementos agregados, reflejando la reinterpretación y refinamiento de las ideas (Schon & Wiggins, 1992). Estos dibujos, aunque desordenados para un observador externo, son valiosos para el creador por su capacidad de revelar nuevas perspectivas (Goldschmidt, 1991; Goldschmidt, 2003).

Momento 4: el dibujar para recordar y el dibujo convencional rudimentario. En el desarrollo del proceso creativo, los arquitectos revisan sus dibujos de concepción para recordar y reactivar el proceso creativo (de Lapuerta, 1997). Los dibujos convencionales, como vistas diédricas y axonométricas, aunque rudimentarios, facilitan este recuerdo y permiten una mejor confrontación de ideas. Estos dibujos, realizados de manera esquemática, son esenciales para fijar las ideas y prepararlas para su desarrollo posterior, manteniendo su función como una herramienta de referencia crucial en el proceso arquitectónico (Herbert, 1988; (Rey, 1985).

Conocer las condiciones y características del dibujo de concepción es fundamental para mantener un flujo creativo ininterrumpido y evitar que cualquier tecnología digital altere los procesos cognitivos esenciales en las fases iniciales del diseño arquitectónico. Estos conceptos deben ser claramente establecidos en la enseñanza del diseño arquitectónico, especialmente en los primeros años de estudio, para asegurar que cualquier mediación tecnológica no altere ni suprima tales procesos cognitivos fundamentales.

Figura 72
Dibujos de concepción de la estudiante Carolina Ramírez del Taller de Diseño 1. Imagen fotografiada por el autor



5.3. El proceso creativo mediado por la maqueta conceptual

Las maquetas conceptuales, también conocidas como maquetas de concepción o maquetas boceto, juegan un rol similar a los dibujos de concepción. Estas maquetas, permiten materializar ideas de manera tangible, tridimensional, exploratoria y preliminar. El artículo 3 titulado “The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator” ha permitido establecer que el proceso de creación de la idea arquitectónica a través de una maqueta comparte con algunas diferencias la misma condición fenomenológica y las cuatro características identificadas en el proceso de dibujar.

La Condición fenomenológica: la creación de maquetas ofrece una experiencia directa y significativa que permite entender la tridimensionalidad de las ideas representadas. Este proceso creativo implica una relación háptica entre el objeto y el sujeto, donde las manos complementan la vista y otros sentidos, aportando autenticidad a la creación material. El desarrollo de la creatividad desde el ámbito experiencial se logra mucho más con la creación manual de maquetas que con los dibujos (Carazo, 2011).

Momento 1: el modelado indeciso y lento. El proceso de ideación inicial es lento y lleno de dudas, basado en la indecisión. La creación de formas tridimensionales en esta fase busca eliminar lo superfluo y preservar la ambigüedad deliberada, permitiendo la exploración y la conservación de múltiples alternativas.

Figura 73
Maqueta conceptual creada por la estudiante Valery Arias en el Taller de Diseño 2. Imagen fotografiada por el autor

Momento 2: el modelado rápido y continuo. Superada la fase inicial de indecisión, el proceso cognitivo se abre a muchas posibilidades.



Las maquetas pequeñas permiten una rápida modelación, capturando rápidamente las ideas emergentes. Estas maquetas, aunque elementales y experimentales, facilitan cambios y reformas rápidas.

Momento 3: el modelado perceptual. El modelado se convierte en un acto perceptual que busca interpretar nuevos significados basados en lo creado previamente. La percepción de la materia y las interacciones con la luz y la sombra solo se logran mediante la observación y el tacto de la maqueta. Esto permite analizar características físicas y connotaciones contextuales de los materiales utilizados.

Momento 4: el modelado confrontacional. Al finalizar un ciclo del proceso cognitivo, es necesario configurar la idea para discutirla o retomarla más adelante. La maqueta, al representar la tridimensionalidad desde el primer volumen creado, logra una auto confrontación permanente, permitiendo la crítica y la discusión necesarias para continuar el proceso creativo.

Las maquetas conceptuales como producto tienen tres características principales, dos de las cuales las diferencian del dibujo. Primero, las maquetas permiten una comprensión tridimensional directa de las formas y el espacio, ofreciendo una percepción dinámica de sus vistas. Esto facilita un proceso creativo más intenso que el que se logra únicamente con el dibujo. Segundo, la materialidad de las maquetas proporciona una experiencia táctil y sensorial, permitiendo explorar relaciones entre formas, vacíos, iluminación y sombras de una manera que el dibujo solo puede capturar de forma limitada. Y finalmente al igual que el dibujo, las maquetas conceptuales se enfocan en representar las ideas fundamentales del diseño, eliminando detalles innecesarios y favoreciendo la comunicación clara de la visión conceptual.

Figura 74
Maqueta conceptual creada por estudiantes en el Taller de Diseño 1. Imagen fotografiada por el autor

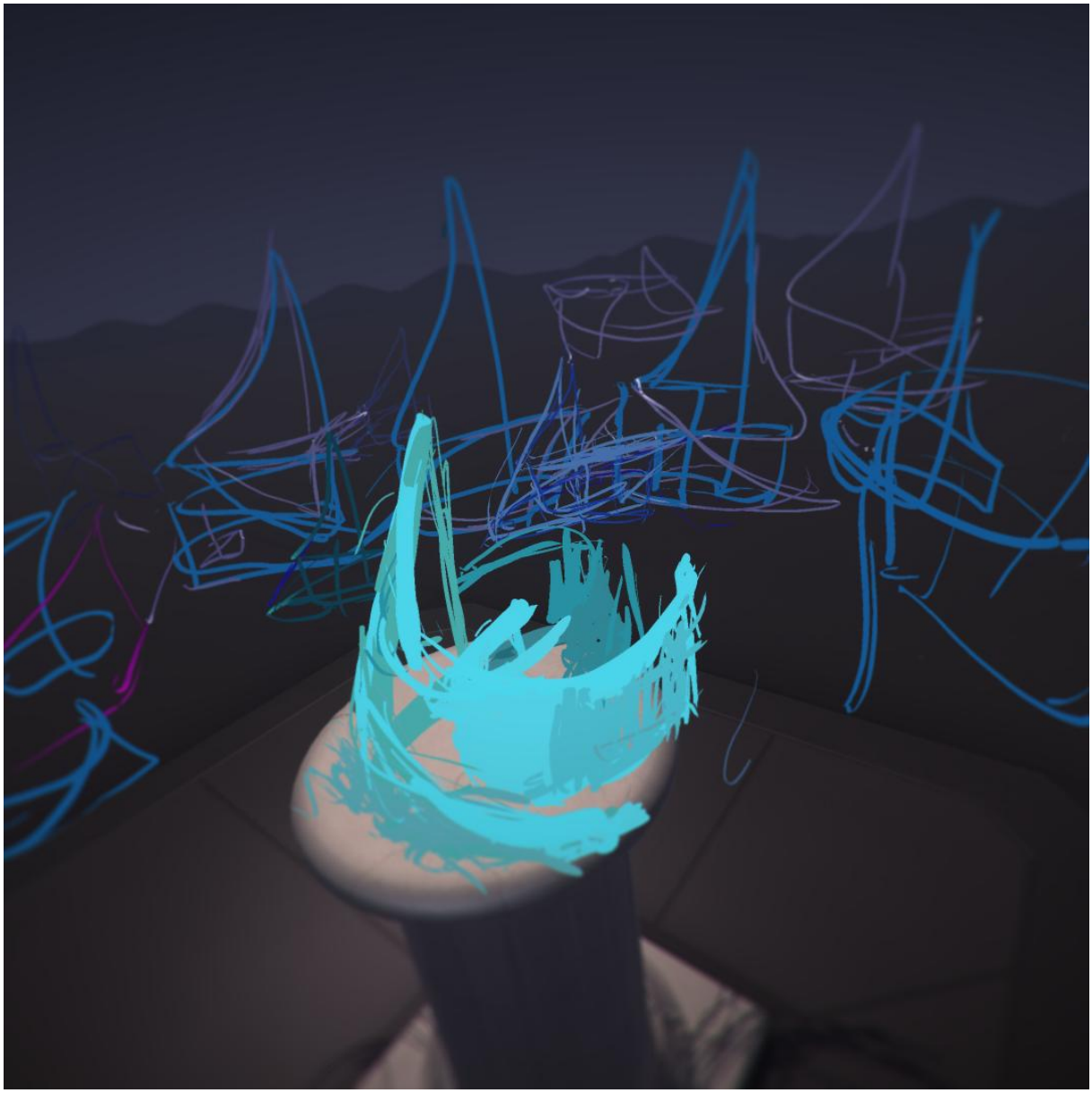


5.4. El proceso creativo mediado por la RVI

Desde las primeras incursiones de las tecnologías en el campo de la arquitectura se argumenta que la integración de estos medios digitales y computacionales interrumpen la conexión sensual y háptica entre la imaginación y el proceso manual creativo, impactando negativamente las etapas iniciales de la concepción arquitectónica (Pallasmaa, 2017) y provocando una crisis en la experiencia sensible de la creación arquitectónica (Bizzotto, 2022). El artículo 2 titulado "The Architectural Conception Drawing in Immersive Virtual Environments" (H. C. Gomez-Tone & Raposo Grau, 2024b) ha experimentado el proceso creativo de una primera idea arquitectónica dentro de un entorno virtual. Este estudio ha permitido abordar el segundo objetivo e hipótesis.

La integración de la RVI con HMD y controles hápticos, junto con las funcionalidades del software Tilt Brush creado para el dibujo artístico a mano alzada, ofrecen un entorno digital ideal para la generación de las primeras ideas de un proyecto arquitectónico. Este entorno ha demostrado facilitar y enriquecer los procesos cognitivos necesarios para la generación rápida y eficiente de las ideas iniciales mediante el dibujo de concepción virtual tridimensional. La experimentación reveló varias ventajas al usar esta tecnología en comparación con el método tradicional de lápiz y papel cuando se trata de materializar las primeras ideas de un proyecto arquitectónico. Los resultados indican que la condición y los cuatro momentos del proceso creativo se preservan con algunas diferencias y en muchos casos se potencian en el entorno virtual como se detalla a continuación.

Figura 75
Resultados de los estudiantes en la experimentación dibujando ideas en RVI. Imagen disponible en https://sketchfab.com/johnbel/collections/ivr-b8be915b5d6949dbafec60a2c7a3cac3



La Condición fenomenológica: La experimentación ha demostrado que crear dibujos de concepción en el entorno virtual no solo es una experiencia entretenida (Haj-Bolouri, 2023), sino que la sensación de presencia y agencia ha generado aspectos relacionales y emocionales que intensifican la experiencia (Cantone, 2023). Estas características del entorno virtual permiten aprovechar las capacidades cognitivas a través de la experiencia corporal y el movimiento, logrando una experiencia fenomenológica clave para el éxito del proceso creativo de las primeras ideas arquitectónicas. Sin embargo, sigue siendo un desafío de la RVI la falta de un vínculo táctil directo entre las manos del diseñador y el objeto creado.

Momento 1: En el inicio del proceso, cuando el acto creativo es indeciso porque es un acto de investigación crítico (Manolopoulou, 2005) y no se sabe ni las formas ni los trazos ideales, se ha dado la primera ventaja. En este momento el entorno virtual ha permitido una creación fácil, rápida y variada de diversos tipos de trazos y formas (Kharvari & Kaiser, 2022). Incluso la indagación de trazos fantasiosos no sugeridos como los trazos con movimiento, con luminiscencia o destellos han ayudado a expresar mejor este momento inicial de investigación y proposición.

Momento 2: El segundo momento caracterizado por su fluidez y continuidad, ha sido notablemente potenciado por la RVI. Al sumergir a los participantes en un entorno virtual libre de distracciones y con un espacio prácticamente ilimitado, la RVI ha maximizado su capacidad de concentración y ha estimulado un flujo ininterrumpido de ideas. Mientras unos participantes aprovecharon la capacidad de realizar múltiples pruebas, otros se enfocaron más en detalles específicos, En ambos casos, la fluidez y flexibilidad inherentes a la RVI han sido fundamentales para potenciar la creatividad y la innovación.

Figura 76
Indagaciones previas y dibujo conceptual final creados por estudiante con Tilt Brush en entorno de RVI. Imagen fotografiada por el autor

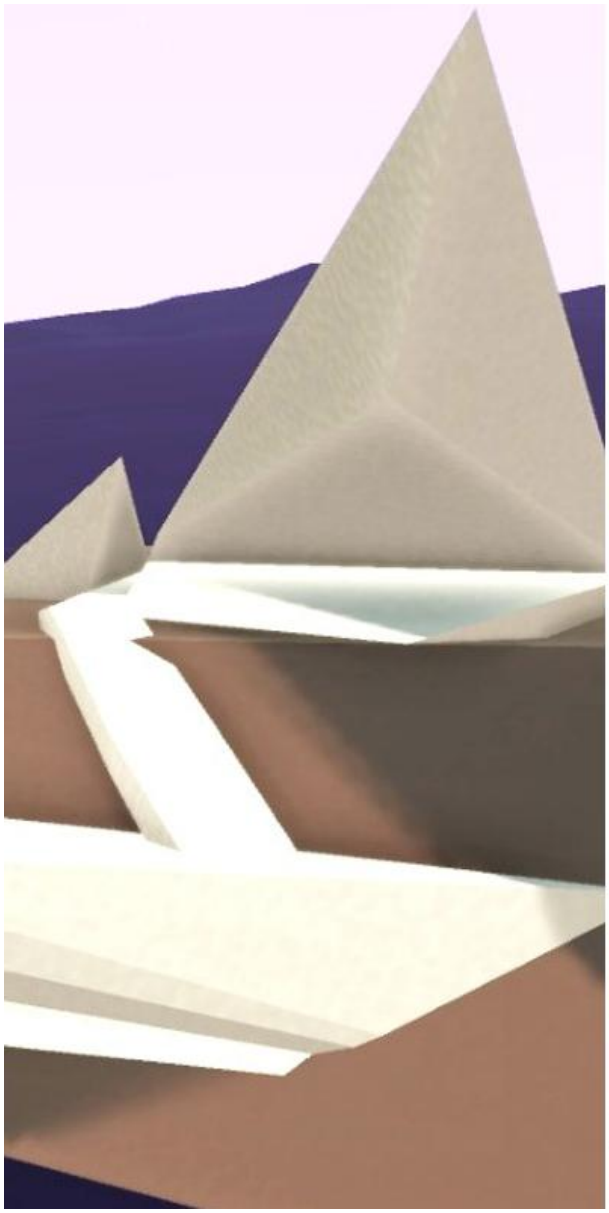


Momento 3: Durante el tercer momento de reinterpretación, la capacidad de percibir y analizar dibujos tridimensionales de diferentes maneras —incluyendo la posibilidad de escalar los objetos y observarlos desde el interior como si fueran estructuras reales— ha ofrecido una ventaja significativa imposible de ser superada por dibujo o maquetas. Esta capacidad no solo mejora la comprensión espacial, sino que también enriquece la experiencia sensorial.

Momento 4: En el momento final, la RVI ofreció la ventaja de trabajar directamente en tres dimensiones, lo que eliminó la necesidad de usar representaciones bidimensionales convencionales. Esto fue particularmente beneficioso para estudiantes con menos habilidades en el dibujo. Además, la posibilidad de exportar estos modelos para ser visualizados fuera de los entornos de RVI facilita el acceso continuo a las ideas para futuras revisiones.

Sin embargo, la implementación de RVI enfrenta desafíos, incluyendo la disponibilidad y accesibilidad del hardware y software necesarios, y las limitaciones de tiempo debido a los posibles efectos negativos de un uso prolongado, como la "ciberenfermedad" (mareos, náuseas, etc.). De otro lado, la falta de competencias técnicas entre los docentes para manejar y enseñar estas tecnologías es una barrera significativa. Mientras que la RVI introduce un medio diferente al tradicional lápiz y papel, ofrece nuevas capacidades que pueden enriquecer el proceso de ideación arquitectónica, sugiriendo una evolución en la forma en que se conciben y desarrollan las primeras ideas en arquitectura. Las diferencias encontradas en el uso de esta tecnología no representan una distorsión del proceso creativo, sino una adaptación a nuevas herramientas que pueden complementar y, en algunos casos, superar las limitaciones de los métodos tradicionales.

Figura 77
Dibujo conceptual creado por estudiante con Tilt Brush en entorno de RVI. Imagen fotografiada por el autor



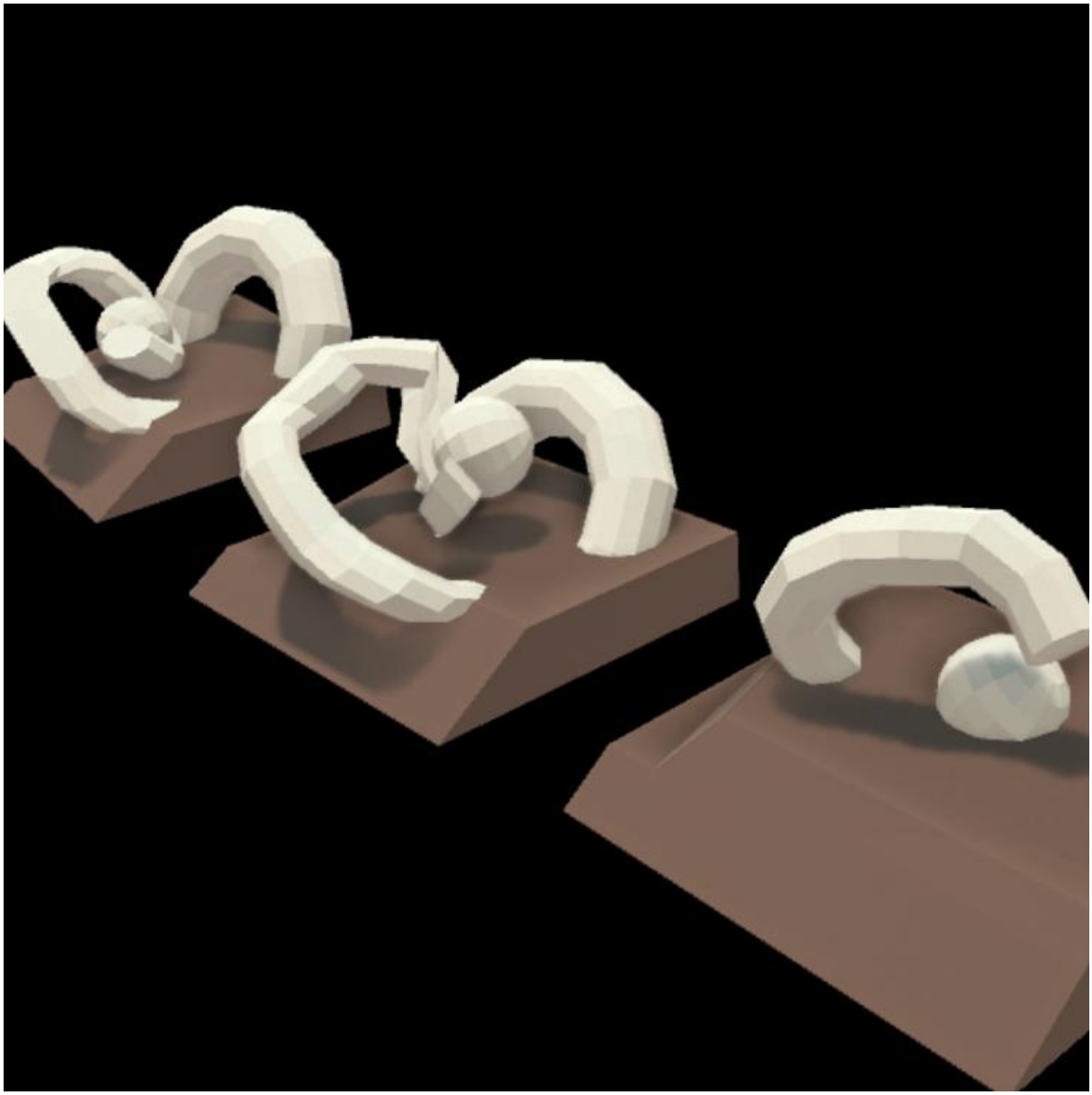


5.5. El proceso creativo mediado por la I3D [+RVI]

Ante el argumento de la desconexión sensual y háptica entre la imaginación y el proceso creativo debido a la incursión de los medios digitales o virtuales en el proceso de creación de las primeras ideas arquitectónicas, surge la I3D. Esta tecnología actúa como un puente entre lo digital y lo físico, revolucionando la creación arquitectónica al materializar diseños en objetos tangibles con rapidez y precisión (Baghaei & Safari, 2018). La I3D permite producir modelos físicos complejos, facilitando la experimentación con formas, materiales y configuraciones espaciales que serían laboriosas o costosas de explorar mediante métodos tradicionales como las maquetas conceptuales.

Aunque la I3D tiene un gran potencial como mediadora entre el pensamiento creativo y la materialización tangible, no puede actuar por sí sola. La idea debe generarse primero en entornos digitales o virtuales y luego materializarse mediante la I3D. El artículo *"The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator"* (H. Gomez-Tone & Raposo Grau, 2024) aborda los objetivos y las hipótesis relacionadas con este tema, explorando cómo la RVI complementada con la I3D impacta en la ideación y configuración de las primeras ideas arquitectónicas a través de maquetas conceptuales. Los resultados de la experimentación que utilizó la RVI con el software Google Blocks e impresoras 3D con filamentos para la generación de las primeras ideas a través de maquetas conceptuales muestran que esta metodología es especialmente eficaz propiciando tanto la condición fenomenológica como los momentos del proceso cognitivo.

Figura 78
Maqueta conceptual creada por estudiante con Google Blocks y luego impresa en 3D. Imagen fotografiada por el autor

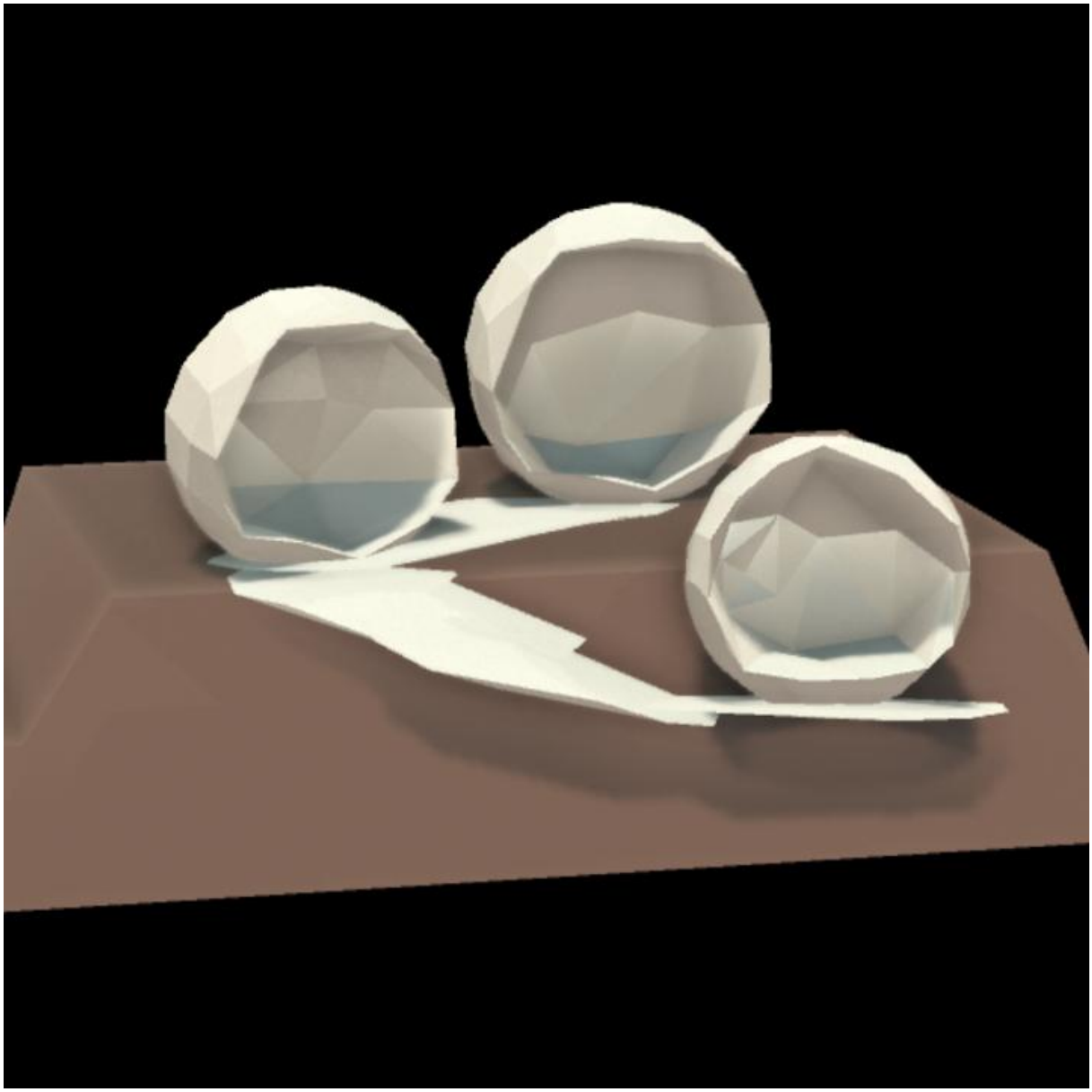


La condición fenomenológica: la experimentación comparativa ha revelado que la RVI ha intensificado significativamente la conexión entre el proceso creativo y la experiencia corporal en comparación con la creación manual tradicional construyendo maquetas. El entorno virtual ha generado experiencias significativas que desafían la idea convencional de que la percepción corporal está limitada al cuerpo físico. Aunque la observación se centró en el movimiento corporal, también se observaron gesticulaciones y expresiones de asombro, reflexión, juzgamiento y satisfacción, lo que indica una experiencia fenomenológica intensa. La incorporación de la I3D complementó y completó esta experiencia, permitiendo a los estudiantes manipular físicamente las piezas impresas y realizar ajustes finales, lo que generó un vínculo háptico directo entre el cuerpo y el objeto creado supliendo esa deficiencia atribuida a la RVI.

Momento 1: **El modelado indeciso y lento**. En el entorno virtual, la exploración e investigación de formas ha sido muy fácil. La creación y modificación de trazos libres y formas geométricas siguiendo el simple movimiento de las manos ha sido instantáneo y sin mayores esfuerzos. Por lo tanto, esta indagación y exploración ha sido muy productiva comparada con la realizada manualmente debido a que la construcción de maquetas tradicionales demandaba más tiempo por la misma producción manual y más aún cuando de formas complejas se trataba.

Momento 2: El modelado rápido y continuo. Una vez indagada las formas, el entorno virtual ha favorecido la fácil copia, derivación y modificación de alternativas comparado con las pocas alternativas generadas manualmente. En estos dos primeros momentos se reconoce una gran diferencia entre crear un objeto manualmente y crearlo con mandos hápticos en el entorno virtual.

Figura 79
Indagaciones previas creadas por estudiante con Google Blocks en entorno de RVI. Imagen fotografiada por el autor



Esta diferencia en facilidad y rapidez se hace manifiesta más cuando de formas complejas se trata demostrado que la RVI como medio de diseño evita la restricción del pensamiento que influya en la manera de explorar y dar respuesta a los problemas (Heath, 1984; Porter & Hanna, 2006).

Momento 3: el modelado perceptual. El tercer momento se centra en la percepción de los objetos previamente creados. La RVI permite escalar los objetos y percibirlos como elementos pequeños escultóricos o como grandes edificaciones que se pueden recorrer, lo que facilita una comprensión espacial más rica y una reflexión instantánea. Esta capacidad es única en comparación con las maquetas manuales en las que la retroalimentación en base a la observación y percepción de lo previamente creado fue menos intensa.

Momento 4: el modelado confrontacional. La configuración final que permite la auto confrontación y la confrontación con otros apoyado con el discurso hablado (Herbert, 1988): Rey, 1985) no ha mostrado diferencias significativas en ambos grupos. Sin embargo, en este momento final la agudización de la percepción visual y táctil para hacer reajustes finales de posición, relación y materialidad ha sido superior en el grupo que imprimió las maquetas. El vínculo háptico directo y la experiencia fenomenológica se ha completado en el grupo experimental cuando se ha manipulado la maqueta impresa.

En resumen, el proceso creativo que utiliza ambas tecnologías para la ideación y configuración de una primera idea arquitectónica ha permitido complementar la mayor deficiencia de la RVI que es la falta del vínculo háptico directo con los objetos creados y su materialidad.

Figura 80
Maqueta conceptual creada por estudiante con Google Blocks y lista para su impresión en 3D. Imagen fotografiada por el autor



Sin embargo, el uso de la RVI muestra, además de las debilidades explicadas en la experimentación anterior, algunas otras desventajas. La carencia del software Google Blocks para crear materiales y texturas (solo se puede asignar colores) a diferencia de otros softwares como el Tilt Brush, limita las ideas conceptuales sustentadas en la materialidad. La predeterminación de formas, aunque de fácil modificación y transformación, restringe la creación de formas libres como se lograba con el Tilt Brush.

En cuanto a la impresión tridimensional existen las siguientes debilidades. La dificultad de ser modificadas y transformadas las maquetas una vez impresas comparadas con las maquetas construidas con cartulina, cartón o palitos de madera le restan su condición de bocetos descartables y modificables para llegar luego de muchas iteraciones a una respuesta final. Una segunda debilidad es la elección del material para realizar la maqueta. La imposibilidad de usar algún material diferente al de los filamentos de impresión limita la elección de materiales que por sus connotaciones o significados pueden expresar mejor una idea conceptual (Carazo & Galván, 2014). El tiempo que demanda la impresión 3D es un tiempo que se le resta al diseñador para la reflexión de lo que se está construyendo (Millán-Millán, 2019) pero a su vez es un tiempo útil para la reflexión en otros aspectos del diseño.

Finalmente, una debilidad de ambas es que, si bien facilitan la creación de formas complejas que antes eran difíciles o imposibles de realizar, plantea un desafío importante: el riesgo de que el proceso se centre en la facilidad de crear complejidad en lugar de la relevancia y el sentido arquitectónico de estas formas. Para evitar esto la metodología educativa debe enfatizar que la facilidad de creación no justifica la falta de contenido.

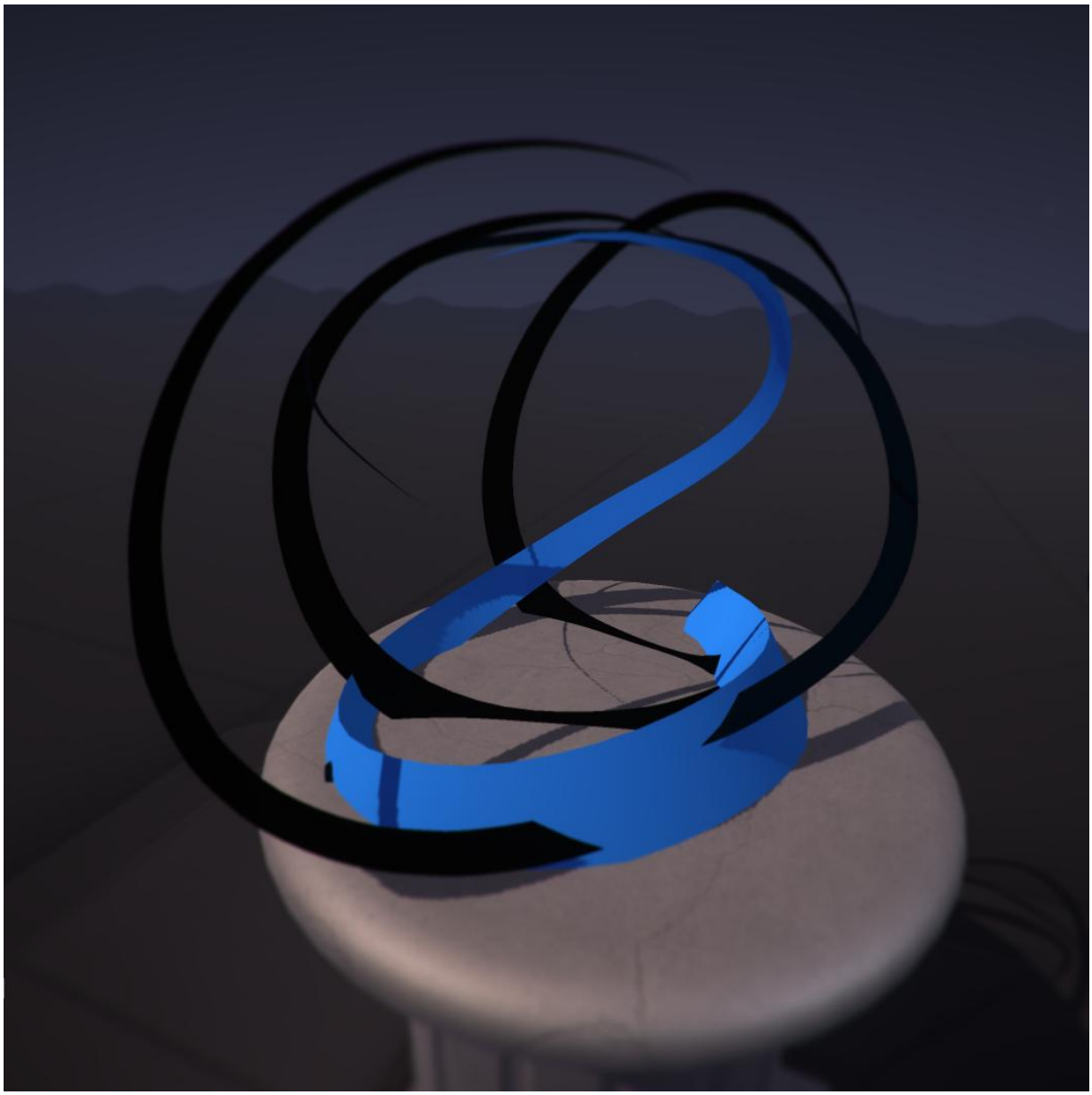
Figura 81
Maquetas conceptuales impresas en 3D luego de su creación en entorno virtual. Imagen fotografiada por el autor


CHIHUAHUA
SALIDA

5.6. Implicancias

Las implicaciones de esta investigación son significativas tanto para la educación arquitectónica como para la práctica profesional, ya que la validación de herramientas digitales como la realidad virtual inmersiva (RVI) y la impresión 3D (I3D) demuestra su eficacia en el proceso de ideación y configuración arquitectónica. Sin embargo, el uso de estas tecnologías no significa el abandono de las herramientas analógicas, sino la búsqueda de procesos de hibridación gráfica que permitan seleccionar las herramientas más adecuadas en cada momento del proceso creativo (Raposo Grau & Paredes Maldonado, 2023). La combinación equilibrada de técnicas tradicionales, como el dibujo manual y la maqueta física, con herramientas digitales posibilita la exploración y materialización de ideas complejas en un entorno contemporáneo, enriqueciendo la comprensión espacial y fomentando la innovación y la creatividad en el diseño arquitectónico. Para los estudiantes, su integración en los currículos académicos proporciona habilidades avanzadas que fortalecen su conexión con el proceso creativo; mientras que, para los profesionales, la adopción de estas tecnologías mejora la eficiencia y calidad de los proyectos, sin renunciar a los fundamentos del pensamiento arquitectónico tradicional.

Figura 82
Primera incursión de las tecnologías en Taller de Diseño 2 en colaboración con el Tecnológico de Monterrey, sede Chihuahua. Imagen fotografiada por el autor



6. Conclusiones

La investigación desarrollada en esta tesis doctoral ha permitido analizar en profundidad cómo las tecnologías digitales, en particular la Realidad Virtual Inmersiva y la Impresión 3D, pueden integrarse en el proceso creativo arquitectónico, generando nuevas oportunidades y desafíos. Los resultados obtenidos destacan el impacto positivo de estas tecnologías en diferentes momentos del proceso creativo, especialmente en las etapas iniciales de ideación y configuración de las ideas iniciales. A continuación, las principales conclusiones:

El proceso creativo arquitectónico: El análisis de los dibujos de concepción de Tadao Ando, Zaha Hadid y Frank Gehry y la revisión del estado del arte permitió caracterizar el proceso creativo en las fases iniciales mediado por el dibujo. Se ha identificado dos fases sucesivas en el proceso creativo que son el núcleo de la creación de la arquitectura: ideación y configuración. Dentro de estas fases, se han identificado cuatro momentos distintos. Cada momento da cuenta del proceso cognitivo y por ello tiene características únicas que contribuyen a la evolución de las ideas desde el primer momento hasta la finalización de la idea configurada. Caracterizar el proceso creativo no solo ha confirmado la importancia de los trazos manuales en la exploración y formalización de ideas arquitectónicas, sino que además ha permitido analizar procesos creativos mediados por otras herramientas. Esta tesis refuerza la hipótesis de que el dibujo a mano alzada es un medio eficaz para preservar y transmitir la riqueza del pensamiento arquitectónico en sus etapas más tempranas.

El proceso creativo mediado por la RVI: La experimentación con RVI evidenció que la RVI proporciona una experiencia inmersiva intensa y vívida, que amplía la percepción espacial y facilita la exploración de ideas en un entorno tridimensional.

Figura 83
Idea creada con Tilt Brush en RVI por estudiante. Imagen fotografiada por el autor



Dibujar en el espacio o crear objetos tridimensionales a través del movimiento corporal enriquece el proceso cognitivo. La interacción virtual con los objetos 3D facilita una conexión háptica con el modelo creado, enriqueciendo la comprensión espacial y sensorial de la idea. Estas cualidades en ningún momento afectan la creación de ideas abstractas o simbólicas y de otro lado ofrecen tiempos reducidos comparados con los procesos manuales. Además, la capacidad de escalar, entrar y recorrer las ideas tridimensionales ofrece una perspectiva única que enriquece la experiencia creativa. Esto valida la hipótesis de que la RVI potencia la creación arquitectónica al enriquecer la interacción cognitiva y háptica en las fases iniciales.

El proceso creativo mediado por la I3D: La integración de I3D en la ideación y configuración arquitectónica demostró que esta tecnología actúa como un puente entre el mundo digital o virtual y el físico, permitiendo la materialización rápida y precisa de casi cualquier idea. Esa cualidad la convierte en un complemento perfecto de la RVI que permite suplir la desventaja más importante de la creación de ideas en entornos virtuales, la inmaterialidad. El vínculo háptico con el objeto físico impreso se vuelve tangible y directo desde que se toman las piezas con la mano para ensamblar la maqueta, disponerla sobre el terreno de cartón y hacer el estudio para la toma de fotografías bajo la luz solar. Esto complementa la experiencia fenomenológica esencial para generar ideas arquitectónicas. De otro lado, la facilidad de materialización física de ideas tridimensionales complejas con bajos tiempos y costos le confieren una ventaja importante sobre la creación manual de ideas. Todo esto confirma la hipótesis de que esta tecnología supera las limitaciones de los métodos tradicionales, aportando nuevas posibilidades para la exploración creativa y la materialización de conceptos arquitectónicos.

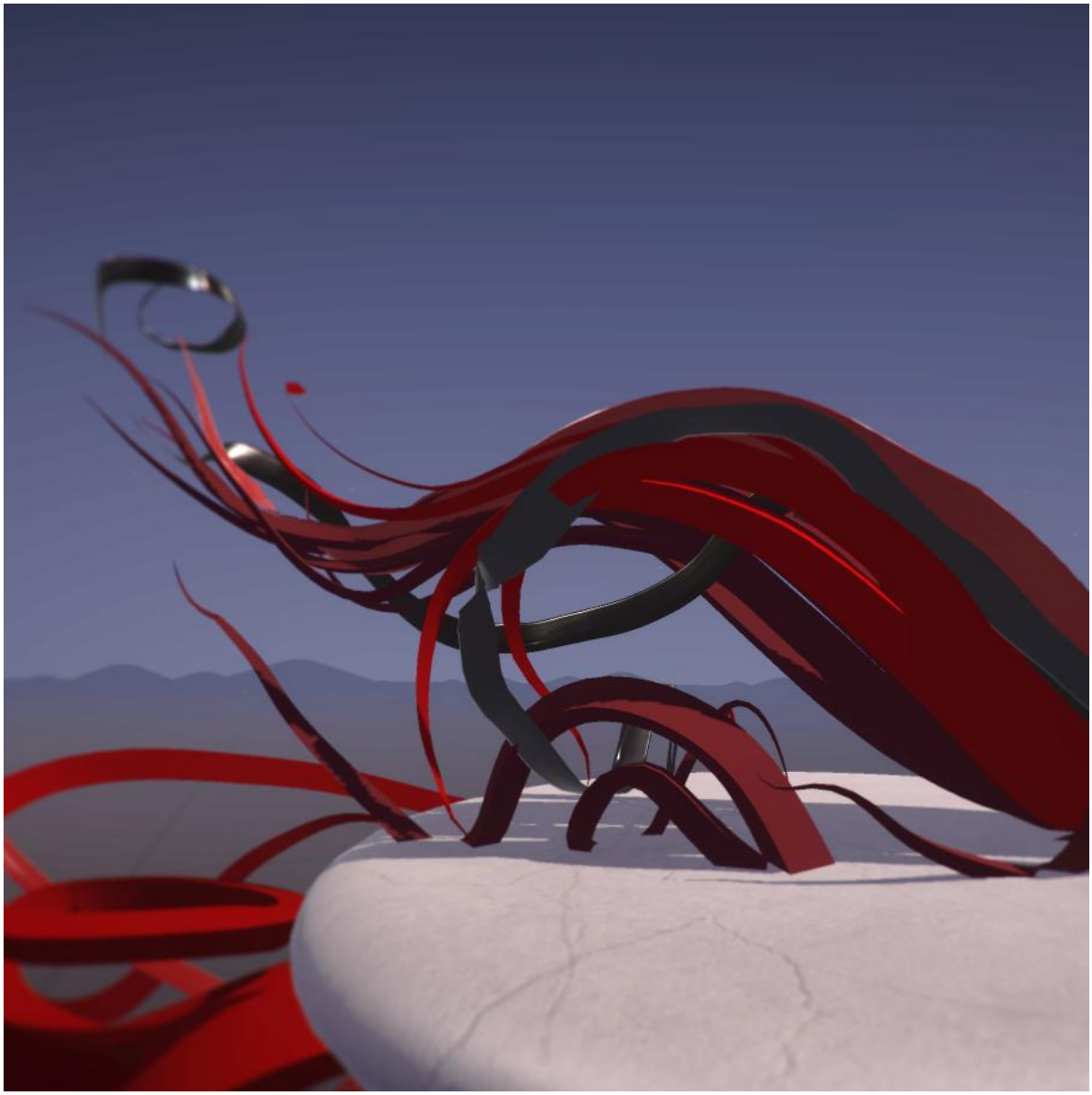
Figura 84
La misma idea anterior impresa en 3D. Imagen fotografiada por el autor



Incorporación de las Tecnologías Digitales: El uso de herramientas digitales no implica el abandono de los métodos analógicos, sino la búsqueda de procesos híbridos que permitan seleccionar las herramientas más adecuadas en cada etapa del proceso creativo. La combinación de ambas estrategias asegura una transición fluida hacia procesos más innovadores, respetando los fundamentos del pensamiento creativo arquitectónico. Su integración gradual en el ámbito académico y profesional asegura que se mantenga una base sólida en la generación de ideas arquitectónicas mediadas por el dibujo manual y la maqueta física, mientras se explora estas herramientas digitales para enriquecer la capacidad creativa y analítica.

Futuras investigaciones: Se recomienda continuar con la exploración y experimentación con otras herramientas de RVI con diferentes interfaces que permitan la creación tanto de trazos a mano alzada como de volúmenes y que puedan ser fácilmente exportados a formatos compatibles con la I3D. Se recomienda investigar la integración efectiva de estas tecnologías en el currículo del diseño arquitectónico universitario, explorando cómo pueden ser utilizadas para mejorar la formación creativa de los estudiantes y prepararlos para las demandas del mercado profesional contemporáneo. Pero también se propone como futuras investigaciones explorar el impacto a largo plazo de estas tecnologías en el proceso de diseño arquitectónico y su aplicación en contextos profesionales. Finalmente, dada la incursión de la inteligencia artificial (IA) como una herramienta poderosa en el diseño arquitectónico, capaz de generar imágenes y modelos tridimensionales de manera autónoma, la combinación de RVI, I3D e IA podría revolucionar aún más el campo, permitiendo a los arquitectos explorar un abanico más amplio de ideas y soluciones

Figura 85
Una idea bien cabe en la palma de una mano. Imagen fotografiada por el autor



innovadoras. Futuros estudios deberían investigar cómo la integración de estas tecnologías puede optimizar el proceso de diseño arquitectónico y sus aplicaciones prácticas en la educación y el campo profesional.

Reflexión Final: A partir de los hallazgos de esta tesis, se proyecta un futuro prometedor para la integración de la Realidad Virtual Inmersiva (RVI) y la Impresión 3D (I3D) en la enseñanza y práctica de la arquitectura. Estas tecnologías, utilizadas estratégicamente, ofrecen una oportunidad única para trascender los límites tradicionales del diseño arquitectónico, permitiendo a los estudiantes interactuar de manera inmersiva con espacios proyectados, potenciando su comprensión de la escala y la espacialidad desde perspectivas innovadoras. En el ámbito profesional, facilitan un diseño más intuitivo y preciso, donde el arquitecto no solo imagina, sino que experimenta y percibe los espacios en las fases iniciales del proceso. La tesis demuestra que RVI y I3D pueden actuar como mediadores perfectos del pensamiento creativo en las primeras ideas arquitectónicas, superando las limitaciones de las tecnologías previas e incorporando ventajas que los medios tradicionales, como el dibujo y la maqueta, no pueden ofrecer. Sin embargo, su implementación debe estar respaldada por una base sólida en métodos analógicos tradicionales, logrando un equilibrio entre innovación y tradición. Esta complementariedad transforma el diseño en un ciclo completo que fomenta la creatividad, la sensibilidad y el rigor técnico, posicionando a las nuevas generaciones de arquitectos para enfrentar los desafíos contemporáneos con herramientas que redefinen su práctica.

Figura 86
Dibujo conceptual creado por un estudiante de arquitectura usando la RVI. Imagen fotografiada por el autor

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En cada uno de los cinco documentos que se anexan a continuación el autor de esta tesis, es el investigador principal (IP), primer autor y autor de correspondencia con filiación a la Universidad Politécnica de Madrid (UPM).

A. Artículo Científico 1: Characterization of conception drawing in architecture to face technological mediations.

B. Artículo Científico 2: The Architectural Conception Drawing in Immersive Virtual Environments. The Journal of Architecture.

C. Artículo Científico 3: The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator. Buildings, 14(8), Article 8.

D. Ponencia en Congreso Internacional 1: Virtual Reality and 3D Printing in Architectural Design. Case study: the Conceptual Model

E. Ponencia en Congreso Internacional 2: Immersive Virtual Reality applied to Architectural Conception Drawing: novices vs. Experts

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RESEARCH ARTICLE

Characterization of conception drawing in architecture to face technological mediations

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Abstract The conception drawing in architecture is that allows to initiate the architectural thinking, visualizing, and discovering the first ideas. This drawing has traditionally been given as an act of linking and collaboration between thought, sight, and the movement of the hands with a tool. Identifying and recognizing its characteristics will make it possible to deal with any mediation of information technologies. To establish such characteristics, three case studies were carried out. An analysis was made of the conception drawings and interviews by the Pritzker Prize laureates: Ando, Hadid and Gehry. One condition and four characteristics have been determined: drawing is a phenomenological action that produces haptic drawings; it is an undecided process that originates unformed drawings; it is a fast action that results in small and multiplied drawings; it is a perceptual act that generates redrawn and remarked drawings; and finally, it is an action that seeks to remember to resume the creative process at another moment, which produces rudimentary conventional drawings. Knowing these before any technological mediation will be an important pedagogical contribution that will allow future architects not to alter the cognitive processes that generate the first ideas in the initial moments of the architectural project.
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1. Introduction

The drawing that initiates the creative process of ideation in architecture is known as the conception drawing. This specific drawing has been traditionally developed in close relationship with the thought, sight, and movement of hands with a tool leaving traces on a sheet of paper. The importance of these first drawings or sketches lies in the fact that they allow to initiate architectural thinking, managing to visualize and discover the first architectural ideas (Smith, 2006). For more than four decades, the incursion of digital technology in the field of architectural design and drawing has generated the controversy of the possible disappearance of traditional architectural drawing, particularly this specific drawing, due to the incorporation of digital media in the process of the architectural project. This research argues that establishing and highlighting the fundamental characteristics and conditions of the act of drawing and conception drawing as mediators of architectural visual thinking will not allow any digitalisation or virtualization of graphic techniques alter or suppress the procedural habits so closely linked to the initial phases of the construction of thought (Llopis, 2018), and particularly the creativity in the early stages of architectural design. The purpose of this research is to achieve pedagogical benefits in the teaching of architectural design in schools of architecture, especially in the first years when it is necessary to establish the process of architectural thinking.

2. Literature review

2.1. The conception of the architectural idea

According to Alberto Campo (2009), "what we, architects, do is to build ideas [...], ideas that have been conceived in our mind, with logic [...] and that at the origin of our thought, there must be the possibility of building those ideas". The materialization of the ideas referred to has been linked, in the field of architectural production, to drawings and the act of drawing itself. Oscar Niemeyer explains it, this way, in the interview for The Guardian "when I have looked at the site for a building, considered its budget and thought of how it might be built [...] the drawings come very quickly. I pick up my pen. It flows. A building appears. There it is. There is nothing more to say" (Glancey, 2007). The conception of architectural ideas has historically developed through drawings and sketches. Its mandatory use has not been proved, but almost all architects have used it and apparently will continue to do so given its importance (de Lapuerta, 1997). In design in general, and in architectural design in particular, this drawing that happens in the initial phase of the creative process has not always been very well differentiated from the rest of drawings used by the architects throughout the process. Due to its importance and the need to clearly differentiate it, its origin, definition, and technological mediation will be established.

2.2. The emergence and importance of the conception drawing

The importance of drawing as a thinking tool goes back to ancient times, but the exact moment of its systematic use is uncertain. There is little evidence of drawings showing the design process before the Renaissance and the easy access to paper. According to Brothers' research (Brothers, 2008), the figure of Michelangelo Buonarroti is the precursor of the use of drawing as a means of conception and invention of architecture in a systematized way. The encountered drawings of the sculptor, painter and architect are very different from those of his contemporaries and predecessors and reveal the gradual formation of ideas through the process of drawing slowly and steadily and at different times repeated. The author argues that he transformed the purpose and appearance of architectural drawings by demonstrating that architecture could be a vehicle for the imagination just like painting or sculpture. The distinctive character of his drawings reflects his conception of architecture as a system based not only on imitation and variation of classical models, but also on invention. Although at his time this way of use these drawing was not very widespread, it survived the western tradition from that time until the twentieth century.

This specific type of drawing gained importance again in the mid-twentieth century, when important efforts were made to conceptualize the actions of architectural production and to singularize the procedures for research related to architectural design and to give real form to constructive intuition (Vagnetti, 1958). Later, in the sixties and seventies, that drawing should no longer be seen only as a preliminary means of the work to be built, but as a form of execution as well. The drawing, as a product, and the act of drawing and executing such drawing would not be seen as separate facts but as a single way of proceeding because when drawing, harmony and precision are achieved at the same time. The theoretical understanding of drawing culminated when it was understood that tracing was a conceptual abstraction and at the same time it was accepted that it was generated by a physical gesture that expressed the vitality of the hand and the energy put into the very act of the trace (Segui, 1986).

At the beginning of the eighties, academic discussions on the importance of drawing in architectural design assumed that this was due to its speculative and tentative character and its intimate relationship with architectural creation (Graves, 1979). Thus, the new term "the conception drawing" arose. This term was first coined in 1985 by Boudon and Deshayes (1985) who proposed to differentiate it from the presentation or communication drawing, the rhetorical drawing, and the drawing of finished works. This drawing was the one that allowed to conceive ideas, a drawing of trial and of the preliminary works. The conception drawing was, then, understood as the drawing to conceive, test, adjust and correct, therefore, a reality-generating drawing, a conjectural and formative drawing of the architectural object that still exists only virtually

(Segui, 1986). No sooner has the theoretical argumentation been made and its importance established, in the mid-eighties, the introduction of technology established the controversy of whether the new and different understanding of drawing mediated by technology could cause a new and different understanding of architecture, that is, whether the means and methods could affect the design thinking or not (Meisenheimer, 1987). By the end of that decade, there were already academic debates regarding the death of drawing as it had been known since the Renaissance (Mitchell, 1989). Nevertheless, the conception drawing had dodged such debates, but not the rest of the architectural drawings that originated before or after the creation of the idea.

2.3. The technological mediation in architecture

The advance of digital technology in this century is changing the ontology of architectural research. Ten years ago, the special issue of CAADRIA alerted to the findings of the impact of digital technology in various fields of architecture as well as in the design process. Technologies reported were design cognition, parametric and generative design, BIM, interactive and responsive architecture, virtual or mixed reality, digital fabrication, and the smart home (Chang and Huang, 2014). It has also been reported that creativity can be enhanced by CAD tools, after experience, sketches and models (Baghaei and Safari, 2018) or by immersive virtual reality (Obeid and Demirkan, 2020). Precisely the latter disruptive technology is the one that can be further introduced into creative design processes. Immersive virtual reality has been reported as the most widely used technology in architecture education, mainly in the subject of architectural design as a tool for simulation, but also for visualization and exploration (Ummihusna and Zairul, 2021). As an increasingly easily accessible tool, it is being used as a stand-alone learning tool but not associated with any learning theory. Without a clear ontology, such a technology can be misguided in the pursuit of futuristic thinking in architectural design teaching and learning (Nisha, 2019). Recent investigations are already probing the introduction of this technology in the early stages of architectural ideation, not exactly in conception drawing, but where architectural thinking and creativity are still determinant (Gomez-Tone et al., 2022). From a technical perspective, virtual reality continues to be introduced more and more effectively into architectural design and other aspects of architecture (Tastan and Tong, 2023).

The vertiginous advance of technology now also threatens the cognitive process of architectural ideation through the conception drawing. Contemporary architecture has changed in close relation to the changes that technology has introduced in graphic methodology. There are currently two opposing positions: one argues that there is a loss of humanism and creativity due fundamentally to the mediatization of technology and the other one that technology increases the architect's abilities to create, manipulate, manage and materialize with wide freedom and without the limitations of two-dimensional manual drawing (Llopis, 2018). In both positions, it seems that computer technologies will end up dominating the entire architectural creative process.

2.4. Definition of act of drawing and conception drawing in architecture

Over the years, the study of this type of drawing has deserved the attention of various fields of knowledge that have incorporated contributions enriching the understanding of the conception drawing in architecture. The following contributions are of particular interest.

The definition that incorporates the phenomenological condition of the drawing process is explained by Pallasmaa.

> Each act of sketching or drawing produces three different sets of images: the drawing that appears on the paper, the visual image recorded in my brain memory, and a muscular memory of the act of drawing itself [...]. The initial mental image may emerge as a visual entity, but it may also be a tactile, muscular, or bodily impression, or a shapeless sensation that the hand specifies in a series of lines projecting a shape or structure. One cannot know whether the image arose earlier in the mind and was then recorded by the hand, or whether the hand produced the image in an independent way, or whether it arose because of a fluid collaboration between the hand and the mental space of the drawer (Pallasmaa, 2017).

A cognitive definition of sketches in the design process proposed by Goldschmidt is as follows.

> The sketch is an extension of mental imagery, and therefore has the freedom of imagery to retrieve previously stored images and to manipulate them rapidly. At the same time, because it leaves a hard trace of these images on a visible surface, and because this is an additive process, the sketching surface soon contains unforeseen configurations and relationships among the graphic components. The resultant displays are open to new interpretations, and if one consciously looks for them, they can be generated with relative ease using additional input from the designer's memory structures (Goldschmidt, 2003).

Finally, one more definition of the sketches at the initial moments of the design from the architectural point of view is tested by Solana and Gutierrez.

> Sketches are graphic expressions that convey an abundant concentrated conceptual meaning [...] They are not normally heavily graphically codified, but their symbolic codification is high [...]. They are drawings of open language and little intention of synthesis [...] that support extensive ideas, lines of action or confirmatory trials [...] and are set as guidelines for subsequent actions, not capable of completely shaping a definitive solution, despite being having the scope to generate discourses the development of which culminates in specific architectonic steps (Solana and Gutierrez, 2015).

Out of the mentioned conceptual approaches, the definition proposed for the conception drawing as process is the

Table 1 Categories to be analyzed in each set of conception drawings.

Categories		Description
a	Traces and instruments	The type of strokes and instruments used, the thickness of the strokes, the use of colors and effects such as filling, flattening, blurring, etc., will be observed. It will also be sought to recognize the physical support on which they were made.
b	Shape and abstraction	The shape of the first drawings created will be observed, trying to determine their ambiguity, their determination, their regularity, their order and their level of abstraction or figuration.
c	Size and quantity	The size of the drawing will be observed, and the speed of its execution will be determined by observing its complexity and level of detail. The number of drawings made in the same format will also be observed.
d	Transformation and derivation	The corrections, additions or transformations of the drawings will be observed, this will be determined by the lines remarked, reworked, crossed out. In addition, the derivation of a drawing in other variants will be determined.
e	Architectural expression	The form of the last drawings created will be observed, trying to recognize the rudimentary use of representation techniques such as plans, sections, axonometric or conic perspectives.

action of linking and collaborating the whole body, but fundamentally the hands and sight, with the mind so that with the help of an instrument and a support, the ideas that come from the architect's creative thinking become visible. This action carried out in the initial moments of the creation of the architectural idea also seeks to reinterpret, add, and modify those first visible ideas using the data stored in the architect's memory.

The proposed definition for the architectural conception drawing as product is the set of strokes made quickly and intuitively that make ideas visible and tangible in the process of thinking and formalisation of architecture. These initially ambiguous strokes do not represent the final answer to the problem to be solved, but rather the guidelines that have the capacity in themselves to generate a dialogue with the architect, once again provoking the action of drawing.

In this way it is understood that drawing as a process and drawing as a product are intimately linked and both are generated cyclically until those visible strokes show a satisfactory evolution of the idea to the point that it becomes the seed of the first architectural ideas.

3. Methodology

After reviewing the literature and understanding that within the process of obtaining the architectural project, the act of drawing must be understood as the process and the drawing as the solution tested or achieved. That drawing is the operational support and the comprehensive and productive tool that functions as the fundamental matrix of figural thinking and as the most appropriate medium for architectural simulation. That to validate the act of drawing is to value the different moments of the creative discourse, while to validate the drawing as product is to validate the final result of the process as a closed and coded solution (Raposo, 2014).

To determine the characteristics of the conception drawing, the case study methodology was adopted. The multiple case study has considered the conception drawings of three Pritzker Prize-winning architects, an award that recognizes talent, vision and commitment embodied in contemporary architectural works of significance to humanity. This ensures a proper design process. The three contemporary architects chosen, have experienced technological change in the development of the architectural project that could determine some influence of this one. It has also been decisive that the authors themselves have published books with their conception drawings so that all of them are available to give an account of the creative sequence or at least a significant part of it. This was done to avoid falling into the analysis of isolated drawings that could be interpreted in different ways. Drawings of small-scale, non-urban architectural projects were selected. The architects chosen were Tadao Ando, Zaha Hadid and Frank Gehry, the latter two well known for their designs supported using digital technologies. In addition, interviews, or statements by the three architects regarding their creative processes were used.

To analyse the set of conception drawings, five categories were identified for examination which can be seen in Table 1.

4. Results

4.1. Tadao Ando's conception drawings for the Kara-za Theatre, Japan, 1985

This project presented in 13 pages of the book "Tadao Ando 0, Process and Idea" by the architect himself (Ando, 2010),

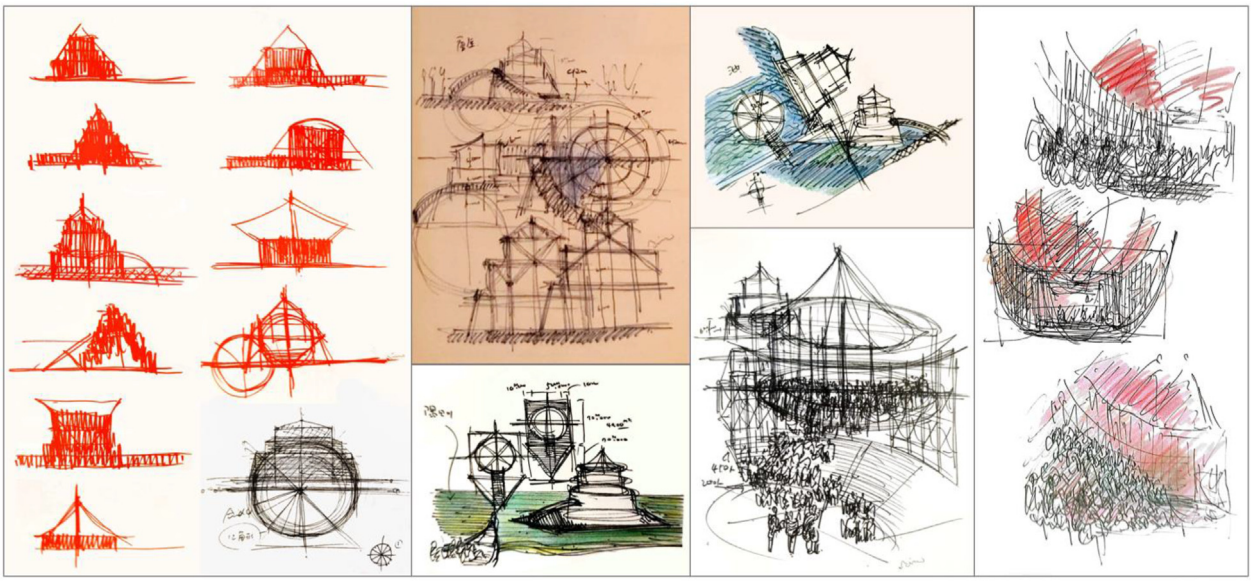


Fig. 1 Set of conception drawings by Tadao Ando for the Kara-za Theatre, Japan, 1985 (Ando, 2010).

shows not only drawings of construction details and photographs, but also conception drawings shown in Fig. 1.

a. Ando uses graphite pencils in preference, but also relies on the use of coloured pencils to highlight ideas. The strokes with the red marker are thick and not very precise but express by contrast a lot of strength and intensity. The rest of the drawings made with black graphite have areas filled in with coloured pencils to express the water or the colour of the covering. Ando expresses his conviction for hand drawing and its haptic emotional link: "they (computer drawings) cannot communicate the nature of an idea as well as a sketch drawn in earnest by a human being nor are they as trustworthy as drawings made with true feeling by hand" (Ando, 2010).
b. The form of the red drawings initially presented are abstractions of the archaic forms of the fortresses of the period of the Japanese war phases that was also his source of inspiration. "To give shape to vague images I make sketches, models and hard-line drawings" (Ando, 2010). The level of abstraction is not so deep so that the drawings can be understood. Only a couple of his drawings are more complex to understand because of intentional overlaps.
c. It is difficult to determine the size of the drawings, however, thanks to some texts and thickness of the strokes it can be determined that they are small drawings. Due to the little detail and complexity, it is determined that they were created quickly. There are ten small drawings traced with red marker that show a significant number of attempts to find the ideal form. "Through repeated studies, I clarify the intentions of the architectural space that is come into being" (Ando, 2010).
d. The sketches made with black graphite show many reworked and remarked lines. There are also overlapping drawings and flattened or filled areas to give more value or hierarchy to certain parts of the drawing. The drawings in red show, in addition to repetition, the derivation and transformation of an idea with the intention of finding the ideal shape.
e. Most of the drawings in this case have been frontal or plan views, both very schematic and rudimentary. Axonometric views and very simple conic perspectives were also used, with few details, but with the use of some colour. All this is enough for an external observer to understand the three-dimensionality and spatiality of the initial idea.

Ando emphasizes in an interview that his hands and mind work together and that the hands are extensions of the processes of thought and creativity. In the initial process he never used digital technologies, but states: "the computer offers another kind of creativity. You cannot ignore the creativity that computer technology can bring. But you need to be able to move between those two different worlds" (Ivy, 2002).

4.2. Zaha Hadid's conception drawings for the Vitra Fire Station, Germany, 1990—1994

This project presented by the same architect on 17 double pages in the volume "Process: sketches and drawings" of the book "Zaha Hadid, complete Works" (Schumacher and Fontana-Giusti, 2004) shows without text the conception drawings seen in Fig. 2.

a. Analysing the strokes, it was found that all of them were made with black ink on paper. In general, and in these drawings in particular, Hadid found in black ink and absorbent paper a means to achieve thin and thick strokes, discontinuous and continuous ones, blurring and filling in certain areas seeking to give more value and contrast. Her strokes are intended to be small research experiments.
b. The form of the drawings is very abstract. She herself declares: "then nobody understands them (her

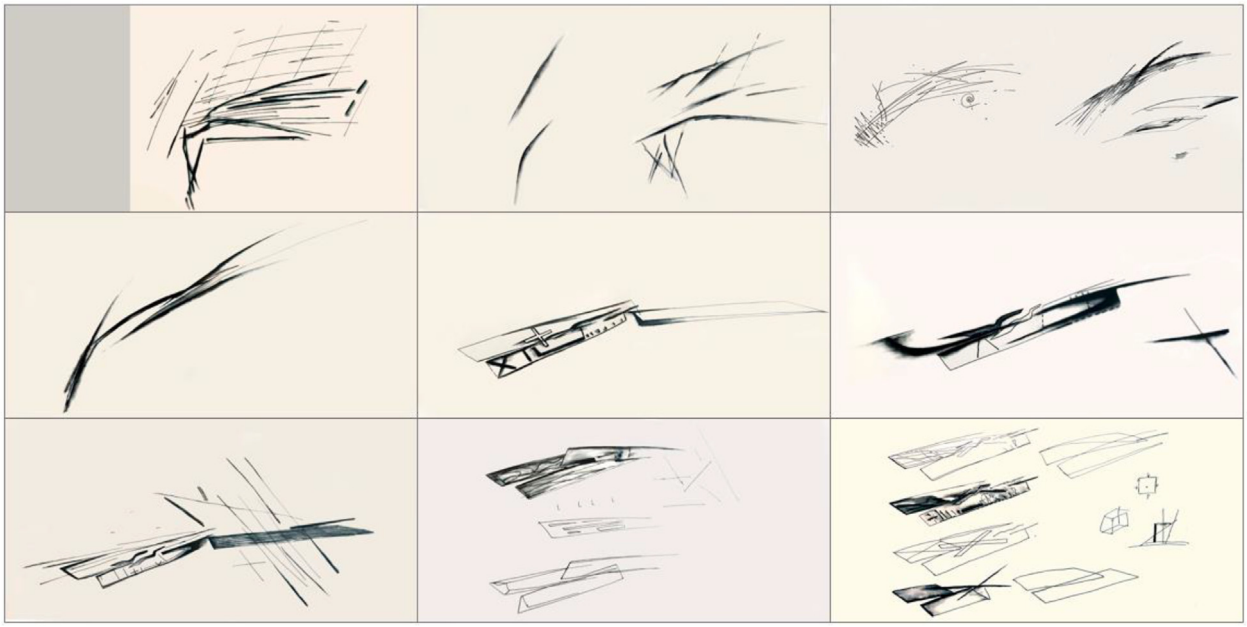


Fig. 2 Set of conception drawings by Zaha Hadid for Vitra Fire Station, Germany, 1994 (Schumacher and Fontana-Giusti, 2004).

drawings), and I have to tell people every day how I want the drawing" (Levene and Márquez, 2004). In some cases, there are two lines, one straight and one curved, both blurred. In others, those lines are multiplied, crossed, combined with other thinner lines. The neatness of each drawing gives it the status of a small finished abstract work.

c. As for the size she says: "I start by sketching them (the drawings) in very small size" (Levene and Márquez, 2004). It can also be recognized from the form of the strokes, their precision and detail that these drawings were not made very quickly. In the first four drawings there is a repetition of forms, and in the last five there is also a multiplicity of drawings.
d. In Hadid's drawings, it is very difficult to find strokes marked out, crossed out or reworked. What can be appreciated is that the strokes have been explored through repetitions, interlacing, superimpositions, and derivations. In the last five drawings there is also a repetition of forms derived from the previous ones. She states "drawing is a lens that reveals aspects that would otherwise be imperceptible [...] it serves, not to crystallize a form definitively, but to demonstrate the possibilities of what it can become" (McQuaid, 2002). It is in the last drawing that a search for forms through the derivation of the first attempts can be appreciated. "If I take any drawing, I could tell how it was worked out from beginning to end and what drawings were derived from it. Each of these drawings transpires many other things" (Levene and Márquez, 1992).
e. The last drawings show all the ideas in plan. Only in the last drawing there is a small glimpse of the use of isometric and section view. It should be clarified that in the same sequence of drawings Hadid shows 8 drawings made with CAD, but all of them with a high level of abstraction of plans and sections. Those drawings have not been analyzed.

Regarding the use of technology in the initial ideation, she states: "I have never used it (the computer) as a design tool. The only use I find for it is to be able to check in three dimensions, and in a quick way, if something works. But I still believe that the hand is much more agile than the computer"(Levene and Márquez, 1992).

4.3. Frank Gehry's conception drawings for the DZ Bank Building, Germany, 1995—2001

In this project the same author shows eight sheets with his conception drawings, as well as photographs and some texts in the book "Gehry Draws" (Bredekamp, 2004). These drawings can be seen in Fig. 3.

a. The strokes were made with black ink on paper. Almost all the strokes are of the same thickness. There is no intention to give more value to some strokes with thickness, type of line or blurred. What can be appreciated is the intention of making a continuous stroke from beginning to end without raising the hand so as not to interrupt the stroke. Although no special strokes suggesting a strong haptic connection can be seen in his drawings, he states: "the most important contribution I have made to the practice of architecture I would say is to achieve coordination between the hand and the eye [...] I am able to transform a sketch into a model and a building" (Zaera, 1995).
b. The form of the drawings, rather than a high level of abstraction, show characteristics of unfinished or not very neat drawings. The author himself recognizes that his drawings look like "doodles". "The drawings are not important to me; they are just stepping stones. They don't even look like buildings! But thanks to them I know what is the next step to take" (Zaera, 1995).
c. The drawings are small in size. Several drawings are made on one sheet, only in two cases there is one

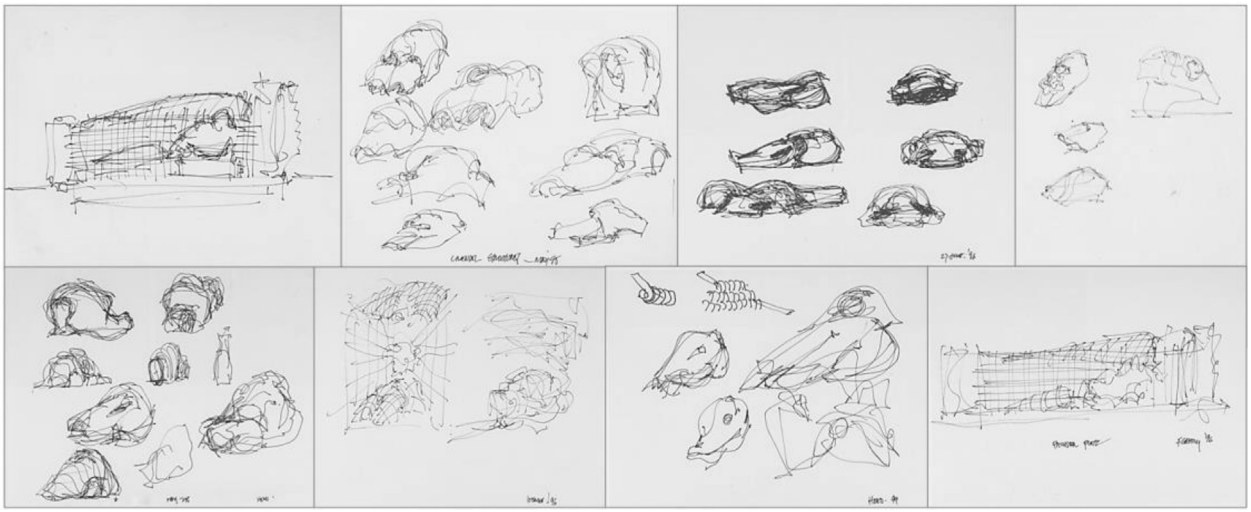


Fig. 3 Set of conception drawings by Frank Gehry for the DZ Bank Building, Germany, 1995—2001(Bredekamp, 2004).

drawing on one sheet. The drawings do not show any detail or complexity that would show that a lot of time was spent on them. Instead, they seem to have been done very quickly. Two sheets show up to eight small drawings.

d. From the number of drawings derived from each other, it can be understood that a transformation of the forms has been sought. He states: "people should make drawings, trust them, and from them they should learn what they are thinking; and what is coming out of there. It's fascinating!" (Colomina, 2003). There is no evidence of redrawing, remarking, or crossing out the drawings. It is inferred that his drawings are so quick and easy to make that he prefers to make another drawing before correcting one.
e. Although Gehry admits that his drawings do not look like buildings, he uses front and plan views. When asked if the first sketches have to do with the general shape, he replies, "No, not necessarily. The first sketches are floor plans" (Colomina, 2003). He also uses rudimentary axonometric and very schematic interior conic perspectives.

Gehry's design process is as follows. In the pre-design he requires a site model and small wooden blocks to get some idea of the volume. "Then I make sketches of different ways of approaching it [...] that's when I pass them on to Anand, Craig and Edwin (his collaborators) [...] then they start making models that evoke those sketches" (Colomina, 2003). The conception model becomes important in his design process. "We build actual models from some of those doodles and similar. And they come to fruition, although we're not quite sure why it happens that way". When asked at what point the computer comes into play, he replies, "As we work with each mock-up, we digitize its surfaces" (Colomina, 2003).

5. Discussion

The drawing that initiates the creative process of ideation in architecture is known as the "conception drawing". This drawing as a product and the act of drawing as a process become the ideal tool for architectural thinking and both show the architect's full intentions.

From the study of the three cases and the literature review, it has been determined that for this cognitive process to occur in an optimal and uninterrupted manner, one condition must be present throughout the process. This condition is phenomenological or haptic and allows the ideal linking of thought, sight, hand movement and the drawing instrument and support. Four characteristics of conception drawing as a process and as a product have also been determined. These are linked to four more or less sequential moments of this cognitive process. Although there are statements such as those of Oscar Niemeyer about a complete conception in the mind and its subsequent unitary drawing, the truth is that this is only a myth (Hiroki and Rozestraten, 2019). It is not intended to be established as a linear or cyclical process, rather, a disordered and explosive process, since rational and sensitive components are brought together in it. For this reason, we have not sought to determine strictly sequential phases of this process. Only four moments have been established that have made it possible to observe and determine the four characteristics (Fig. 4). The "start" is the moment in which an undecided drawing is given and results in formless drawings. Then there is the moment of "inquiry", in which there is a continuous act of drawing and small and multiplied drawings. The third moment is the "interpretation" of the previously drawn in which a perceptual drawing takes place, resulting in a redrawn drawing, and the cognitive process ends with the moment of "ending" in which the drawing is configured to be remembered later giving as a result the conventional rudimentary drawing. The condition and the four characteristics that have been stablished and that are explained next do not pretend to be an absolute systematization. It is intended to seek a heuristic process for pedagogical purposes that allows us to sustain them as a process of architectural thinking regardless of the analogue or digital medium in which it is developed.

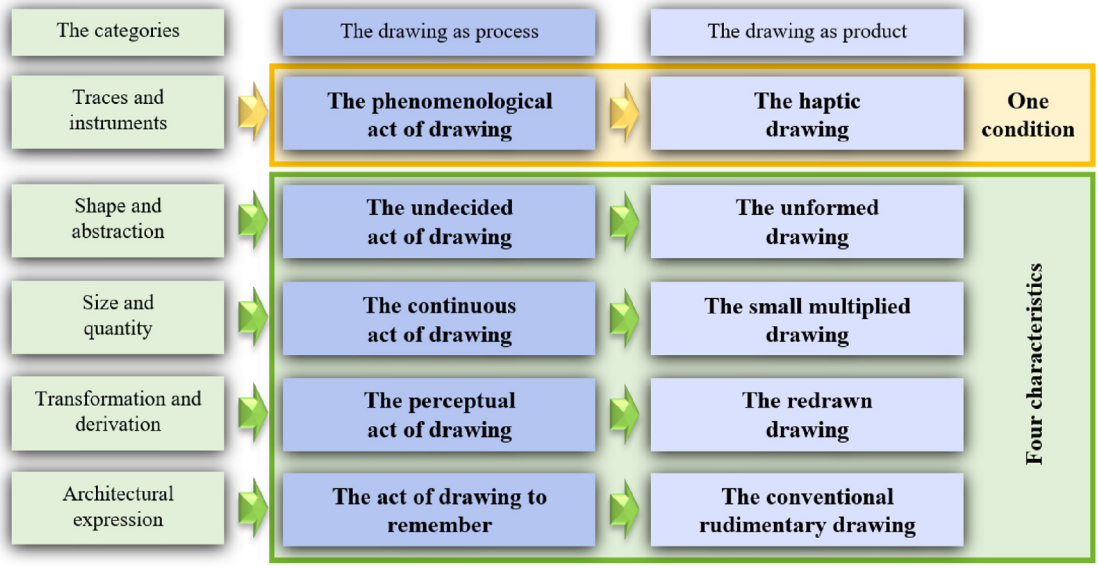


Fig. 4 The one condition and the four characteristics of the conception drawing in architecture, as product and as process.

5.1. Condition: the phenomenological act of drawing and the haptic drawing

According to Pallasmaa (2017), drawings are the result of the intimate collaboration between the hand and architectural thought, although in his argumentation he emphasizes the importance of the experience of hand movement almost as an entity independent of thought. This determines that each movement of the hand, its speed of stroke and its intensity of pressure register in each weight, tone or thickness of the lines drawn a spatial value, so that each drawing is situated in a perceptual or imagined space. Since the ability to draw rescues, from a set of perceptual actions and spatial movements, the knowledge of the bodily experience and since phenomenology focuses on the subject's awareness over the object in direct experience (Tham et al., 2018); the act of holding a pencil or charcoal to draw in sync with the act of thinking generates an image or drawing that, in turn, creates a haptic connection between the drawing and the drawer. In the act of drawing, the conceptual ideas of architectural design become a phenomenological act where the drawer's body becomes the very place of drawing, making living that experience more important than its understanding (Pallasmaa, 2014). This is the fundamental condition that must be present in the cognitive process of drawing and that has been diminished, distorted, or even annulled when it has been attempted to introduce digital media (computer, screen, and mouse) in such process.

As a result of this phenomenological experience, haptic drawings are obtained that leave traces of that experience of drawing through an instrument and the impregnation of almost any material (generally graphite or ink) on a hard and rough support. The haptic link of the drawing can be recognized from the thick and thin, intense, and weak, straight, and curved, continuous, and discontinuous, monochromatic, and polychromatic or blurred and filled in strokes. While it is true that these simple drawings do not leave a high or low relief on the surface, you can visually perceive the intentions of the act of drawing itself, even in the choice of techniques, instruments and supports. There is an initiatory paraphernalia within the design process that is associated with the creative process and to the very experience of creating that does not occur in the same way in later moments of the architectural project development (de Lapuerta, 1997).

Figure 5 shows the use of finger-blurred charcoal on tracing paper in Louis Kahn's drawings for the Philadelphia College of Art in Pennsylvania (Kahn, 1965a). The second example shows Frank Gehry's drawing for the Ohr-O'Keefe Museum of Art in Biloxi, Mississippi made in 1999 (Bredekamp, 2004). In this drawing, despite the lack of thickness, blurring or colour, the curved lines seemingly without a beginning and an end and reworked in zones capture movement and fluidity and thus express the haptic link. Then in the same figure is Tadao Ando's drawing for the Forest of Tombs Museum in Kumamoto in Japan made in 1990 (Ando, 2010). In this drawing it can be seen the use of blue ink with different coloured pencils making a quick filling of areas to give them a different value. Finally, the fourth drawing shows the work of Zaha Hadid for the Rheinauhafen project in Cologne, Germany (Schumacher and Fontana-Giusti, 2004). This drawing shows the use of ink on an absorbent paper, achieving well-defined strokes and at the same time controlled stains with the running ink. The intentionality and the desire to investigate show an intimate link between the author and the drawing.

5.2. Characteristic 1: the undecided act of drawing and the unformed drawing

The process of creating the architectural idea is a slow and progressive process full of doubts that is based on

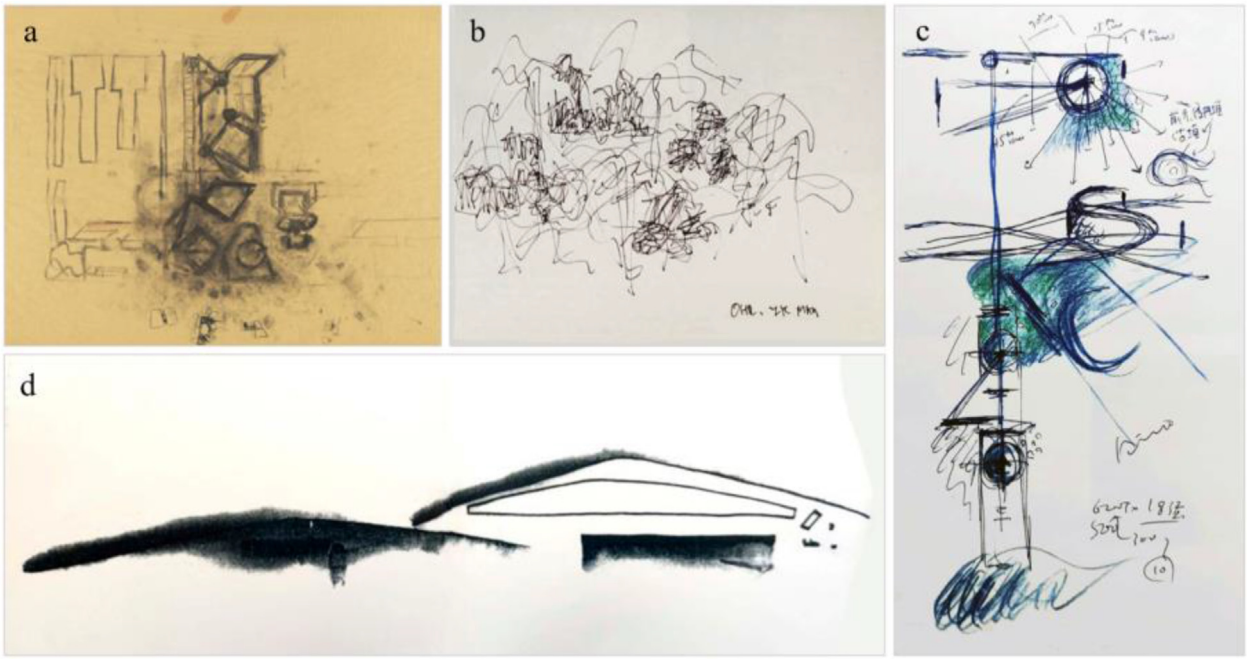


Fig. 5 The haptic drawings of Louis Kahn (a), Frank Gehry (b), Tadao Ando (c), and Zaha Hadid (d).

indecision. The act of drawing such ideas is more an act of critical inquiry than an act of simple enlightenment (Manolopoulou, 2005). It is a journey that takes us from the first abstract intuitions to the best configured convictions. Drawing in the initial stages of design is an undecided act where manual gestures are essentially "proactive" because it accompanies the thought through indefinite and tentative graphic gestures. It does not need concrete and specific data to accompany the manual stroke, since this stroke is not a project data, but an idea made a graphic (Llopis et al., 2013). This deliberate or accidental indecision or vagueness of the act of drawing allows the alternatives to be preserved. Architects execute conception drawings with deliberate ambiguity because they still don't know enough about the resulting image. They draw what they know or seek to catch the idea in the networks of the strokes themselves (de Lapuerta, 1997).

The result of this indecisive, ambiguous, and investigative act arises the unformed drawing. This characteristic refers to an abstract and little determined drawing, completely opposite to the conventional drawing used in later stages of the design process. These drawings are mostly only understood by the author. Unformed drawings are alive, changeable, and raise more questions than answers (Manolopoulou, 2005). They are suggestions of something that needs to be researched and redrawn later.

This feature can be seen in their sketches of the four conception drawings by architects Kahn, Gehry, Hadid and Ando shown in Fig. 6. Louis Kahn, in his sketches for the Sher-e-Bangla Nagar Prayer Hall in Bangladesh (Kahn, 1965b) leaves blurred spaces and blank spaces where the strokes fade or seem unfinished, with many alternative contour lines and others missing, with thin lines and others thick, with blurs and marks of manipulation with the fingers. All this concludes in an abstract drawing. Frank Gehry in his initial drawings for the Walt Disney Concert Hall in Los Angeles, California (Bredekamp, 2004) shows wobbly, jagged, jumbled, or messy strokes sometimes made without lifting the pencil, which has been called Gehry's doodles. On the other hand, drawings can have mysterious dark shadows and stains like those executed by Zaha Hadid for The Rheinauhafen project in Cologne in Germany made in 1992 (Schumacher and Fontana-Giusti, 2004). The last example in the figure shows a drawing with firm and more determined strokes, but equally reworked and lined, all done in blue pencil. This is Tadao Ando's conception drawing for the Oyamasaki Villa Museum in Kyoto, Japan, made in 1991 (Ando, 2010) that initially only made sense to the author because of its abstraction.

5.3. Characteristic 2: the continuous act of drawing and the small drawing

The act of drawing is a continuous cognitive process that seeks to maintain an uninterrupted flow of thought and design that is more effective than one interrupted or impeded (Herbert, 1988). Continuity and speed are necessary for conception drawings to keep the rhythm and to capture as much as possible since the cognitive part of the design activity usually goes faster than any other activity, including drawing. This cognitive process forces the architect's imagination to be open to many possibilities, the same ones that must be drawn at high speed to capture the quick flashes of mental stimulation (Smith, 2006). Such continuity and speed of the cognitive process is achieved by making drawings of reduced size that, in addition to being faster to make, allow to have a short cognition circuit that avoids the distraction that a large drawing requires by the wider and more diffuse visual field. A small drawing is not only physically faster to make, but, according to the physiology of visual spatial perception, the ability to process the visual image in maximum detail is limited to the

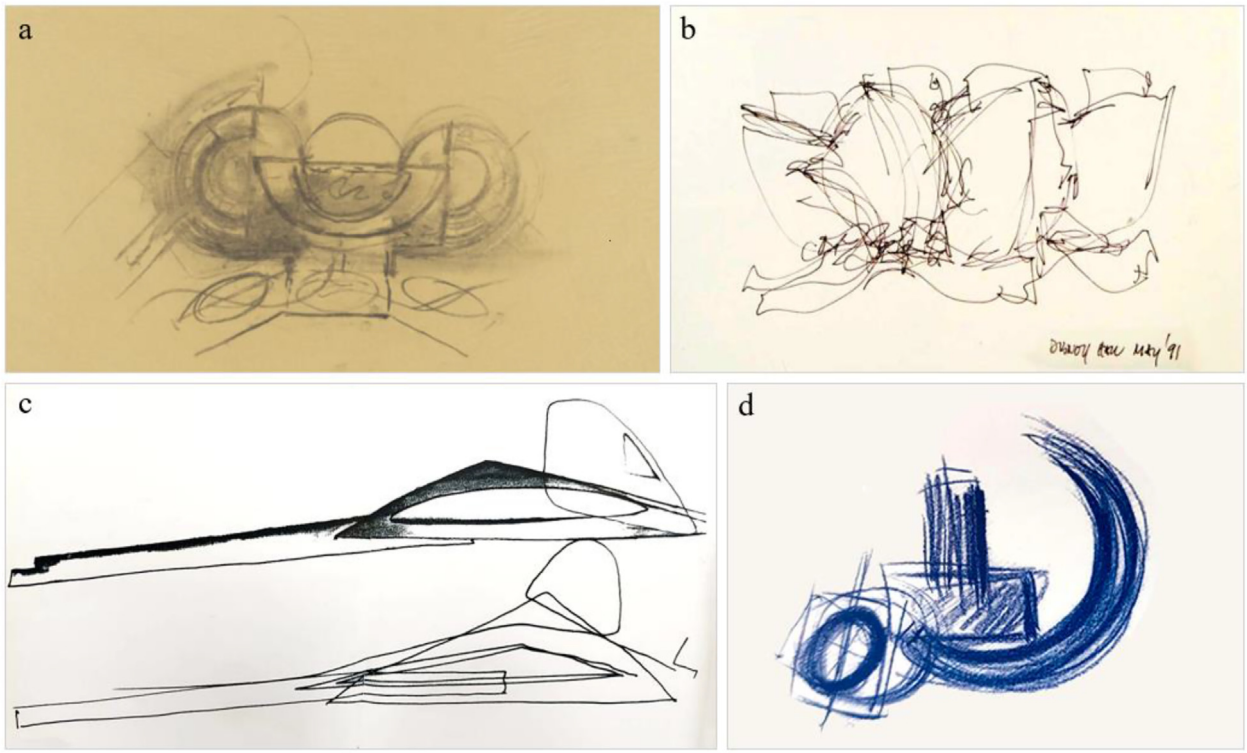


Fig. 6 The unformed drawings of Louis Kahn (a), Frank Gehry (b), Zaha Hadid (c) and Tadao Ando (d).

most central part of the visual field, that is, to a visual field of no more than 15 degrees of eccentricity (de Lapuerta, 1997). The angle calculated with the distance between the drawer's eyes and the surface means drawings from two to 7 cm in size on average.

Such cognitive continuous and fast processes generate the small and multiplied drawings. This feature, in addition to emphasizing its small size, implies its ease of execution which causes a multiplicity of small drawings that minimize unnecessary conventions and reduce details. They are drawings that are as easy to make as they are as easy to discard (Herbert, 1988). On the other hand, the support for conception drawings that have transcended ages and countries are the sketchbooks that have small dimensions to make them more comfortable to transport and keep close. These supports are ideal for small drawings and enough to abstract general design topics in the desired proportions (de Lapuerta, 1997). In their absence and the impulse to materialize architectural thought, drawings on restaurant napkins, airline tickets or event tickets are well known.

Fig. 7 shows the variety of small drawings achieved by Louis Kahn for Eleanor Donnelley Erdman Hall, Bryn Mawr College, Pennsylvania (Kahn, 1960), but it can also be appreciated its lack of neatness due to the speed of execution and its ease to be discarded with a simple crossing out. The speed and multiplicity is also recognized in Frank Gehry's drawings for his own residence in Santa Monica, California made in 1989 (Bredekamp, 2004). The third example shows Zaha Hadid's conception drawings for the Zollhof 3 Multimedia Park in Germany made in 1989 (Schumacher and Fontana-Giusti, 2004) in which a multiplicity of small, not very detailed drawings made quickly can be seen in contrast to other known drawings made with more time and dedication. Sometimes, due to the fleeting and unexpected condition of architectural thought, small drawings are made on unsuspected supports such as the cinema tickets used by Tadao Ando for the first ideas of the Chichu Art Museum in Naoshima, Japan (Ando, 2010).

5.4. Characteristic 3: the perceptual act of drawing and the redrawn drawing

The act of drawing the architectural idea, at some point in the process, becomes a perceptual act that seeks to interpret or discover through the "mind's eye" new meanings based on the drawings previously made (Fish and Scrivener, 1990). In nebulous, imprecise, and ambiguous images, it is created the need and impulse to complete them, to suppress or erase something that does not fit or to generate other drawings that respond to the previous one (de Lapuerta, 1997). These perceptual discoveries, intentional or not, cause the act of drawing to continue on the same drawing or derive from the original (Schon and Wiggins, 1992). To make this perceptual condition of the act of drawing happen, the long-term memory is also required. Sketches give access to different material from such memory and other areas of knowledge that are relevant to the design on which the designer is working but were not part of the designer's thinking at the time of the first drawing (Goldschmidt, 1991). For these processes to happen, then, it is important that the previous drawings and other images are at hand and visible in the work area to provide that stock of images and to support the active role of studio drawings (Herbert, 1988). The information that may be hidden in a

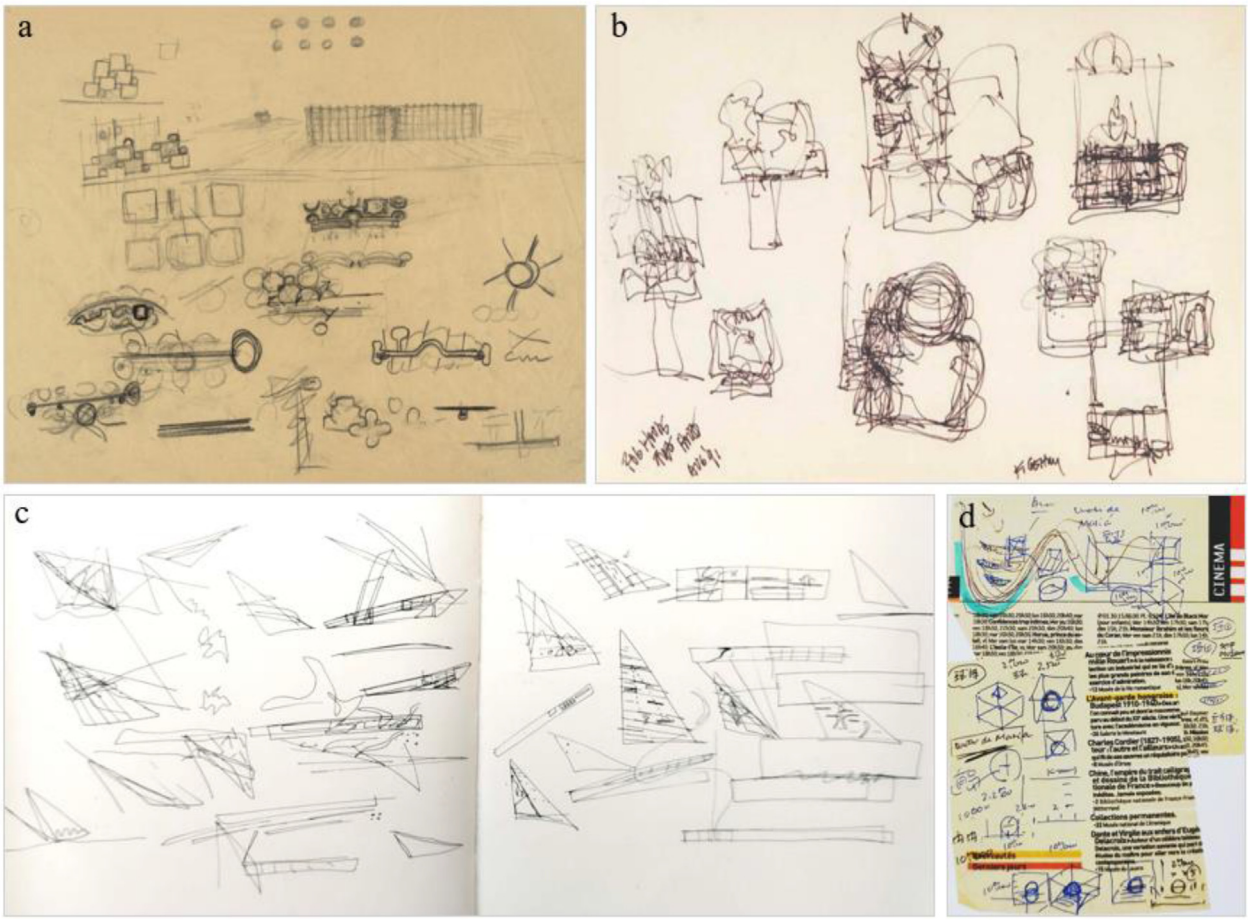


Fig. 7 The small and multiplied drawings of Louis Kahn (a), Frank Gehry (b), Zaha Hadid (c) and Tadao Ando (d).

drawing must be perceived, extracted, and made available also to other mental processes, such as the verbal thinking, but more importantly, to feed new motor commands that drive drawing.

The act of drawing as a perceptual act gives rise to the redrawn drawing. This characteristic means that in the same drawing it will be found strokes that have been remarked, reworked, or crossed out to highlight the reinterpreted idea. In other cases, several drawings will be found side by side, some derived from the previous ones with the same intention of highlighting the reformulated idea resulting from the perception of what has been drawn. These drawings are not very organized and legible to the eyes of others, but of high perceptual value for their creator.

Fig. 8 shows Kahn's drawings for the Mikveh Israel Synagogue in Philadelphia, Pennsylvania (Kahn, 1963) in which the derivation of forms in search of the ideal can be appreciated. The second drawing belongs to Tadao Ando for the Rokko Housing, Japan made in 1978 (Ando, 2010) with strokes reworked several times with the same blue pencil to highlight what was perceptually wanted to highlight. The use of coloured pencils to differentiate and highlight ideas or moments through their chromatic qualities (de Lapuerta, 1997). In other cases, such as Zaha Hadid's drawings for the Rheinauhafen project in Cologne, Germany (Schumacher and Fontana-Giusti, 2004), the intention to maintain more possibilities of reinterpretation can be appreciated, therefore the drawing is repeated side by side looking for transformations, modifications and refinements seeking satisfaction with the results (Goldschmidt, 2003). Finally, Frank Gehry's drawing for the Guggenheim Museum in Bilbao, Spain (Bredekamp, 2004) is also an example, although not very frequent, of the reworking of strokes in the search and perceptive discoveries of the most important reinterpreted idea. Gehry generally makes new drawings quickly.

5.5. Characteristic 4: the act of drawing to remember and the conventional rudimentary drawing

The sketch works as a kind of annex to the memory to expand it and for the architect to capture and save graphic information for another time or to constantly reinterpret it (de Lapuerta, 1997). It is easier to remember from preconfigured drawings such as orthographic and axonometric views, even if they are rudimentary, rather than very abstract and shapeless drawings. Therefore, the ability to sketch an idea that needs to be fixed requires mastery of the conventional projection system when three-dimensional objects are being designed as it occurs in architecture (Goldschmidt, 2003). Conception drawings that use rudimentary graphic conventions must contain the essentials of the architect's conception work and that final

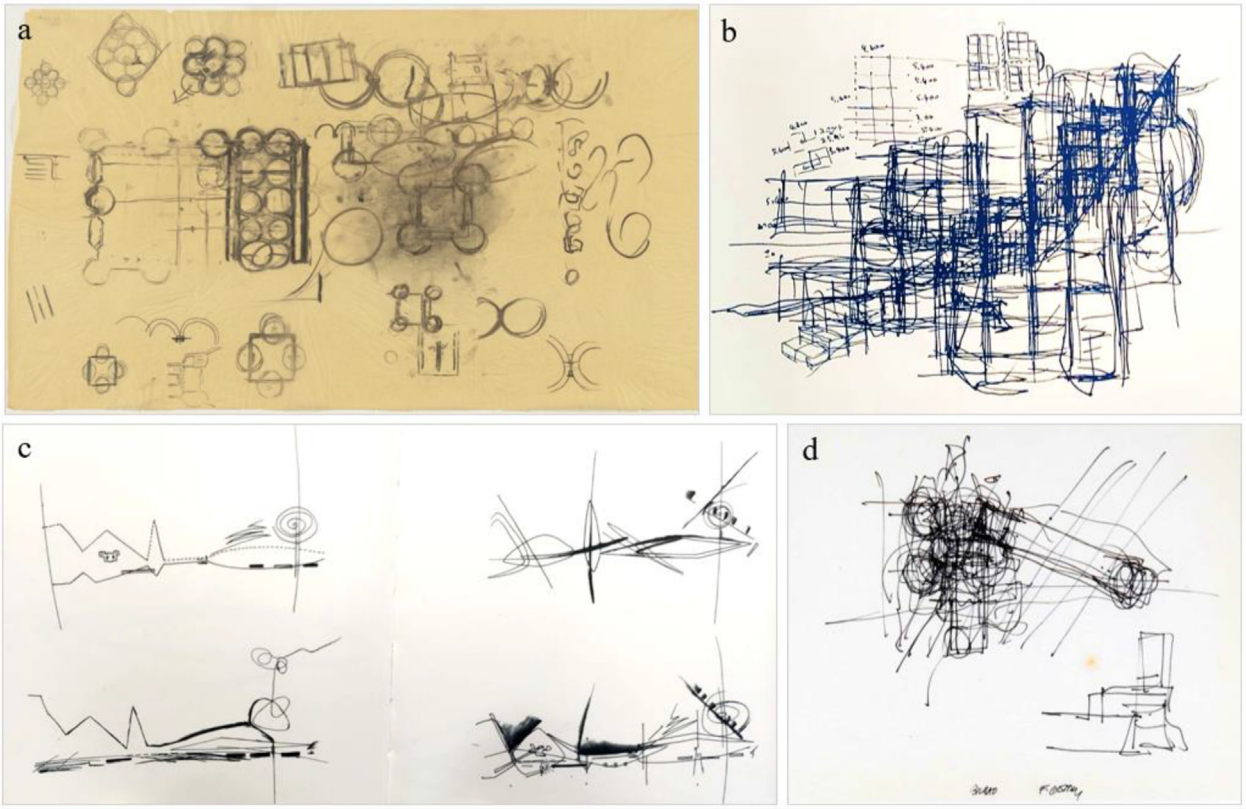


Fig. 8 The redrawn drawings of Louis Kahn (a), Tadao Ando (b), Zaha Hadid (c) and Frank Gehry (d).

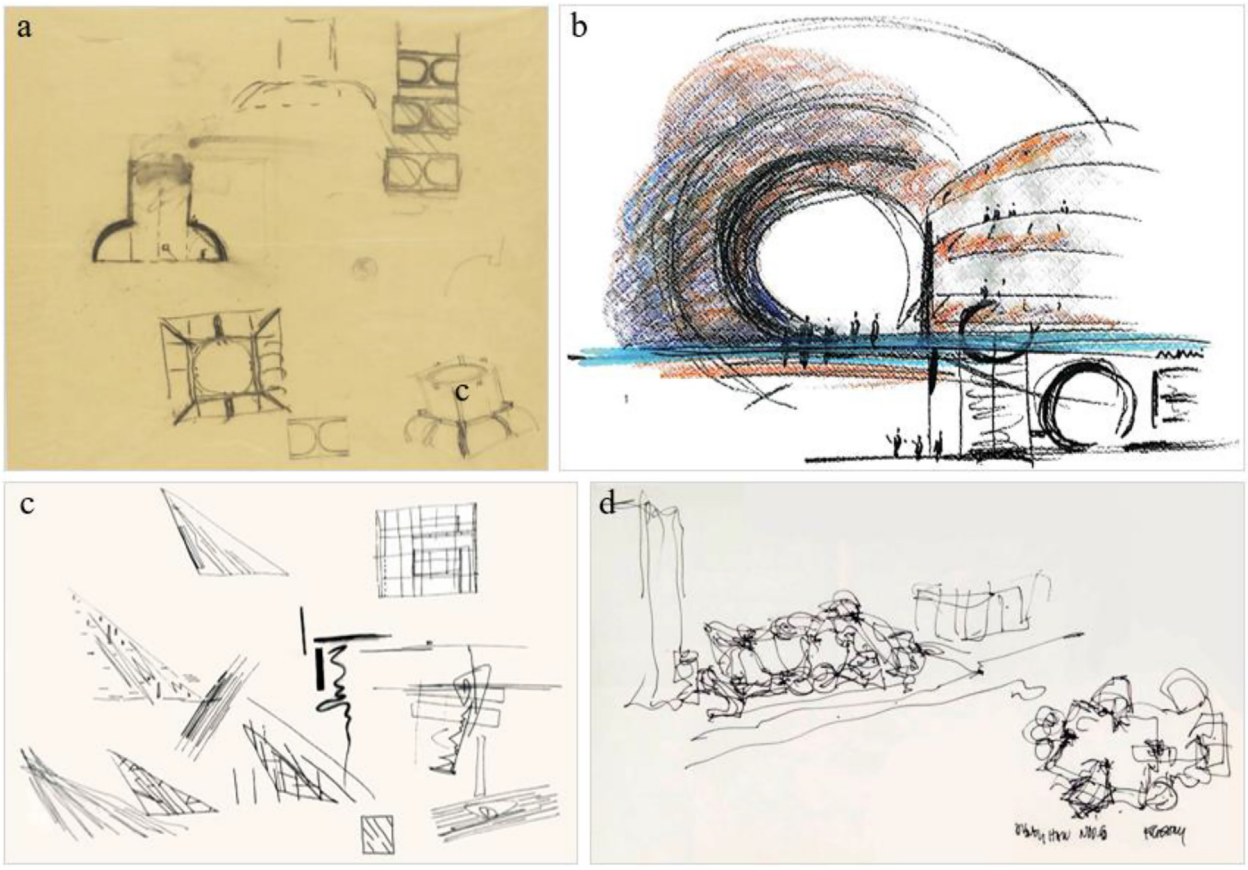


Fig. 9 The conventional rudimentary drawings of Louis Kahn (a), Tadao Ando (b), Zaha Hadid (c) and Frank Gehry (d).

image must allow self-confrontation, as well as confrontation with others supported by spoken discourse (Herbert, 1988; Rey, 1985). However, it is important to clarify that representation systems can be in themselves a limitation that causes selective losses of information or can distort ideas only if some of the systems are used selectively or are not well-used (de Lapuerta, 1997).

The completion of a small cycle within the prolonged process of creation of ideas ends with drawings executed under the technical criteria of axonometric, dihedral views or conic perspectives. But all of them made in a very schematic or rudimentary way. This will allow the recall and reactivation of the creative process at another time. It is not very common, though, for architects to use all representation systems in the conception drawing. Since this drawing is very personal, the architect chooses the presentation modes within their own creative process. The plan is one of the most used drawings due to its benefits to show the proportions, locations, and distributions.

Fig. 9 shows Louis Kahn's sketches (Kahn, 1965b) for the Prayer Hall of Sher-e-Bangla Nagar in Dhaka, Bangladesh (Kahn, 1965b). In these drawings it can be seen the use of plan and cross-sectional views as well as an axonometric view, all of them made in a very simple and rudimentary way. The second example shows very schematic, overlapping and different sized conic perspective, section and plan drawings made for the Shanghai Poly Theater in Shanghai, China (Ando, 2010). The floor plan has always been for Zaha Hadid the most important element in her conceptual process. The third drawing shows the various triangular plan views and a rectangular elevation for the Zollhof 3 Multimedia Park in Germany made in 1989 (Schumacher and Fontana-Giusti, 2004). The last drawing shows Frank Gehry's use of the plan view and an axonometric for the Walt Disney Concert Hall in Los Angeles, California (Bredekamp, 2004). These drawings have a rudimentary and unconventional character.

6. Conclusions

After the case studies of the conception drawings of Pritzker Prize winners Tadao Ando, Zaha Hadid and Frank Gehry and the literature review, it is concluded that for the cognitive process of architectural ideation to be successful, there is one condition and four characteristics that must be fulfilled. The condition refers to the fact that the act of taking an instrument to draw in synchrony with the act of thinking must be a phenomenological experience where the hands and body of the architect become the very place of drawing making living that experience more important than understanding it. This results in drawings that have a haptic connection with the performer. The first characteristic refers to the fact that in the first moments of the cognitive process there must be an inquiry and investigation through the first strokes. This occurs through an undecided act due to its propositional and investigative nature. This first moment results in traces and drawings that do not have a defined form and are rather abstract and of limited understanding for other people. The second characteristic occurs at a second moment when ideas begin to flow naturally, and the imagination is opened to many possibilities. It causes a quick act of drawing to capture the flashes of stimulation of the mind and body. This generates small and multiplied drawings, many times captured in unexpected formats due to the haste of their execution. The third characteristic occurs when the drawing process has already advanced. Then the act of drawing becomes a perceptual act that seeks to interpret or discover new meanings based on the previously made drawings. The perception of these previous drawings generates the impulse to complete them, to delete or erase something to arrive at the best idea. This act generates redrawn, remarked, erased, or crossed out drawings. Finally, in the last moment of a cycle of the cognitive process, the act of drawing seeks to configure more clearly the idea worked on to remember it in another moment of the long process of ideation. This act of drawing to remember generates drawings with the characteristics of conventional representation systems, but as they are only the first ideas, these drawings are very schematic or rudimentary plans, sections, axonometric or conic perspectives.

The way of conceiving architectural ideas can be altered due to mediation of computer technologies. Learning the conditions and characteristics of the conception drawing will ensure that the cognitive processes that allow creative thinking to materialize to generate architectural ideas in the initial stages of architectural design not to be altered or suppressed. These theories and their learning should be very clearly established in the first years of the study of architecture in universities. In this way, regardless of the medium in which the process of creating ideas develops, the conception drawing, and the act of drawing will remain the only way to proceed as a response to architectural thinking.

The creation of conception drawings mediated by immersive virtual reality with haptic controls and freehand drawing software is proposed as the next research to determine the impact of technology on the process of architectural thinking and the relevance of having established the condition and characteristics of the conception drawing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ARTÍCULO CIENTÍFICO 2

The architectural conception drawing in immersive virtual environments

Cognitive processes involved in initiating architectural ideas can be affected by technological incursion. Moreover, technological development of emergent and disruptive tools, such as immersive virtual reality, can further foster these processes. This research argues that the use of a virtual reality environment with HMD, haptic controls, and software created for artistic freehand drawing can generate the necessary phenomenological condition to facilitate the cognitive process of creating the first ideas of the architectural project; furthermore, the creation of such ideas would have the same characteristics of the traditional conception drawing made with pencil on paper. To verify this, experiments were carried out as part of a multiple case study methodology with 28 students in their first and last year of studies in a professionally accredited course of architecture and three instruments. The experimentation involved virtual creation of conceptual drawings of a small architectural project. The results showed insignificant differences in terms of the condition and characteristics of the cognitive creative process, and showed larger, but not significant, differences in terms of the drawing as a final product. While the process of virtual drawing presents some significant advantages that can make this technology an effective complement when creating the first architectural ideas, it cannot fully substitute the creative process.

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Introduction

The first ideas of an architectural project have traditionally been created through the close link between thought, sight, and the movement of the hands that leaving traces by means of a drawing instrument on a sheet of paper.[1] This special type of drawing is known as conception drawing and has remained unscathed by technological incursions, such as the evolution of digital design tools in visualising and developing architectural ideas. Such technological mediations are believed to alter the natural cognitive process, provoking a sensual and haptic disconnection between thought, imagination, the hand, and drawing, thus obstructing the immediacy of hand drawing in conceiving architecture.[2] However, given the development and evolution of emergent and disruptive technologies, such as Immersive Virtual Reality (IVR), technology has begun to be seen as a promising alternative that not only would not affect the creative process but could also overcome some of the limitations of the traditional method of conceiving and developing design with pencil and paper. The aim of this study is to explore how three-dimen-

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sional drawing in an immersive environment can influence or facilitate architects' cognitive and creative processes. The research focuses on assessing whether the IVR offers the necessary conditions for the creative process and whether the characteristics of the drawing process and the final drawing are similar to those of traditional manual drawing. Through this approach, the study aims to provide an empirical basis to better understand the advantages and limitations of VR in architectural education and practice, thus contributing to a body of knowledge that can guide future implementations of advanced technologies in the field.

Literature review

The phenomenological condition of the act of drawing in architecture

In architecture, it is important to recognise that perception is an act of the whole body and that such bodily perception is fundamental for the experience and understanding of the world.[3] Sensory and bodily knowledge is fundamental in architecture not only to understand and perceive the three-dimensionality of space from one''s own three-dimensional body but also to imagine and create such spaces. In order to express such ideas of bodily perception and sensations in the physical world, a typical process would be to trace them through the movement of the body and the hand with an instrument such as the pencil, which is believed to be linked to the mind conceiving the ideas. At the same time, the act of drawing as an experiential and expressive bodily process is believed to reflect accumulated experiences and feelings about the world. This suggests that the hand and body serve as a framework and model for all that we come to know about ourselves and the world.[4] Juhani Pallasmaa''s *The Thinking Hand* highlights such importance alongside the evolution of human skills, intelligence, and conceptual abilities. The hand is not just a faithful and passive executor of the mind''s intentions, but rather has its intentionality, its knowledge and its own abilities.[5] Drawing reflects the ability to bring an idea into the physical world. It rescues the knowledge of bodily experience from a set of perceptual actions and spatial movements. The attention and dexterity necessary for drawing is not related to the knowledge of graphic techniques, but to a special type of bodily cognition, different from that of everyday experience.[6] Therefore, the action of drawing is a phenomenological action that reflects prior experiences and perceptions of the sensory body, which are then made visible by the person who draws through the movement of the hands with an instrument. When reaching the condition that the drawing person forgets the hand and the pencil, the emerging drawing thus pertains to an automatic projection of the imagining mind.[7]

The characteristics of conception drawing in architecture

The conception drawing in architecture is an act of drawing that makes visible the architect''s creative thinking in the initial moments of the architectural project. This resulting conception drawing is understood as a set of initially ambiguous strokes that do not represent the final answer to the problem to

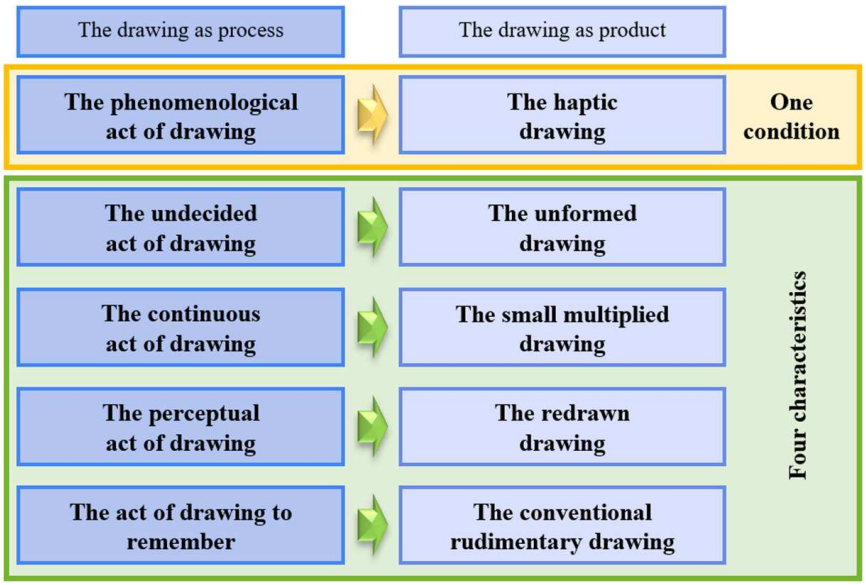


Figure 1.
The phenomenological condition and the four characteristics of the conception drawing in architecture, charted by the authors,2024, in Hugo C. Gomez-Tone and Javier F. Raposo Grau, 'Characterization of Conception Drawing in Architecture to Face Technological Mediations', *Frontiers of Architectural Research*, 13.3 (2024), 425–38

be solved, but the initial guidelines that generate a dialogue with the designer. This research is based on the specific phenomenological condition explained above and the determination of four characteristics of drawing as both a process and a product (Fig. 1).[8]

These four characteristics correspond directly to the four moments that occur in the creative process and the materialisation of the first architectural ideas. It is, therefore, very important to recognise and determine whether any technological mediation can affect these cognitive processes.

1. The process and outcome of drawing respond to an undecided process because it is not a resolute act nor an act of simple illustration; it is more an act of critical investigation.[9] It is a propositional act that seeks to investigate rather than give an immediate answer. This deliberate or accidental indeterminacy allows the preservation and generation of alternatives.[10] The result is a drawing without form or with a poorly defined form that is abstract, uncertain, and changeable, which then may be later completed, changed, or augmented.[11]
2. The process and outcome of drawing respond to a need to be continuous because it requires keeping the cognitive process uninterrupted so that as much as possible can be captured from thought at high speed to follow the rapid flashes of mental stimulation.[12] The results are a series of small yet multiplying drawings. The reduced size implies ease and speed of execution and discarding which in turn becomes a multiplication of small drawings with minimum conventions and reduction of details.[13]
3. The process and outcome of drawings also respond to a perceptual action because, by observing what has been previously drawn, new associations are generated in the memory and new motor commands that drive the

drawing towards the discovery of new meanings.[14] The result is constant redrawing, revising, crossing out, and redoing that generates a messy, scratched, and illegible drawing that is also record of transformations, modifications, and refinements.[15]

4. Finally, the process and outcome of drawing responds to the need to remember what has been drawn at some later time. The cycle of thought seeks to finish the ideas drawn, even if they are not the definitive ones, to remember, reinterpret, and reactivate the process of generating the architectural idea.[16] The result is a drawing that requires the use of conventional projection systems because it deals with three-dimensional objects.[17] The drawing tends to become plans, sections, axonometric, and conic perspectives, but in a very rudimentary way.

The phenomenological condition of Immersive Virtual Reality

Technological advancements have increasingly immobilised humans while activating machines. The predominance of screen-based interactions has exacerbated a crisis of sensory experience.[18] However, not all technologies immobilise the body and generate such crises. The IVR has special and different features gathered from other technologies that can make the experience of using it a phenomenological and ideal experience for the realisation and learning. One such feature is 'presence', which is defined as the psychological experience of 'being there', or the experience of being in one environment even when the person is physically in another.[19] This challenges the phenomenological idea that our sense of bodily presence is anchored in our physical body and broadens our notion of what bodily presence can mean.[20] It has also been proposed that bodily invariance with respect to the virtual environment should be conditional, that is, virtuality requires that the environment and the body be digitally isomorphic.[21] In any case, the boundaries and distinctions between the physical and virtual worlds are becoming increasingly blurred.[22] At one extreme is the position that the lived body is transposed to virtual reality as a virtual body made of intensities, pure forces, or magnitudes within a vector space, thus losing its affective qualities,[23] while at the other extreme is the position claiming that, in virtual reality, one has the possibility of becoming a 'virtual being' of experiences that are not only entertaining or fun but also meaningful in and through different 'worlds'.[24] These meaningful experiences happen, despite a reduction of perception in the visual, thanks to the fact that it is more important that the feeling of being there, the sense of self in relation to one''s own body, and the ability to act in space implies relational and emotional bonds.[25] These characteristics represent for this research an ideal phenomenological condition for conception drawing in architecture.

The possibilities of Immersive Virtual Reality for architecture education

The IVR offers five unique features:[26] (1) *embodiment* which is the perception of the virtual body as one''s own biological body and virtual actions as real life; (2) *interactivity* which is the degree to which one interacts with virtual objects and agents; (3) *navigability* which is the ability to freely move the virtual body in

the virtual navigable space; (4) *sensory capability* which is the ability to feel through the senses in the virtual environment; and (5) *creation capacity* which is the possibility to create existing and non-existing environments of the physical world. These characteristics are ideal for developing educational activities in many professional fields.[27] For the case of architecture education, the IVR also offers high attention control and decreased distraction in the virtual environment, allowing more cognitive resources to be allocated to the processing of essential information.[28] It also offers many facilities for learning and solving conceptual or highly complex problems that require spatial understanding, and for coping with processes that are difficult or impossible to perform in the real world.[29] But the feature that is outstanding for architecture education is its effectiveness in visualising concepts and understanding the spatial layout of three-dimensional objects in a three-dimensional environment. This has made IVR an ideal tool in the field of architecture education over engineering, health, natural, and social sciences.[30]

Although its implementation in architectural education is extensive and superior even to the professional field of architecture, engineering, and construction (AEC) itself, where research has generated a large, diverse but fragmented body of knowledge, it is still not optimal.[31] This deficiency happens because of cultural change and lack of competencies.[32] This lack of competencies are not only technical but also pedagogical because there are few studies that have a clear theoretical pedagogical model as a guide for designing the instructional content of the virtual reality educational application.[33] In addition, several researchers and academics in the field of architecture have always blocked the appreciation of explorations and use of digital tools, taking time to accept them.[34] Technology-mediated learning will only be strengthened when society becomes more aware and has a better understanding of the technological possibilities in education.[35]

The possibilities of Immersive Virtual Reality for the teaching of architectural design and drawing

To achieve meaningful learning, methods that use the above-mentioned characteristics of the IVR should be applied. It is also possible to foster its three technological factors, immersion, control, and representational fidelity and enhance the sense of presence and agency that are unique possibilities of this technology.[36] The sense of presence is a determining possibility for the teaching of architectural design and space. In the very early stages of design education, presence allows correlating the space of small models and full-scale models helping to develop spatial awareness.[37] Presence in spatial experience is that which allows the transfers of feelings and meanings, faraway from merely understanding the spaces through flat drawings. This allows more dimensions of the design process to be taught, which were previously more difficult to grasp.[38] It also allows for reflection during the process of design, aiding critical thinking and problem-solving activity in addition to increasing spatial perception about the design and enhancing learning and teaching .[39] However, the agency of generating and controlling actions

and interaction in the virtual environment has not been developed much in relation to creation and drawing in architecture. For this reason, research emerges to determine that the use of IVR is beneficial in the later phases of design rather than in the initial and more creative phases.[40] This happens because modelling software tends to obstruct manual control and agency; as Pallasmaa argued, drawing with mouse and computer breaks the sensual and haptic connection between imagination, hand, and drawing. This is harmful in the most sensitive and vulnerable phases of the project process, when the architectural essence of the building is conceived and determined.[41] Even when the virtual immersive environment replaces the interface of the mouse, the computer, and the flat screen, possible agency in the natural interaction and creation of objects and drawings remain under-exploited. Only a few recent attempts have sought hand and body control for immersive three-dimensional sketching by taking advantage of the multimodality of the IVR, which gathers and connects design behaviours associated across sketching on paper, CAD modelling, and physical modelling.[42] This multimodality enables designing, drawing, and building in a freehand manner to support architectural visual thinking.[43]

Hypothesis

As the conception drawing is a crucial moment of seeding architectural ideas towards a project, any technological incursion attempted at the time can affect these cognitive processes. However, due to their characteristics, IVR as recent technological tools can not alter or disrupt these cognitive processes and, on the contrary, foster them. This research supports two hypotheses:

Hypothesis 1: the use of a virtual reality environment with HMD, haptic controls, and software created for artistic freehand drawing can generate the phenomenological condition necessary for the cognitive process of creating the first ideas of the architectural project.

Hypothesis 2: the use of a virtual reality environment with HMD, haptic controls, and software created for freehand artistic drawing can facilitate the creation of the first ideas of the architectural project with the same characteristics of the conception drawing made with pencil on paper.

Materials and methods

For this research, the multiple case study methodology was used, which is an instrumental study extended to several cases seeking redundancy and variety to lead a better understanding and a better formulation of theories.[44] Since we seek to understand how IVR impacts the cognitive process of creating the first ideas of the architectural project through the conception drawing, the cases were chosen through convenience sampling.

Participants

The multiple case involved a group of students from the Faculty of Architecture and Urbanism of the Universidad Nacional de San Agustín de Arequipa in Peru. Seeking redundancy and variety, the convenience sampling looked for two types of students. The first subgroup, called 'novices', consisted of students who completed the first year of the course and passed the subjects of architectural drawing, descriptive geometry, and architectural design 1 and 2. The second subgroup, called 'experts', were students who completed four years of the course and passed all the subjects of graphic expression and eight subjects of architectural design.

A Google Forms questionnaire was used for recruitment, which also collected information on specific conditions such as colour blindness, epilepsy, dizziness, nausea, and migraine. These conditions also restricted participation in the study. Of the 80 first-year students, only 14 met the conditions and were willing to participate; of the 60 final-year students, 14 also met the conditions and were willing to participate. The average ages of the novice and expert participants were 20.08 and 23.43 years, respectively. All 28 participants signed a consent form to participate in the experimentation.

Experimental design and instruments

To verify the hypothesis that the IVR environment creates the perfect conditions for conception drawing to succeed, as a process and product, in an ideal way, an experimental design was established. The experimental design consisted of participant observation and interviewing during the process of creating an idea through conception drawing using the IVR. It also consisted of observation and evaluation of the conception drawings created within the virtual environment. Three instruments were used to collect information (Fig. 2).

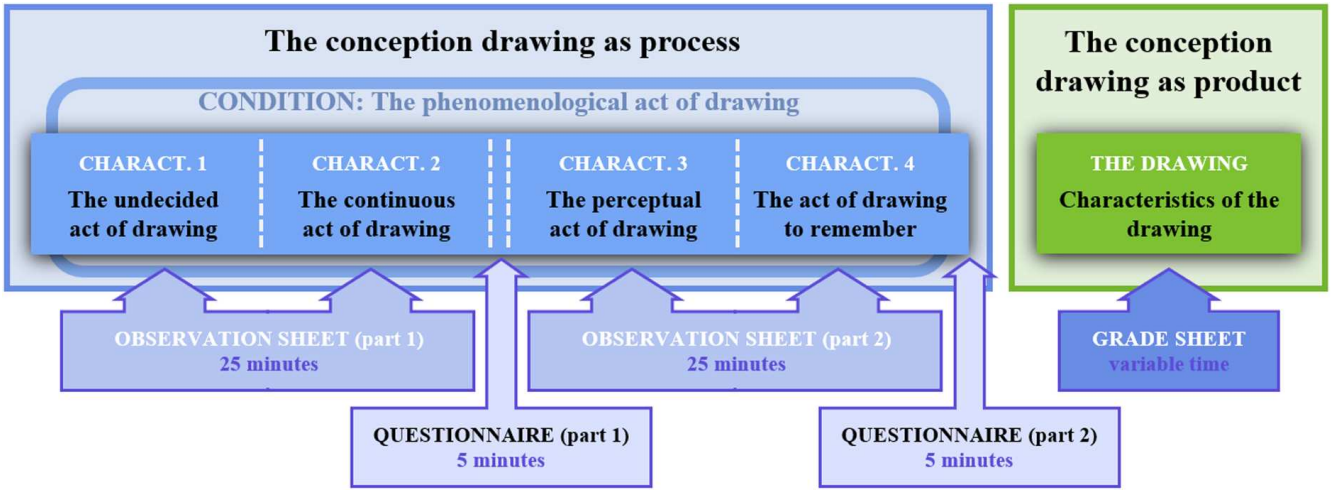


Figure 2.
The three instruments used to collect the information and time used, charted by the authors, 2024

Observation sheet: an observation sheet was designed with a 5-level Likert scale. This sheet made it possible to observe and record the participants throughout their drawing process. Body and hand movements, gestures, body reactions, intentions, speed, concentration, displacement, and the use of language to explain the drawing were observed. The first observation was related to the bodily, haptic, and phenomenological condition that occurs when drawing. The next four observations were related to the four moments of the creation of the idea and their four characteristics. To observe the drawing process, a 65-inch screen was used to show the environment, and the strokes made in real time (Table 1).

Questionnaire: the second instrument was a mixed questionnaire (with open and closed answers) that was immediately applied to the students in two moments as shown in Fig. 2. This questionnaire allowed us to know the perception and opinions of the use of the tool in relation to the drawing process and results. Similarly, the first question was related to the condition and the next four questions were related to the four moments and characteristics of the process of drawing the idea (Table 2).

Grade sheet: the third instrument was a grade sheet that evaluated the drawing as the final response to the process. This instrument made it possible to observe all the drawings that were recorded in the virtual environment, and it was used to determine the characteristics of the conception drawing as a result. The first criterion assessed was again related to the haptic condition and the traces it may have left on the drawing, and the next four criteria were related to the four characteristics of the finished design drawings (Table 3).

Table 1 The observation sheet with the criteria to be observed and the five Likert levels, charted by the authors, 2023.

Student name:	Very low frequency /intensity	Low frequency /intensity	Moderate frequency /intensity	High frequency /intensity	Very high frequency /intensity
Shows intense arm and body movements	○	○	○	○	○
Creates strokes and shapes just to explore options	○	○	○	○	○
Creates multiple strokes easily and quickly	○	○	○	○	○
PAUSE					
Perceives the drawing by moving and changing scale	○	○	○	○	○
Explains their final proposal using the drawings	○	○	○	○	○

Table 2 Questionnaire with closed-ended (5 Likert levels) and open-ended questions, charted by the authors, 2023.

Student name:	Very low usefulness /intensity	Low usefulness /intensity	Moderate usefulness /intensity	High usefulness /intensity	Very high usefulness /intensity
How intense was the experience of drawing in IVR?	○	○	○	○	○
What made the experience special or intense?					
How useful was it to try out strokes and shapes at first?	○	○	○	○	○
What has been most interesting in the first part of the exploration?					
How useful was it to create strokes easily and continuously?	○	○	○	○	○
What impediments have you found during the drawing process?					
PAUSE					
How useful was it to change scale to perceive the drawing?	○	○	○	○	○
What has been most striking in this second part of the drawing process?					
How useful was it to draw in 3D instead of 2D?	○	○	○	○	○
Why didn''t you make two-dimensional drawings at the end of the process?					

Equipment and tools for experimentation

The two Head Mounted Displays used for this experimentation were of the HTC Vive Lite brand with two haptic controllers each. Two personal computers with 16 GB of RAM and two 65-inch TV screens. This hardware is installed in an exclusive space for simultaneous experimentation by two users (Fig. 3). Each experimentation area is 7 m^2 which allows for comfortable and unobstructed movement of each user. In addition, the computer control and the position of the Observer Researcher do not affect the experimental space.

The software used to create the concept drawings was Google''s Tilt Brush. Four criteria were considered when choosing this application. It should offer a high freedom of freehand strokes and at the same time have low geometric

Table 3 The grade sheet with the criteria to be observed and assessed and the five Likert levels, charted by the authors, 2023.

Student name:	Very low presence /quantity	Low presence /quantity	Moderate presence /quantity	High presence /quantity	Very high presence /quantity
Strokes of different types, thicknesses and colours expressing a haptic link.	○	○	○	○	○
Abstract and indeterminate drawings without form or with a poorly defined form.	○	○	○	○	○
Small and multiplied drawings with few conventions and details	○	○	○	○	○
Redrawn, repainted, crossed out, messy and highlighted drawings	○	○	○	○	○
Rudimentary drawings with the conventions of graphic representation systems	○	○	○	○	○

precision. This is because the conception drawing or sketch serves as an extension of mental imagery, allowing the manipulation and retrieval of stored images, the search for unexpected graphic relationships, and the representations to open to new interpretations in an additive process that enriches the creative process. Therefore, the use of geometrically precise instruments is avoided to ensure flexibility, encourage innovation, and adapt quickly to

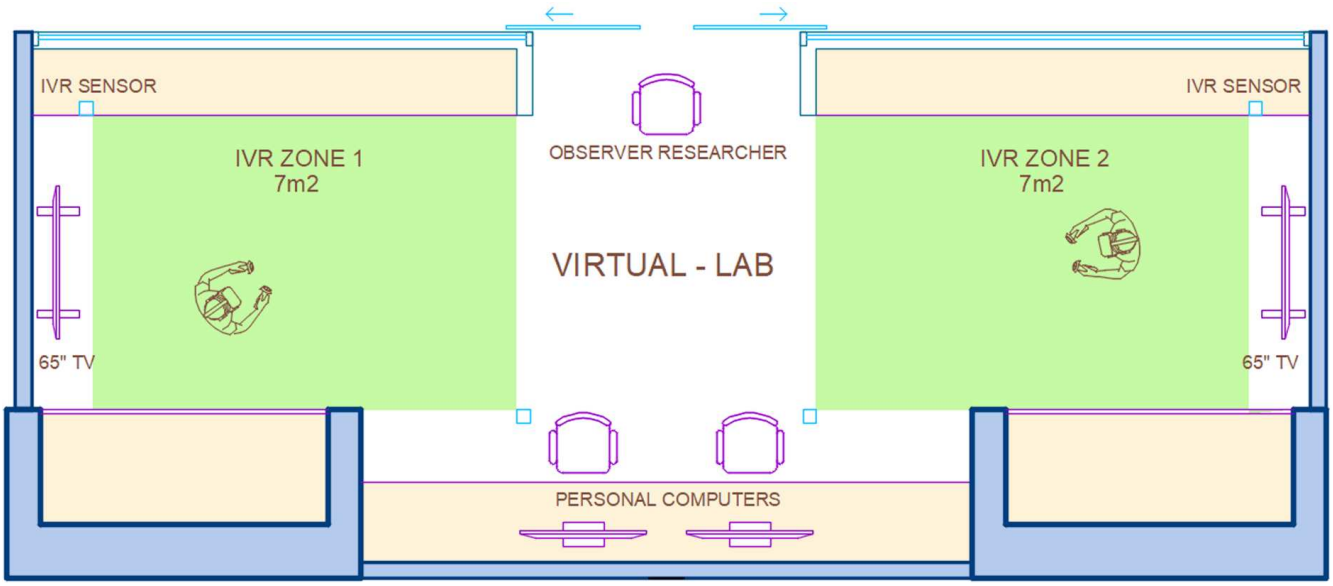


Figure 3.
Distribution of the Virtual Lab within the university for experimentation by two users simultaneously, drawn by the authors, 2024

Table 4. Comparison of eligibility criteria for IVR software

Application	Freedom of freehand strokes	Geometrical precision	Creative brushes and tools	Learning curve
Tilt Brush	High	Low	High	Low
PaintLab VR	High	Low	Moderate	Low
Quill	High	Low	High	Moderate
Gravity Sketch	Moderate	High	High	High
Blocks	Low	Moderate	Low	Low
ShapesXR	Moderate	Moderate	Low	Moderate

architectural thinking. Another criterion was the presence of creative tools and brushes to allow experimentation with the strokes. Finally, since the application had to be trained quickly, it had to be quick to learn. Tilt Brush has proved to be the most ideal tool chosen for the objectives of the research over other applications (Table 4).

Tilt Brush is a virtual reality application created for artists to draw and paint in 3D on a 6 degrees of freedom motion interface. It has a palette of 48 types of strokes that can be created with simple movements of the hands. In addition, it has a 'guides' tool that allows strokes to be made on 4 types of volumes to avoid depth errors (Fig. 5). Among other tools, the scale tool stands out. The restricted tools were the last two brush palettes because they are more literal, such as bubbles, fire, electricity, petals, stars, etc. The use of symmetry and straight stroke tools was also restricted. The main environments created by the application are minimalistic (Standard, Night sky, Space, Dress form, and Pedestal). This seeks not to distract with unnecessary visual stimuli and to immerse the user in a virtual space that influences their mood and motivation to enhance their creativity and concentration.[45] In addition, some environments, such as the one with a central pedestal, also function as a stage to present the created work. This is the environment that has been chosen for this experimentation.

Procedure

The pilot study and its evaluation took place in three sessions. The first session sought to standardise the concepts and importance of conception drawing as a process of architectural thinking. In order to find a shared understanding of the conception drawing between the participants, who came from different groups in which different teachers taught them the subjects of drawing and design, a ten-minute multimedia presentation was given in which the importance of conception drawing and its characteristics were explained. In the same session, a group training for all participants on the use of Head



Figure 4.
The multimedia presentation explaining the importance and characteristics of the conception drawing (left); And a student training in the use of the hardware and software (right), photographed by the authors, 2023

Mounted Displays with haptic controls and the use of the Tilt Brush software was carried out (Fig. 4).

In the software training, most of the brush tools, colours, guides, and other tools such as select, erase, transport, as well as save, export, and photograph were taught. However, the use of the straight stroke and symmetry tools was restricted (Fig. 5). The last part of this training allowed each participant to use the hardware and software for 20 minutes. At the end of this session, each participant was given the poem 'El Viento' by the Peruvian writer José María Eguren. No explanation was given beyond reading, understanding, and recognising the feelings and sensations that this text generated.

The second session was the actual experimentation with the IVR that each participant carried out. It began with the explanation of the design theme to be carried out, which was the creation of an architectural idea for the design of a Habitable Sculpture that allows the sensations of the poem to be experienced. It was explained to the participants that the aim of the design exercise was not to achieve a precise and finished architectural proposal, but only to convey an initial idea that could be further developed. The creation of the



Figure 5.
The 48 brushes offered by the Tilt Brush and the colour picker (above); and other tools, including the 'guides' tool (below), captured by the authors, 2024



Figure 6.
Two students creating their conception drawings with the HTC Vive HDM and Tilt Brush software, photographed by the authors, 2023

idea going through the four moments of the creative cognitive process explained above would have to be done entirely in the virtual environment (no pencil nor paper were used). The virtual environment with a pedestal was chosen and participants were asked to record the whole ideation process around the pedestal, as well as the finished idea on the pedestal. The whole experience lasted 60 minutes per participant, during which time the main researcher was present applying the observation sheet and the questionnaire and verifying compliance with the following time sequence that can be seen in Fig. 2. Initially, participants used the software and hardware for 25 minutes and in the virtual environment created the three-dimensional drawings of the first ideas. During this time, it has been applied the observation sheet (first instrument part 1). The movement, actions, reactions, and gestures of the participants were directly observed while they created the drawings, and what they drew was observed through a 65-inch TV screen as shown in Fig. 6. This was followed by a five-minute break to rest and also to apply the first part of the questionnaire (second instrument part 1). They then continued for another 25 minutes to observe the drawings previously made, scale them up, finish their inquiry, and finalise a conception drawing which was briefly explained by each participant. Throughout this time, the observation sheet (first instrument part 2) continued to be applied. At the end of the activity in the virtual environment, and for 5 minutes each participant finished answering the second part of the questionnaire (second instrument part 1).

In the third session, the Principal Investigator and two architects who are experts in architectural design reviewed the final drawings exported to the Sketchfab platform where the objects can be viewed, moved, and rotated through the computer screen (Fig. 7). The final drawings were also observed with the use of HMDs and haptic controls by entering the virtual environment of each participant. To evaluate the finalised ideas and their characteristics, the three experts applied a grade sheet (third instrument), which is shown in Table 3.

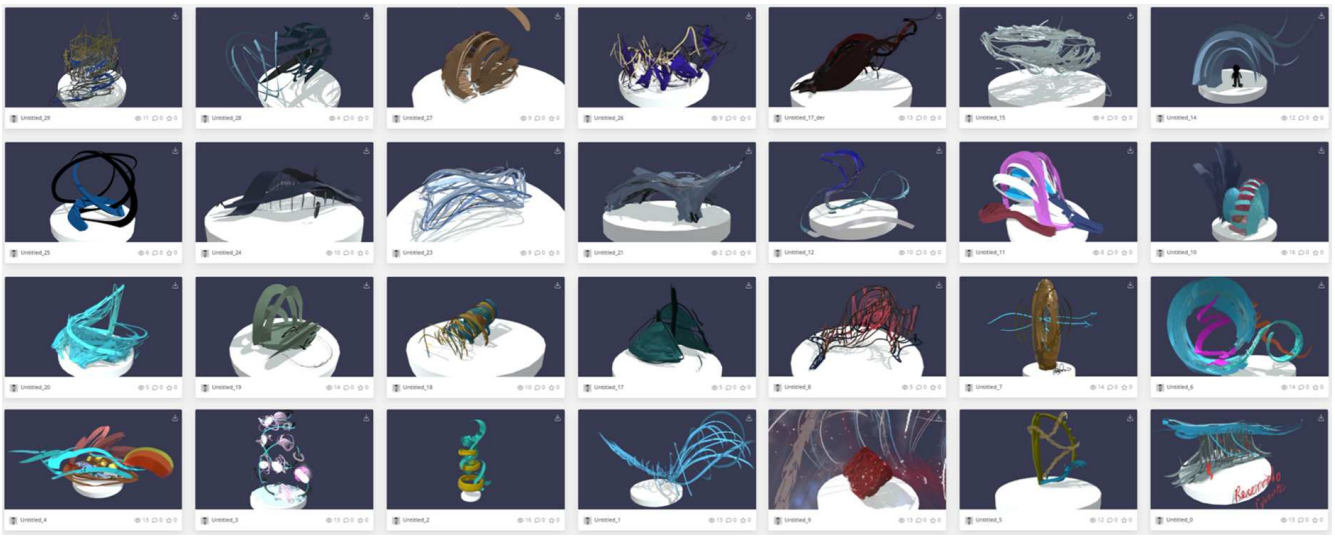


Figure 7.
The 28 conception drawings as a product, available on the Sketchfab platform <https://sketchfab.com/johnbel/collections/ivr-b8be915b5d6949dbafec60a2c7a3cac3>, uploaded by the authors, 2024

Results

The conception drawing as process

The observation sheet and the questionnaire provided the following results regarding drawing as an action and process. In both cases a 5-level Likert scale was used (Figs. 8 and 9).

Regarding the condition named 'the phenomenological act of drawing', the first observation was related to body movement and other gestures when drawing, as shown in Fig. 8. No exaggerated body or arm movements were found. The 3.3 points of the novices and 3.6 of the experts out of a maximum of 5 on the Likert scale mean tracked movements of hands, arms, and body are not exaggerated, but far superior to the movements of a person drawing with a pencil on a table or interacting with a computer via a mouse. Gestures expressing admiration, awe, or other feeling of satisfaction were very rare. However, when asked in the questionnaire (Fig. 9) about the experience of drawing in the virtual environment and its intensity, very high levels were obtained (4.7 novices and 4.8 experts). When asked what made the experience of drawing in IVR special or intense, the most recurrent comments were the feeling of being in an alternate or parallel world (Fig. 10). This appreciation by the majority indicates that participants experienced significant immersion in the virtual environment. On the other hand, the appreciation of both the possibility of creating almost anything or any stroke with the simple movement of the hands and the possibility of inquiring with the variety of strokes and effects offered demonstrate adequate agency.

Regarding the first characteristic, 'the undecided act of drawing', the observation regarding the initial creation of strokes and shapes in an inquiring way to investigate alternatives has resulted in 3.0 points in novices and 3.1 in experts, as shown in Fig. 8, demonstrating how all students have investigated types, thicknesses, colours, and shapes in a moderate way. It should be noted that,

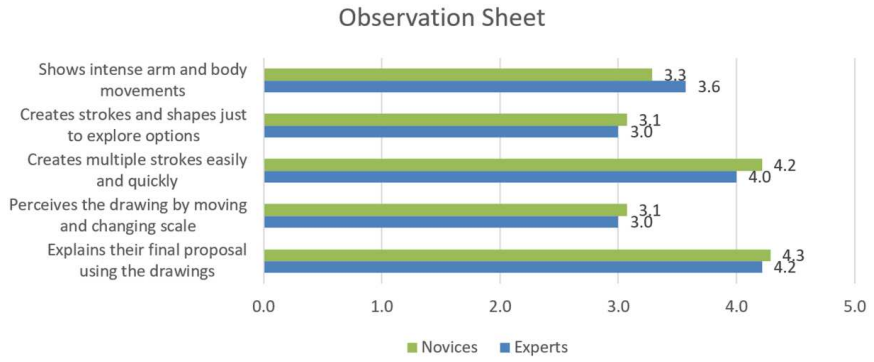


Figure 8.
Values obtained from the observation sheet regarding the drawing as process, compiled by the authors, 2023

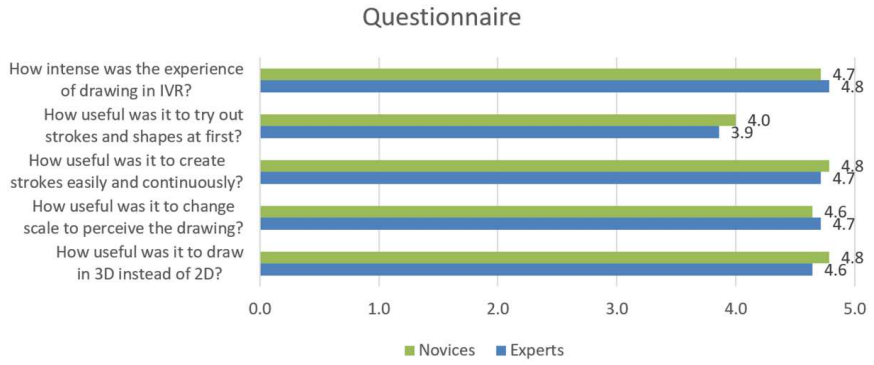


Figure 9.
Values obtained from the questionnaire regarding the drawing as process, compiled by the authors, 2023

before starting the experimentation, students were asked not to use more literal strokes, such as electricity, snow, sparkles, etc., or straight strokes with the square tool. They were allowed to use the 'guides' tool. Fig. 9 shows that, in the questionnaire, the valuation of the usefulness of trying various strokes and shapes was almost one point higher than what was observed (3.9 novices and 4.0 experts), which shows how the students felt that the inquiry through the types of strokes, colours, and thicknesses was useful in the search for materialising the initial idea. When asked about what was most interesting in the first moments of inquiry, the most recurrent answer was the facility to create diverse and varied types of strokes that favoured the creation of free and three-dimensional forms. The second most recurrent response was the feeling of being transported into another world. In both cases, the responses reaffirm what was expressed in the previous open question, as the sense of agency and presence have been important (Fig. 11).

Regarding the second characteristic, 'the continuous act of drawing', the novices have produced many previous inquiry drawings following the given instruction. Unlike them, the experts have created few drawings in the process and have developed the details of their ideas more. However, in both cases, whether inquiring through multiple drawings or developing an idea in more detail, students have had an intense and continuous drawing process (4.2 for novices and 4.0 for experts) as seen in Fig. 8. The ratings given by novices and experts to the usefulness of easily and continuously creat-



Figure 10.
Values obtained from the questionnaire regarding the phenomenological condition, compiled by the authors, 2023

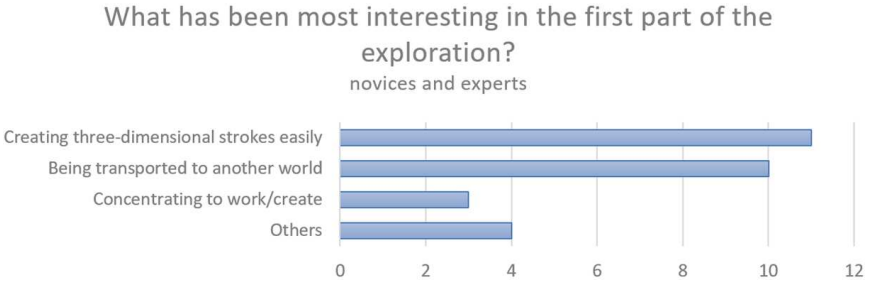


Figure 11.
Values obtained from the questionnaire regarding the first characteristic, compiled by the authors, 2023

ing drawings have been very high (4.8 and 4.7, respectively) and can be seen in Fig. 9. In the open question that sought to know the impediments during the drawing process, the most repeated answer has been the lack of time to draw since they did not find any impediment to create strokes in a fluid way except for the difficulty to draw depth which is overcome with the 'guide' tool which was also reported as a difficulty (Fig. 12).

Regarding the third characteristic, 'the perceptual act of drawing', after the 5-minute break, both groups were asked to observe the drawings created and to change scale for better perception and make corrections or new drawings later. Fig. 8 shows that both groups moved and used the change of scale to perceive what was drawn at a moderate level (3.1 novices and 3.0 experts). It was observed that no student dared to correct the existing drawings, but created new drawings as derivations of the previous ones. It has also been found that, to observe an object, the students used the controls to turn it much more than to move the body around the object. Fig. 9 shows that the value given by the students to the convenience of changing the scale to perceive the drawing was much higher (4.6 novices and 4.7 experts). In response to the open question about what was most striking in the second half of the drawing process, the most recurrent answer was how amazing it was to give scale and to be able to get inside their creations and observe from the inside. The second recurring response was to be able to fully perceive the three-dimensionality of the things created, and the third was to be able to observe the whole process of creating the idea (Fig. 13).

Regarding the fourth characteristic, 'the act of drawing to remember', it was observed that students moved and rotated the final 3D drawing to briefly explain their intentions and ideas (4.3 novices and 4.2 experts). Only three students wrote short texts in the virtual environment related to

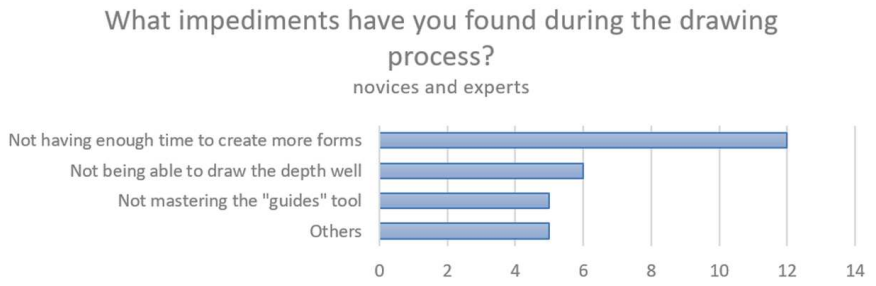


Figure 12.
Values obtained from the questionnaire regarding the second characteristic, compiled by the authors, 2023



Figure 13.
Values obtained from the questionnaire regarding the third characteristic, compiled by the authors, 2023

the main idea to support their explanations in them, as shown in Fig. 8. It should be clarified that all students dispensed with the technical conventions of axonometric, dihedral views, or conic perspectives when drawing three-dimensionally. When asked in the questionnaire about the usefulness of drawing in 3D to continue and develop the idea later, they expressed a high usefulness (4.8 novices and 4.6 experts), which can be seen in Fig. 9. When asked the open question of why they did not make two-dimensional drawings, all the answers expressed that it was not necessary having the possibility of doing it in three dimensions.

The conception drawing as product

To determine the characteristics of the design drawing as a product, a grade sheet was applied. For this purpose, the final drawings exported to the Sketchfab platform were observed, where the objects can be viewed, moved, and rotated through the screen of a computer or cell phone, as shown in Fig. 7. However, it was more useful to access the virtual environment with the HMDs and haptic controls, and directly observe the process drawings and the final result. A grade sheet (instrument 3) with a 5-level Likert scale provided the results (Fig. 14).

Regarding the phenomenological condition of the haptic drawing, before reviewing the four characteristics of conception drawing, it was observed whether the phenomenological experience of drawing in the virtual environment left traces of a haptic link between the drawer and the drawing. For this purpose, the use of various types of strokes, thicknesses, and colours was observed. It was found that expert students used more types of strokes, colours, and thicknesses, giving a very high level of haptic connection

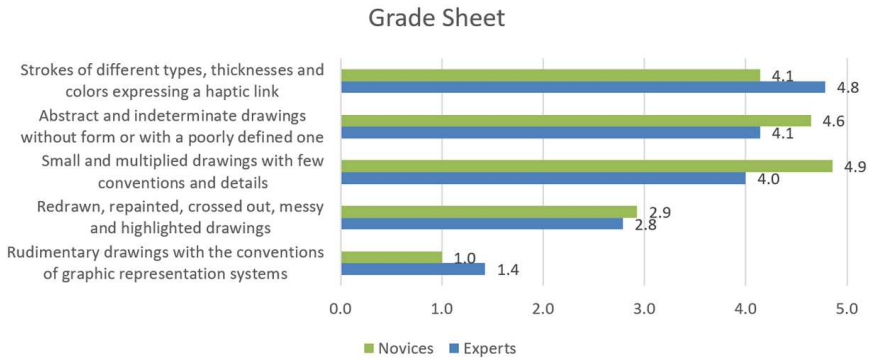


Figure 14.
Values obtained from the grade sheet regarding the drawing as product, compiled by the authors, 2023

(4.8). Although it was indicated not to use the more literal strokes such as electricity, flashes, strokes with movement, etc., it was observed that three of the experts used them. This expressed a greater haptic link with what was drawn. While the novices did not use the more literal strokes, their use of strokes, thickness, and colours were high (4.1), but lower compared to the experts.

Regarding the first characteristic, 'the unformed drawing', the observation of the drawings in terms of their form, indeterminacy, and level of abstraction has resulted in a very high level in the novices (4.6), and high but lower in the experts (4.1). This observation was mainly in the exploratory preliminary drawings rather than in the final drawing. Since the use of the square tool was restricted, all the abstract strokes were curved and free. Only two participants used the guide tool to make inquiry strokes. The finished drawings, being a final response to the cognitive process, were better configured and did not show much abstraction.

Regarding the second characteristic, 'the small, multiplied drawing', diversity of sizes has been found due to the different scales in which they were created. In an environment without many references, it is easy to lose the notion of scale. In all cases, the size of the drawings corresponds to the size that allows the movement of the hand with the forearm and arm, and this is larger than the small size of the drawings with pencil on paper that corresponds to the movement of the hand and wrist. Therefore, the assessment focused on the iteration and multiplicity of the drawings. A very high level has been found in novice students who have made many previous inquiry drawings (4.9) while experts have shown a high level, but lower than novices (4.0).

Regarding the third characteristic, 'the redrawn drawing', moderate values were found: 2.9 for novices and 2.8 for experts (Fig. 14). This showed the difficulty of recognising deleted, erased, or crossed-out strokes. In the virtual environment, deleting a stroke is very quick, easy, and leaves no trace. What has been found are superimposed strokes or accompanying strokes that have highlighted the idea giving them more value and detail, but at the same time generating a messy drawing. It is reminded that, after the 5-minute break, no one corrected, increased, or erased anything from the previous drawings; they only created new drawings.

Regarding the fourth characteristic, 'the conventional rudimentary drawing' and the use of graphic conventions to represent three-dimensional objects, it was found that only two expert students made some initial drawings in a two-dimensional way. But, in the final drawing, all students constructed the idea in a three-dimensional way. The results in Fig. 14 show very low ratings (1.0 and 1.4) because it was not required to use plans, sections, axonometric, or conic perspectives. Since only freehand strokes were used and not the straight stroke tool, all strokes are imprecise giving the final product a rudimentary finish. But they were three-dimensional enough to be understood and remembered clearly at any later time either in the same virtual environment or through the screen of a computer or cell phone.

Discussion

Impact of digital tools on architectural conception

The cognitive process of graphic ideation in the initial moments of the architectural project has been developed and historically strengthened through the drawing or sketch in which the sight and the movement of the hand are linked with an instrument, such as pencil or pen and a support such as paper where traces are left. Since the introduction in architecture of digital or computational technological, there is a consensus today that such incorporation alters the sensual and haptic connection between imagination, hand, and drawing, which has been deemed to negatively affect the initial moments of conception of the architectural essence of the building.[46] This, furthermore, is generating a crisis of the sensitive experience in architectural creation.[47] However, this research has found that the special features of the IVR with HMD and haptic controls added to the features for freehand artistic drawing of the Tilt Brush software represent a well-suited digital medium that offers the conditions and facilitates the cognitive processes for the quick and

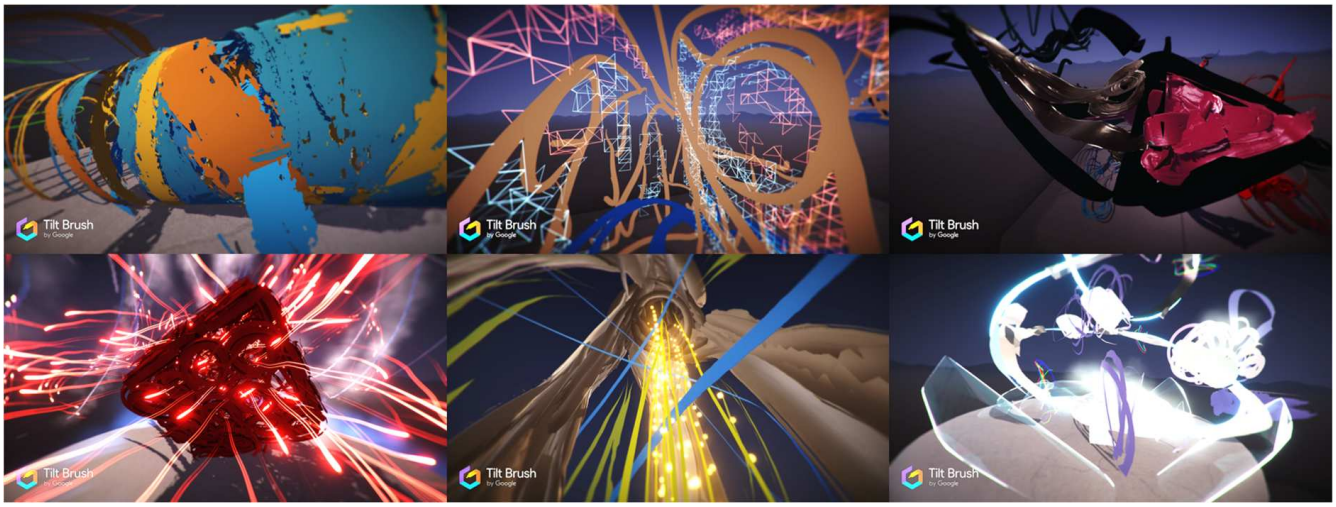


Figure 15.
Examples of the various types of strokes used by the students that denote a haptic linkage, with the lower part showing the use of the more literal strokes, compiled by the authors, 2024

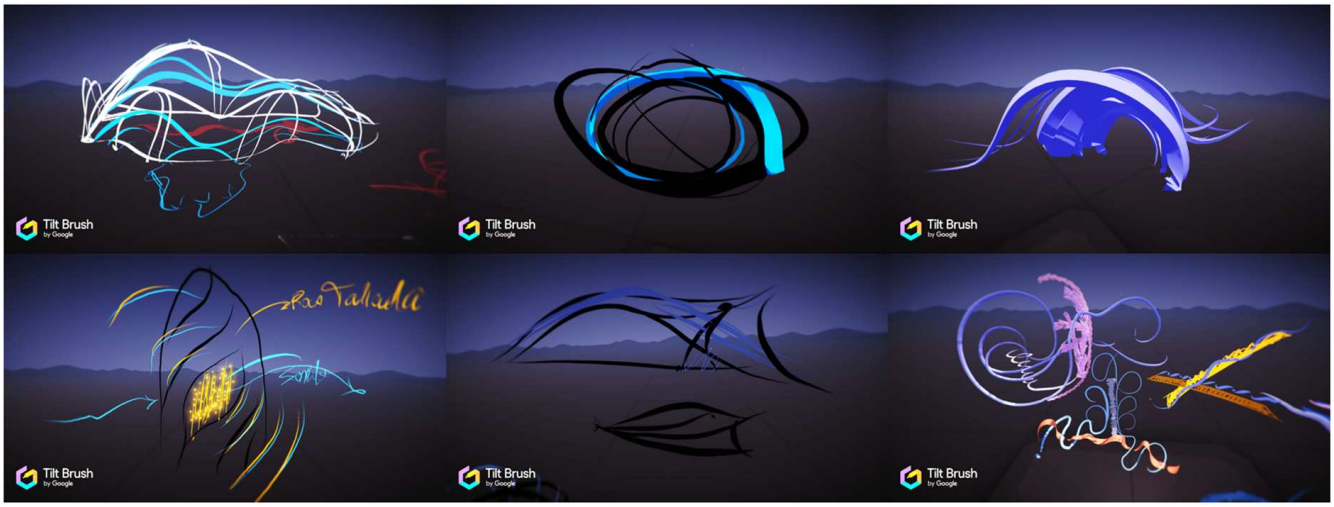


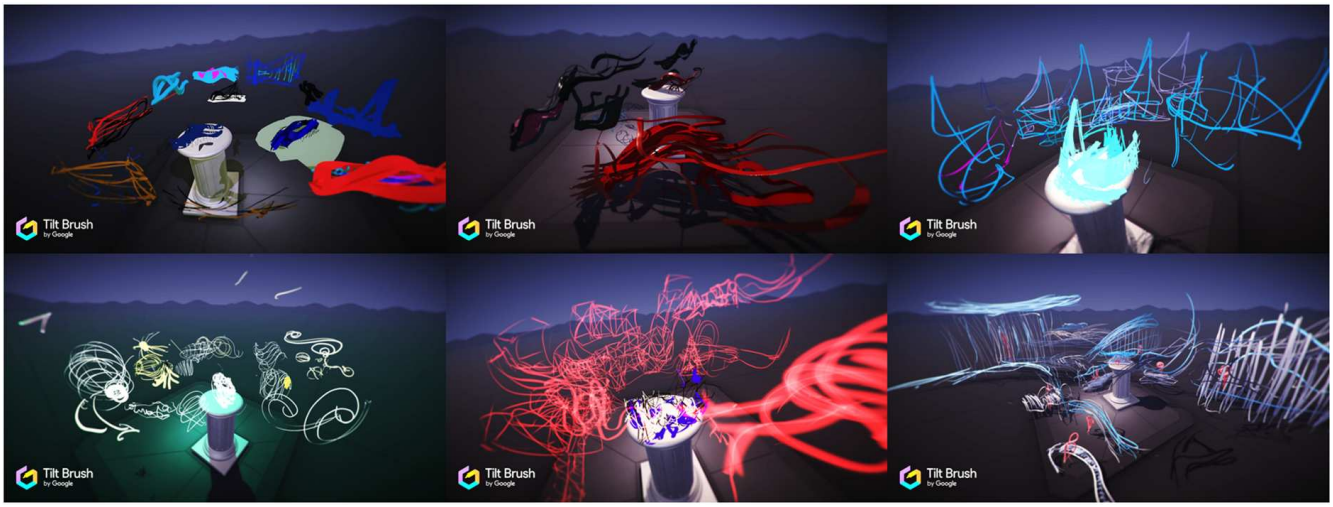
Figure 16.
Examples of the unformed drawing, compiled by the authors, 2024

Figure 17.
Examples of the multiplied inquisitive drawing that can be seen around the pedestal, compiled by the authors, 2024

easy creation of the first ideas of the architectural project through conception drawings (Figs. 15–19).

The virtual conception drawing as process

Regarding the condition necessary for the cognitive process, it has been found that the experience has been very intense according to the first closed question of the questionnaire. It is known that questionnaires, unlike biometric screening, may give socially desirable rather than true answers, which may underestimate or overestimate what is to be measured.[48] However, the first two responses to the open-ended questions seeking students' perceptions have been overwhelmingly direct in expressing the intensity of the experience due to the feeling of being in an alternate world and the ease of creating strokes with the simple movement of the hands. In other words, the creation of the conception drawings in the virtual environment has not only generated an



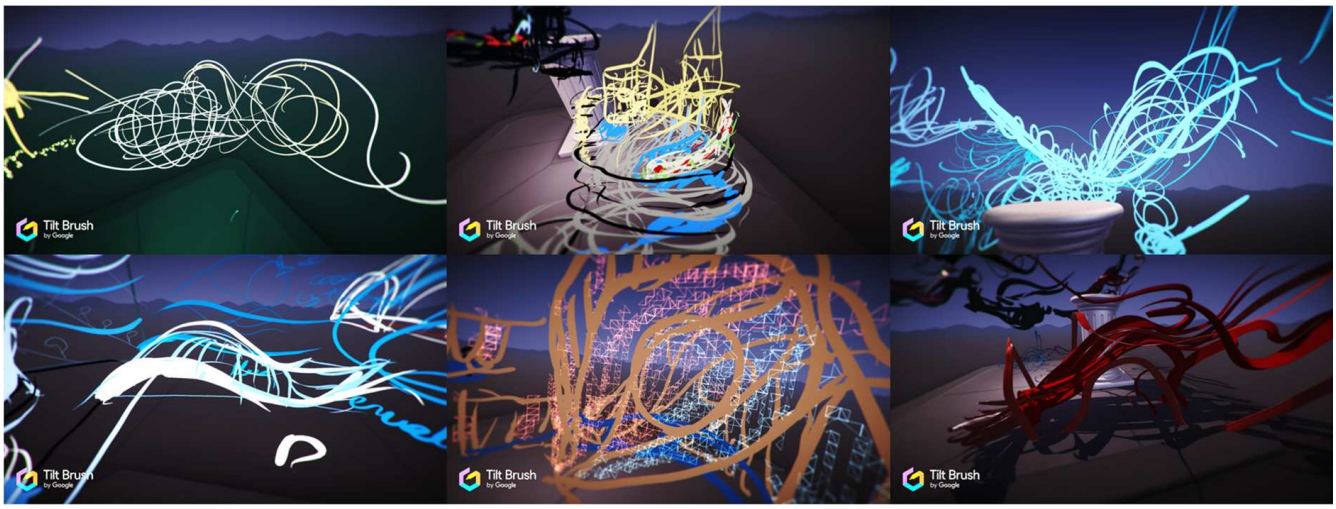
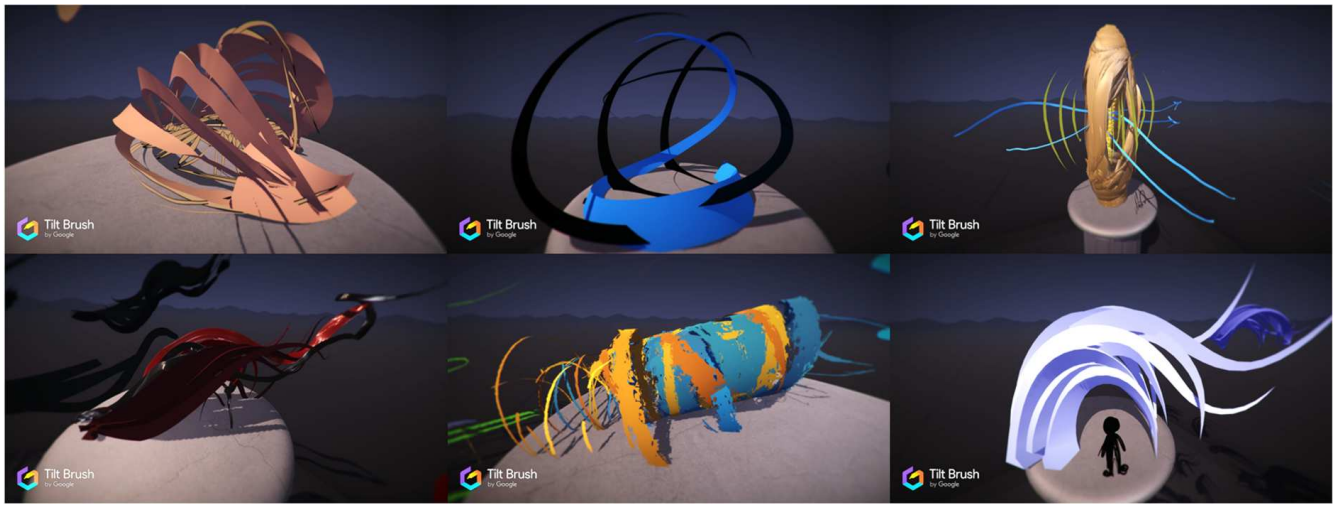


Figure 18.
Examples of the redrawn drawing, compiled by the authors, 2024

Figure 19.
Examples of the use of three-dimensional drawing instead of the bidimensional conventional rudimentary drawing, compiled by the authors, 2024

entertaining experience in the virtual world but also the feeling of being there (presence) and acting there (agency), which engages with the relational and emotional aspects of architectural conception that have made the experience very intense.[49] It can be inferred then that these two characteristics of the virtual environment have allowed the use of cognitive abilities to act in a virtual environment through bodily experience and movement which has generated a phenomenological experience, a necessary condition for the successful cognitive process of creating the first ideas of the architectural project.[50]

Regarding the characteristics of conception drawing as a process, it has been found that the four moments of the cognitive process mediated by the IVR have not been altered, interrupted, or deteriorated. This statement is made based on the last four items registered in the observation sheet and the questionnaire that sought to recognise the four characteristics of the four moments of the creative process. It can even be affirmed that the four moments of the



process have occurred naturally and with the following advantages with respect to the traditional process carried out with pencil on paper. At the beginning of the process, when the act of drawing is undecided because it is an act of critical investigation, when neither the forms nor the ideal strokes are known, the first advantage has been demonstrated.[51] At the point when it is required to inquire into the possibilities through the same tracing, the virtual environment has enabled easy, fast, and varied creation of different types of strokes and shapes as demonstrated in the second item of both the observation sheet and the questionnaire.[52] Even the observation of the restricted literal strokes, such as strokes with movement, luminescence, or flashes, have helped to better develop this initial moment of investigation and proposition.

In the second moment, which occurs when the strokes and forms used have been determined and the act of drawing now becomes continuous and fast, maintaining the flow of thought,[53] two advantages have been revealed by the third item of both the observation sheet and the questionnaire. The first refers to the fact that the continuity of drawing has been favoured by the almost unlimited space available in the virtual environment to build strokes, with minimum distractions and maximum clarity of interaction, which not only fosters creativity but also promotes concentration.[54] The second advantage relates to the easy creation of strokes and three-dimensional shapes. The continuous and almost uninterrupted process of the novices has taken better of the first advantage by developing many test drawings while the experts have taken more of the second advantage by focusing more on drawing details and making few iterations. The experts have learned throughout their college careers that time is of the essence when designing and that any idea is a good idea if it is given a good development. In either case, whether iterating or detailing, the continuous process of drawing happened fluently.

The third moment, destined to the action of perceiving and interpreting new meanings based on the drawings previously made in order to reinterpret, correct, expand, and improve, has also revealed two important advantages as shown in the fourth item of the observation sheet and questionnaire.[55] The perception of the drawings, being three-dimensional, has been easier and has required, in addition to movements and turns of the object, the movement and displacement of the body, which has reinforced the act of drawing as an experiential and expressive bodily behaviour. But the outstanding advantage has been the possibility of scaling the drawings to observe them very small or very large, and from the inside as if they were constructed buildings. The perception of space even if they are simple conception drawings is an outstanding advantage offered by the IVR.[56]

The fourth moment, demarked by the completion of a short cycle of this cognitive process to save the graphic information that can be resumed at another time,[57] has been shown to better configure and remember the idea developed. Here is another outstanding difference and advantage deduced from the last item of the observation sheet and questionnaire. Since the drawing in the virtual environment is three-dimensional, it has not been required to configure

and finalise the idea using the traditional two-dimensional representation systems, such as axonometric, dihedral views, and conic perspectives. The IVR conditions in this research have become a multimodal tool that allows drawing, designing, and constructing the architectural ideas three-dimensionally.[58] This three-dimensional configuration and completion have been much more useful and valued, especially by novice students who did not have the skills for conventional technical drawing. On the other hand, saving the file on the computer allows viewing at any time with simple viewers such as Microsoft''s Visor3D without the need for IVR hardware or software. And the simple export of the drawings to platforms such as Sketchfab (sketchfab.com) allows the object to be viewed three-dimensionally at any time from another PC or mobile device. This ensures quick and easy access to the drawings to resume the ideation process at other times.

The virtual conception drawing as product

Since each medium has its own praxis that another medium cannot provide to the designer,[59] the similarities and differences between this virtual immersive environment and traditional drawing have been analysed and compared in terms of their results or outcomes. Regarding the first characteristic, it has been found that the inquiry of strokes and shapes has resulted in formless and abstract drawings very similar to those done with pencil on paper. The major difference would be in their three-dimensionality. In the second characteristic that refers to small, multiple drawings, it has been found that the size of virtual drawings is not so small because it results from the movement of the whole arm and body in contrast to the movement of only the hand and wrist in traditional drawing. But, with respect to the multiplicity of the drawings, this has been given the same conditions. As for the third characteristic that refers to redrawn, reworked, crossed out, and remarked drawings, a small difference has been found, since the ease of eliminating strokes without leaving traces or duplicating an object to modify it has produced drawings with few of those characteristics. What has been found is other types of strokes that, when superimposed with the initial ones, have conferred greater enhancement and at the same time disorder. Finally, the last characteristic that refers to the use of conventional representation systems in a rudimentary way is the one that is the most differentiated. The only thing that has been found is a single final drawing that, being three-dimensional, has more characteristics of a conceptual model. This three-dimensional object, being scalable, has more characteristics of a rudimentary and schematic building, which expresses more convincingly the intentions of the initial idea of the architectural project. It was to be expected that the use of a medium very different from the traditional pencil and paper would result in different outcomes, possibly registering an altered or distorted cognitive process. Contrary to this assumption, virtual conception drawing shows the important advantage of three-dimensionality and scalability over the creation of ideas through conceptual and

material models. To demonstrate this, the research team is currently conducting further experiments that will be reported in future publications.

In general, according to the evaluation through the grade sheet and the appreciation of the three design experts, the 28 finalised drawings show architectural ideas with a high degree of abstraction, symbolism, and graphic expression, which are difficult to obtain at the same time (one hour) using pencil and paper. The finalised ideas are shown as a synthesis and three-dimensional materialisation of the architectural idea in its pure state and with a certain formal autonomy typical of sculptures as more or less precious objects.[60] This is the way in which, from the most renowned architects to students of architecture, the first ideas of any architectural project must be conceived to house the essence of the idea to allow in later phases the development of the architectural project.[61]

Challenges in implementing IVR in architecture

The most important disadvantages are related to the availability of hardware and software and the duration of use of the technology. It is not common or easy to have spaces with IVR devices installed and ready to be used in architecture schools. Time of use is another disadvantage as it cannot be used for a very long time to avoid reported cybersickness such as nausea, dizziness, or visual fatigue, among others.[62] Finally, another difficulty is the lack of technical skills of teachers to facilitate and experiment with these technologies to determine their possibilities, uses, advantages, and disadvantages.[63]

Conclusions

After conducting an experiment with architecture students of the first and last year of university studies to materialise their first ideas for the design of a habitable sculpture in an immersive virtual environment, the results provide preliminary evidence to support both hypotheses. That is, the use of a virtual reality environment with HMD, haptic controls, and a software created for freehand artistic drawing seems to generate the necessary phenomenological condition for the cognitive process of creating the first ideas of the architectural project. Furthermore, these results suggest that the IVR could facilitate the creation of such ideas with the same characteristics of the traditional conception drawing made with pencil on paper.

The research also identifies preliminary advantages in the use of the virtual environment for conception drawing during the process of creating the first ideas. The act of drawing the first architectural ideas in the virtual environment has developed in many cases as a phenomenological extension of the body which is the necessary condition for a successful cognitive process. This has happened due to the immersion developed by the virtual system combined with the possibility of creating three-dimension drawings through bodily experience and movement.

The ease of creating different types of strokes, thicknesses, colours, and shapes without the need to be familiar with the techniques of using such instru-

ments greatly favours the exploration of possibilities through the tracing itself. The almost unlimited space and the highly immersive environment offered by the virtual environment for the creation of three-dimensional drawings foster concentration and continuity in the cognitive process so capture thoughts as much as possible. The possibility of giving scale to three-dimensional objects as well as rotating and moving them improves the perception of the drawings created. The perception of the objects from the outside to understand their volumetry is important. But even more important is the perception of the objects from the inside as if they are rudimentary buildings, but enough to understand and feel them.

The multimodality and confluence of the actions of drawing, designing, and constructing architectural ideas as three-dimensional objects has facilitated the configuration of the final idea. This has happened without the need to use traditional two-dimensional representation systems, such as axonometric, dihedral views, and conic perspectives. This advantage is of particular interest to novice students who have not mastered technical drawing or whose spatial skills are weak.

Regarding conception drawing as a result or product, the findings suggest that the finalised ideas created in the virtual environment have the same characteristics as conventional drawings made with pencil on paper with the following advantages. The final drawing shows a finished idea with a high degree of abstraction, symbolism, and graphic expression that is very difficult to obtain at the same time (one hour) using pencil and paper. The three-dimensionality of the idea and its perception from different angles and scales is a feature that cannot be achieved by traditional conception drawings. The rest of the characteristics remain small but in no case do they interfere with the process of creating the first architectural ideas. What must be understood is that this new medium for conception drawing will give different results, which must be handled and used in different ways, but with the same purpose and usefulness of materialising the first ideas.

The implications of this research for the teaching and practice of architecture are promising, suggesting that the integration of IVR into the architectural design curriculum could potentially enhance the creative training of architecture students. This research represents a starting point, and it is crucial to continue researching and developing interfaces and tools within the IVR that further enhance these capabilities, ensuring that the technology serves as an effective complement to, rather than a substitute for, the human creative process.

The small sample size is a significant limitation in this research, as the results of the study should be considered as only indicative of trends rather than definitive confirmations of the effects assessed. These conclusions should be understood as preliminary although they are encouraging and convincing.

Based on the results obtained and the limitations encountered, future studies should be conducted with larger samples that can provide a more rigorous validation of the preliminary findings presented and to use other data collection

instruments such as biometric screening. This will not only help to confirm or refute the trends observed in this study but will also allow for a deeper exploration of the variables and conditions under which virtual reality can be more effectively integrated into architectural education and practice.

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The Conceptual Model Mediated by IVR and 3DP as a First Architectural Idea Generator

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Abstract: The first ideas generation of the architectural project has traditionally been carried out through sketches. Even though in recent decades models have also gained importance, their use is still restricted due to the time required to make them and their difficulty of realization when it comes to complex forms. This research argues that the use of concept models mediated by two disruptive technologies such as Immersive Virtual Reality and 3D Printing can foster the cognitive process of the ideation and configuration of the first architectural ideas. To demonstrate the hypothesis, a pilot study was conducted with 32 architecture students; 17 students created models manually and 15 used IVR and 3DP. Two observation sheets were used to collect information. The results show that in the process of generating ideas, the group that used the two technologies developed three of the four characteristics of the cognitive process better, being an undecided and slow process, then fast and continuous, and finally perceptual for reinterpretation. Also, both technologies complemented each other and favored the development of an intense, tactile, and phenomenological experience. Finally, regarding the model as a product, a better result was found in 3D-printed models in terms of two of the three characteristics, three-dimensionality complexity and materiality. It is concluded that these two technologies ideally complement each other as mediating tools for three-dimensional architectural thinking, making it possible to use the conceptual models as the first generators of the architectural idea.

Keywords: architectural modeling; ideation; configuration; creativity; technologies; mock-up

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1. Introduction

The conception of the first architectural idea occurs in two successive phases, ideation and configuration. In the ideation phase, the first ideas are generated, and in the configuration phase, such ideas are concretized in architectural figurations [1]. This process has traditionally occurred through drawing. Models could also have been used as the first generators of the idea if their construction occurred with the same naturalness and ease with which sketches are made [2]. These special feature models are called concept models, and only in the last decades have they started to be used more frequently, becoming even a sign of professional or vanguard credentials of the most prestigious architectural firms [3]. However, when it concerns ideas involving complex forms, the construction of a model becomes a difficult task to execute, which may require the mastery of some special fabrication technique or simply require a lot of execution time. This research seeks to recognize the advantages and disadvantages of the use of a conceptual model mediated by Immersive Virtual Reality (IVR) and 3D Printing (3DP). For this purpose, an empirical study was designed with architecture students divided into two groups: one using traditional manual modeling techniques and the other using IVR and 3DP. Observation sheets were used to record the creative process and the characteristics of the final models to allow for a comprehensive comparative analysis between the two methodologies.

2. Literature Review

2.1. Architectural Idea Generation Using a Conceptual Model

Conceptual models, also known as conception models or sketch models, serve as sketches or conception drawings in the process of the ideation and configuration of the first ideas of the architectural project, so they are also known as three-dimensional sketches [4,5]. In this regard, the cognitive process of the creation of the first architectural idea through a model shares with the process of drawing the same phenomenological condition and its four characteristics [6]. It is important to recognize the condition and characteristics that have led the concept model to be an important competitor to conception drawing today. Understanding this will then allow for being critical of technological incursions that may affect the creative process.

2.1.1. The Phenomenological Condition

The creation of models has been shown to play a significant role in the construction of the experience of knowledge [7]. That experience in direct relation to the human body not only allows for understanding the three-dimensionality of the spaces in the model [8] but also creates a phenomenological experience [9]. The development of creativity from the experiential realm is achieved through the manual creation of models [4]. Modeling like drawing involves actions and reactions of highly subjective, sensitive, and emotional content that are sustained by the haptic relationship between the object and the subject. The hands complement the sense of sight and the rest of the senses to fill the material with authenticity [10] and create the phenomenological experience. Subtracting this condition from the creative process breaks the intuitive and emotional connection between the designer and the model, resulting in more generic and less sensible designs that lack the depth needed to create meaningful spaces.

2.1.2. Characteristic 1: Undecided and Slow Modeling

The ideation process at first is a slow and progressive process that is full of doubts and based on indecision [11]. Since the idea is not completely defined, its creation does not seek to arrive at a final answer but rather to make the modeled objects elements of creation and the organization of ideas [12]. Moreover, this process must eliminate the superfluous elements to show the idea in its pure and abstract state [13]. This abstraction effort in search of the guiding idea then becomes its goal [14]. As in drawing, deliberate or accidental indecision or indeterminacy allows for preserving alternatives while retaining a deliberate ambiguity [15]. Thus, the first moment of the cognitive process is slow and indecisive in the choice of forms and materials. In computational modeling processes this reflection is either eliminated or accelerated to the point where it results in the less in-depth exploration and evaluation of alternatives, resulting in less thoughtful and potentially less relevant ideas.

2.1.3. Characteristic 2: Rapid and Continuous Modeling

After the first moment, the cognitive process itself opens up to many possibilities, which must be caught quickly in order to capture the rapid flashes of mental stimulation [16]. The process then becomes fast and continuous, and for that purpose, it uses the size and the elementary. The small size of the models not only allows for a fast modeling process but also allows for processing the visual image with maximum detail due to the visual field [15]. This means making models that may well fit in one hand [17] or are never larger than 15 $\times$ 15 cm [14]. On the other hand, elementary implies simple and experimental objects [18], and even if high three-dimensional complexity is required, one should look for unfinished and imprecise objects that can be changed and reshaped quickly [3,18]. Although the manual process of creating conceptual models itself often does not achieve the multiplication that allows new ideas to be captured and explored quickly for the continuous and dynamic development of the design, it is necessary to recognize its importance, as the prestigious Office of Metropolitan Architecture (OMA) does when they state that they start with a conceptual model of the building that can then easily grow to 30 or 50 models [19].

2.1.4. Characteristic 3: Perceptual Modeling

The process of modeling the idea, as with the act of drawing, at some point becomes a perceptual act that seeks to interpret new meanings based on what was previously created [20]. The importance of creating ideas with models lies in the degrees of imprecision, undefinition, and suggestive indeterminacy that allow for reflection, exploration, and inspiration towards alternative designs [21]. The perception of the material delimiting the emptiness and the effects of shadows and light can only be given by observing and touching the model [8,14,22]. The perception of the material itself with which they have been made allows for analyzing their physical characteristics [23] and their connotations or meanings that can give a new context to the architectural idea [14]. Subtracting this characteristic from the creative process could limit the ability to interpret and reinterpret the design, reducing the opportunity to discover new possibilities and contexts for the architectural idea.

2.1.5. Characteristic 4: Confrontational Modeling

At the end of a cycle of the cognitive process, it is necessary to finish configuring the idea to discuss it or take it up again at another time. Unlike the act of drawing, which configures through rudimentary representational drawings, the model has the advantage of representing the space in its three perceptible dimensions from the first volume created [18]. However, the final configuration that allows for self-confrontation and confrontation with others, supported with spoken discourse [24,25], is achieved by sharpening visual and tactile perception and making final readjustments of the position, relationship, and materiality. The confrontation will allow for revealing gaps in the idea and opening criticism and discussion. It will also allow for clarifying erroneous conclusions about the intention of a project [3]. All this will allow for continuing the cognitive process in the next cycle.

2.2. Characteristics of the Conceptual Model

Conceptual models, as opposed to presentation and working models [18], are important tools in the ideation and configuration phases of the first ideas of the architectural project. This allows for materializing in a tangible, three-dimensional, exploratory, and preliminary way the fundamental ideas and concepts underlying the architectural proposal to be evaluated, discussed, refined, and validated before continuing with the next phases of the creative process. As with the process, it is important to recognize their following characteristics as finished products to understand the advantages and disadvantages when compared to other manufacturing methods.

2.2.1. Representation of Three-Dimensionality

The main characteristic of any physical model is that it offers the unique possibility of representing space in its three perceivable dimensions. This in the conceptual model allows for a direct understanding of space, which is more relevant when dealing with complex shapes [26]. Because of its small size and easy handiness, it perceptually approaches axonometry, which allows for a dynamic perception of its views vistas [14,27] and the discovery of new possibilities and potentialities of architectural space [23]. Finally, in the perceptual process of its three-dimensionality, views and volumetric relationships emerge out of what is anticipated, promoting and developing a more intense creative process [28].

2.2.2. Representational and Experiential Materiality

Another characteristic that is as or more important than three-dimensionality is its material and volumetric sense, which gives rise to other senses such as touch and "physicality" [4,27]. This allows for a tactile and sensory understanding of the materialized idea that enables direct experiences because light is seen by perceiving shadow and emptiness is understood by detecting matter [22]. The qualities of materiality allow one to explore correlations between different forms, between forms and illumination, and between forms

and emptiness [23]. Furthermore, the choice of material for its own connotations or meanings gives it abstract qualities [14] that transcend the merely visual qualities, allowing for a sensory and haptic experience that influences the conception.

2.2.3. Conceptual Abstraction

These models encapsulate the conceptual essence by concentrating on the visual representation of fundamental ideas without detailing specific elements. It reveals the essential and avoids the superfluous in order to focus on the only thing that is proper to the architect: reason, matter, and light [22]. Its small size facilitates this approach to abstraction, presenting itself as a synthesis and constituting the physical materialization of the architectural idea in its pure state [13]. Abstraction confers a certain formal autonomy inherent to sculptures that makes it a more or less a precious object [14]. This abstraction facilitates effective communication and allows for a more flexible interpretation of the conceptual vision, highlighting the importance of physical materialization in expression.

2.3. The Digital Model

The digital model is an accurate, detailed, and three-dimensional computerized representation of an architectural object created by 3D modeling software that allows for visualizing, analyzing, and modifying the object before its physical construction. Its visualization and modification are carried out through interfaces displayed on the computer screen and data entry via the keyboard and mouse. Its main advantage, which has led it to almost displace the presentation model completely, is its accurate and realistic representation of three-dimensionality and materials. Despite its wide range of qualities and advantages that continue to transform the practice of architecture, digital modeling is not yet an important possibility when it comes to constructing models at the conceptual level, i.e., at the first stage of the creative process, for the following reasons. Its lack of materiality [29] and tangibility [30], or, as others call it, physicality [27], detract from the phenomenological experience and the haptic and direct experience with materiality [10]. Although there are now software that offer a high degree of manual control over the modeling process, which is ideal for creative and artistic tasks, such as digital sculpture and 3D animation (Zbrush and Blender, among others), most of them offer a high degree of geometric control [29] and high mathematical precision [30], making digital modeling a deterministic process that operates in a limited solution space and with predefined options [21]. This added to its immediateness and contrasts it with the indecisive and slow reflective process needed to achieve effective abstraction [10,22]. While this immediacy allows for the easy duplication and modification of models, it is not the iteration that confers advantages in the intuitive, rapid, and continuous creation process [23,31]. Finally, the perception and confrontation of the three-dimensional idea through a computer screen is effective, but not as effective as the tactile perception of the physical model.

2.4. The Virtual Model

The virtual model is also a digital model, so it shares with it all its characteristics, with the following differences. The visualization and manipulation of the objects take place in an immersive environment, which allows for realistic immersive experiences of full-scale designs for a better perception of the three-dimensionality and interaction with the object. For this reason, most of the 3D modeling software for architecture (Autodesk VRED v2024, Iris VR Prospect v1.0, Enscape v3.5, and Graphisoft BIMx v2023, among others) have their version for IVR. However, these versions are mainly focused on visualization as the digital models are created in digital modeling software and exported to the virtual environment where they can be modified, but with very little possibility of creation. Although other software allow for the creation of volumes, they maintain the characteristics of high geometric control and mathematical accuracy. For these reasons, the choice of software is important [23]. Some studies have used more artistic than architectural software to explore its creative potential for the early stages of the architectural design process [32]. For example,

software designed exclusively for creating in the immersive environment such as Tilt Brush, Gravity Sketch, MasterpieceVR, Quill, or Blocks (2023 versions) offer the advantages of the free creation of strokes and objects in direct relation to hand and body movement [32], where geometric control or mathematical accuracy is not required. These characteristics foster reflection through indecisive and slow modeling, leading to conceptual abstraction, and foster rapid and continuous modeling due to the ease of creation. Although it is true that a phenomenological experience cannot be fully given in the virtual environment, it comes very close thanks to the movement of the body and hands, with the haptic controls fulfilling that condition. Finally, despite not having physicality, which avoids the haptic experience of the material, the representation of materials that foster conceptual abstraction can be very useful.

2.5. The 3D-Printed Model

A 3D-printed model is a three-dimensional physical representation of an architectural object created by means of three-dimensional printing technologies that allow for a tangible interaction of the architectural structure and thus a better spatial understanding of it. Since every 3D-printed model has its origin in a digital model, it adopts the advantages and disadvantages of the digital modeling process described above. However, the main advantage of the model as a final physical product is its tangibility, which distances it from the digital and virtual models and puts it on a par with the hand-built model. In this way, the 3D-printed model fully meets the first two characteristics of the conceptual model: the representation of three-dimensionality and the representational and experiential materiality. However, this last feature does not yet take advantage of the technological development that allows for printing in translucent and color resins, in filaments with stone, metal, or wood-like finishes, or in materials that are on a par with translucent micas, balsa wood, or textured cardboards, which achieve such good results in the execution of manual conceptual models. Another important advantage is the ease of materializing complex shapes that are very difficult to create manually. This 3D printing capability allows designers to move forward with any idea regardless of its complexity [26], removing the limitations imposed by traditional manual modeling techniques. With 3D printing, architects can explore intricate geometries and precise details that would otherwise be too laborious or even impossible to build by hand. Finally, conceptual abstraction, which is the third characteristic, is not fed by a reflection process when it is created digitally; therefore, 3D printing does not improve it either [21] because the manufacturing process is completely detached from the hands and time of the creator. This can end up producing fascinating objects that have "escaped" from the computer screen without any concept to support them [29]. In addition to this disadvantage, there is an attitude of visualizing the printed models as a final product, and there is a lack of a sense of scale as a conceptual resource [30].

3. Hypothesis

The weaknesses and strengths offered by digital technologies such as digital models, virtual models, and 3D-printed models compared to those of the traditional physical model are summarized in Figure 1.

This research argues that the cognitive process of the ideation and configuration of the first idea of an architectural project through a conceptual model can be fostered with the incorporation of two disruptive technologies that complement each other to obtain all the advantages of manual modeling and models (see the green route in Figure 1). The first technology is Immersive Virtual Reality (IVR), which, in addition to fostering the quick and easy creation of strokes and volumes with the simple movement of hands equipped with haptic controls, allows such creation to be a phenomenological experience. Furthermore, it fosters the perception and understanding of the shapes and spaces created by allowing the immersive environment to easily change scale, which allows for immediate reinterpretations. The second technology is FDM 3D printing, which is low-cost, very

precise, and fundamentally very versatile for manufacturing objects of complex geometries. This technology, among other advantages, fosters and creates the haptic link with the materiality of the object, a major disadvantage of all digital models including the virtual one. Moreover, by allowing the physical and three-dimensional materialization of the idea, it provides it with all the advantages of the manually manufactured model. The following hypotheses are proposed:

H1: *The integration of the IVR in the process of the ideation and configuration of the first architectural idea through a virtual conceptual model not only shows similar characteristics and conditions as the same traditional process with physical conceptual models but also favors the quick and easy creation and modification of multiple forms and volumes, making such creation a phenomenological experience. Students using IVR are expected to have a higher number of iterations and modifications to their conceptual models due to the ease of virtual manipulation through hand and body movement compared to students using manual techniques.*

H2: *The integration of 3DP in the materialization of the first architectural idea not only helps to produce physical models with similar characteristics as the manually produced conceptual models but also favors the more accurate creation of three-dimensionally complex forms. 3D-printed models are expected to exhibit greater three-dimensional complexity, allowing for a better spatial and tactile understanding of architectural ideas compared to hand models.*

Modeling & Model	Features	Handmade model	Digital model	Virtual model	3D printed model
Modeling as a process	Phenomenological condition	✓✓	X	✓✓	X
	Undecided and slow modeling	✓✓	X	✓✓	X
	Fast and continuous modeling	✓✓	✓✓	✓✓	✓✓
	Perceptual modeling	✓✓	✓	✓✓	✓
	Confrontational modeling	✓✓	✓	✓✓	✓
Model as a product	Three-dimensionality representation	✓✓	✓	✓	✓✓
	Represent. and experiential materiality	✓✓	✓	✓	✓✓
	Conceptual abstraction	✓✓	✓	✓✓	✓✓

Figure 1. The features of the modeling as a process and of the model as a product and their comparison with three technological tools. ✓✓ means high strength, ✓ means low strength, and X means weaknesses. The ideal technological route is shown in green.

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4. Methodology

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H2: The integration of 3DP in the materialization of the first architectural idea not

4.1. Pilot Study

The pilot study was carried out with students of the Architecture course at the Universidad Nacional de San Agustín de Arequipa in Peru. It has been focused on the analysis of the phases of the ideation and configuration of the first idea of a small architectural project within the subject "Architectural Design Workshop 1". The students were divided into two groups: one using traditional manual modeling techniques and the other using IVR and 3DP. Each group developed conceptual models from an initial architectural idea. Observation sheets were used to record the ideation and configuration process and to evaluate the characteristics of the final models. The evaluation criteria considered four process characteristics and one phenomenological condition, and the final model evaluation criteria considered three characteristics.

4.1.1. Participants

For the experimentation, the 33 students in group B of the subject were divided into two subgroups. The division was random but maintained equity in terms of their academic performance, as reflected in their grades in the first part of the subject. This ensured that the inequality of prior learning did not distort the results of the experiment. For the final selection, Google Forms was used to determine who met the following archetype: students who were taking the subject for the first time, who had not used virtual reality glasses

final selection, Google Forms was used to determine who met the following archetype: students who were taking the subject for the first time, who had not used virtual reality glasses before, who did not suffer from color blindness, who did not suffer from migraines, and who did not have an easy tendency to dizziness. With this information, the experimental group consisted of 15 students, made up of 7 females and 8 males, with an average age of 17.8 years. The control group consisted of 18 students, made up of 13 women and 5 men, with an average age of 18.1 years. For their participation, the students signed a consent form endorsed by the Ethics Committee of the university.

4.2. Instruments and Materials

Two observation formats were created for data collection. Observation Sheet 1 was designed to observe the behavior of the students during the process of generating the architectural idea through the construction of a conceptual model. The experimental group was observed in the virtual environment, and the control group was observed during the manual construction of the models. The five aspects observed and shown in Figure 2 are directly linked to the single condition and the four characteristics explained in Section 2. The evaluation was carried out through a five-level Likert scale.

Observation Sheet 2 was designed to observe and evaluate the presentation of the model as a final product in both groups. The three aspects referred to the three characteristics of the conception model explained in Section 3 (Figure 2). The evaluation was also carried out with a five-level Likert scale.

OBSERVATION SHEET 1 Student name:	Very low frequency / intensity	Low frequency / intensity	Moderate frequency / intensity	High frequency / intensity	Very high frequency / intensity
Shows intense hand, arm, and body movements	○	○	○	○	○
Creates shapes and volumes just to explore options	○	○	○	○	○
Creates multiple shapes and volumes easily and quickly	○	○	○	○	○
Observe the shapes and volumes to reorganize them	○	○	○	○	○
Explains the conceptual idea by showing the model	○	○	○	○	○

OBSERVATION SHEET 2 Student name:	Very low frequency / intensity	Low frequency / intensity	Moderate frequency / intensity	High frequency / intensity	Very high frequency / intensity
It displays a three-dimensional complexity that can only be understood by moving and observing the object	○	○	○	○	○
It displays a materiality that induces to touch the object and to study it under the sunlight	○	○	○	○	○
It displays a simple conceptual abstraction that gives it the autonomy of a beautiful object	○	○	○	○	○

Figure 2. The Observation Sheets 1 and 2 with the criteria and the five-level Likert scale.

The IVR equipment consisted of two HTC Vive Head Mounted Displays (HMD) along with their haptic controls, which are controls that allow for tactile interaction with the virtual environment. This hardware is complemented by two Intel Core i7 PCs with a NVIDIA GeForce RTX 3080 graphics card and 32 GB RAM and two 65" TV screens. All the IVR equipment is installed in two rooms of 7 m^2 each exclusively for IVR experiments. The software for the 3D modeling was Google Blocks. This application was chosen because it was created exclusively for freehand modeling using haptic controls with moderate geometric control and mathematical precision. While its modular nature might limit creative freedom, two other aspects influenced its choice. First, it is a tool with a relatively low learning curve, which facilitates its integration in a short experimentation. Second, unlike other applications such as Tilt Brush, Gravity Sketch, or Quill, the models exported from Blocks are accepted by 3D-printing applications. Finally, for 3D printing, four Creality filament printers and the Ultimaker Cura software (v 5.3.0) were used to set up the print. For the work with the control group, the workshop classroom was used for the development of the subject.

4.3. Experimental Design

The experimentation consisted of the materialization of the first idea for a tourist pier and viewpoint on the banks of the Chili River in the city of Arequipa through a conceptual model. The 33 students, after the analysis or pre-design phase, proposed the first idea of the project in a workshop. This idea was executed through freehand drawings on an A3 sheet of paper. Once the teachers' feedback was finished, they were called together three days later to finish the ideation and configuration of the first idea through a conceptual model. The specific task was to build a conceptual model of the tourist pier and viewpoint without a specific scale on the ground model measuring 20 × 20 cm. This conceptual idea had to consider three spaces: the reception, the viewpoint, and the pier. The model was to be white on the brown ground. To carry out this specific task, the experimental group worked separately in two sessions as follows.

In the first session, the experimental group underwent training in the use of the HTC Vive HMDs with haptic controllers and the "Google Blocks" software (v 1.0) within the Digital Design and Fabrication Lab. The students learned how to create 3D objects in a virtual environment using only the six available tools of the software: Shape, Stroke, Eraser, Grab, Paint, and Modify. With the shape tool, they created various types of polyhedral and curved surfaces such as cones, cylinders, and spheres. With the stroke tool, they created freehand strokes, and with the modify tool, they transformed the constructed objects. This application is very simple, with no texture effects or special lighting, but it is sufficient for the purposes of the experimentation. Each student used the HMD and software for 20 min, which ensured the mastery of the tool.

In the second session, which took place in the virtual environment, the students were reminded of the task to be carried out, which had been explained two days before. Each student used the hardware and software (as shown in Figure 3) for 60 min, with a 5 min break in between. Since the location of the pier was on the banks of the river, it was pertinent to have the terrain modeled schematically and introduced into the virtual environment so that each student could take it into consideration when generating the idea. The indication for the first part of the session was to start with the exploration of three-dimensional shapes considering the modeled terrain. It was also indicated to leave a record of the whole process and not to erase the initial strokes or shapes. Figure 4 shows four examples of the different alternatives generated in the creative process by the students on the brown terrain. After 25 min, there was a five-minute break. After that, the indication for the second part of the session was to recognize and observe the previously created shapes, use the scale tool, and then correct, increase, or eliminate the shapes and finalize the best idea. During this session, the Principal Investigator applied Observation Sheet 1 for 60 min.



Figure 3. Two of the students modeling the idea with HMDs and haptic controls.

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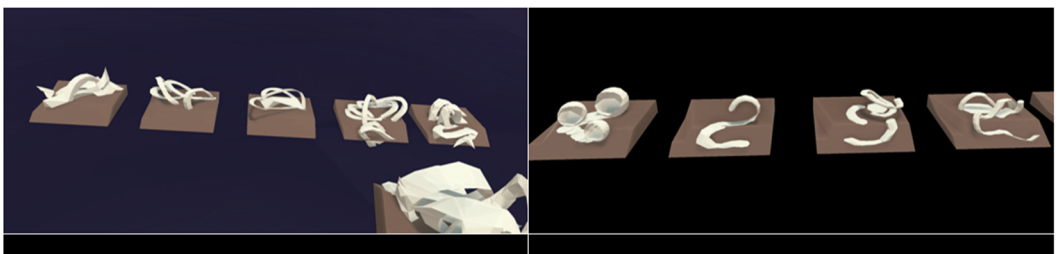




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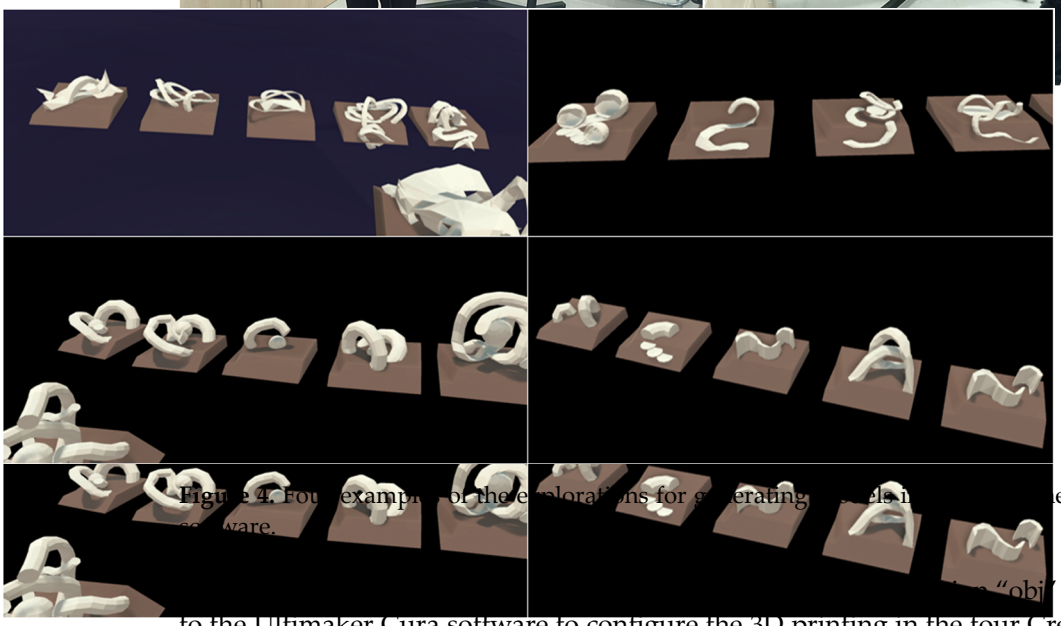


Figure 4. Four examples of the explorations for generating models in IVR with the Google Blocks software.

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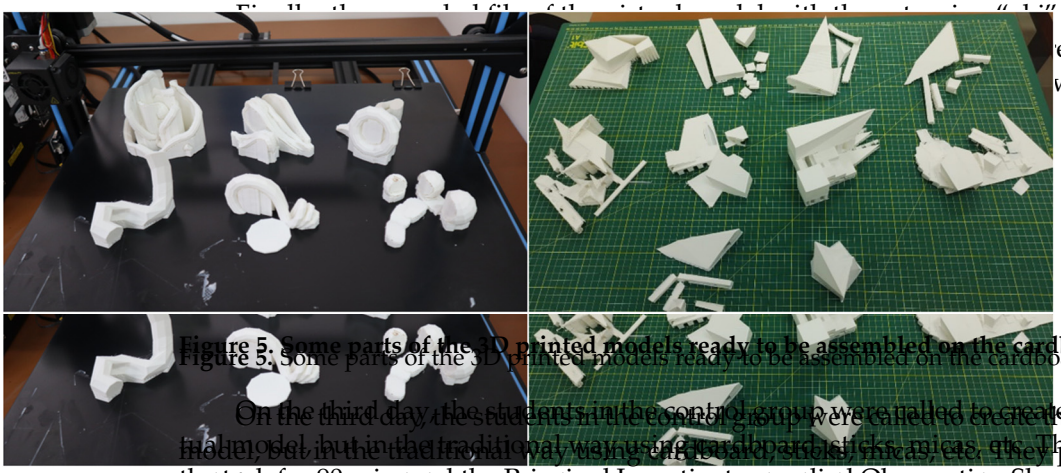


Figure 5. Some parts of the 3D printed models ready to be assembled on the cardboard terrain.

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On the third day, the students in the control group were called to create their conceptual model, but in the traditional way using cardboard, sticks, micas, etc. They performed the task for 90 min, and the Principal Investigator applied Observation Sheet 1. After that, the students of the experimental group joined the control group to give them the 3D-printed pieces. At this point, both groups were instructed to finish and present the models in an additional 30 min. During this time, the experimental group was asked to arrange and fix the 3D-printed pieces on the terrain model that was previously laser-cut on the task for 90 min, and the Principal Investigator applied Observation Sheet 1. After that, Figure 6 shows three examples of 3D printed models placed in the terrain. Finally, for the the students of the experimental group joined the control group to give them the 3D-evaluation of the conceptual models, each student was asked to present their conceptual printed pieces. At this point, both groups were instructed to finish and present the models idea for 3 min. For this, they had to use the final physical model (hand-made or 3D printed) in an additional 30 min. During this time, the experimental group was asked to arrange to help explain the reasons for the choice of forms and location. During the presentations and fix the 3D-printed pieces on the terrain model that was previously laser-cut on of the students from both groups, the first-year architect teacher, an expert in architectural design, applied Observation Sheet 2. Figure 7 shows the manually created and 3D printed models before the presentation.

A synthesis of the process using IVR and 3DP is shown in Figure 8. First the model created in IVR is shown, then exported and opened in .obj format, subsequently configured for 3D printing. Finally, the 3D printed parts and the finished models are shown and presented to be photographed.

cardboard. Figure 6 shows three examples of 3D printed models placed in the terrain.
Finally, for the evaluation of the conceptual models, each student was asked to present their conceptual idea for 3 min. For this, they had to use the final physical model (hand-made or 3D printed) to help explain the reasons for the choice of forms and location. During the presentations of the students from both groups, the first-year architect teacher, an expert in architectural design, applied Observation Sheet 2. Figure 7 shows the manually created and 3D printed models before the presentation.

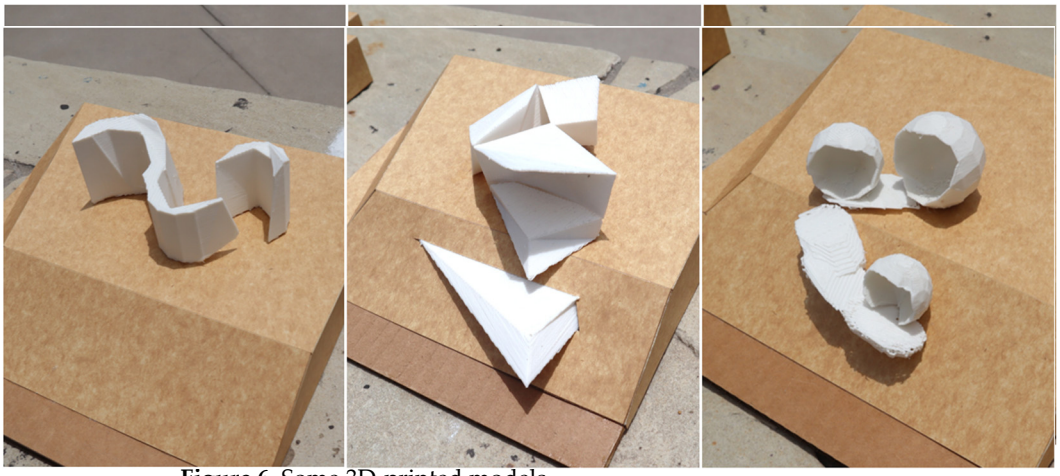


Figure 6. Some 3D-printed models.



Figure 7. All models presented by both groups.

A synthesis of the process using IVR and 3DP is shown in Figure 8. First the model created in IVR printing. Fi- photographed.

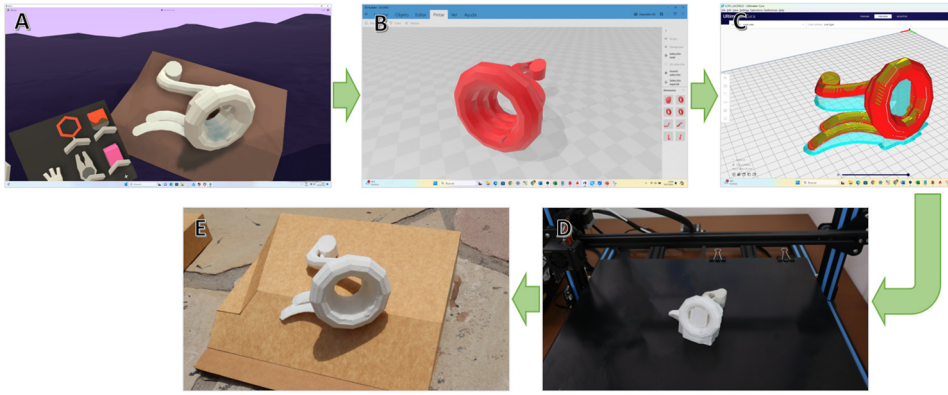


Figure 8. The complete process with both technologies. (**A**) The model created in the Google Blocks environment, (**B**) the model exported to the .obj format and opened in 3D Builder, (**C**) the model imported into Ultimaker Cura and configured for 3D printing, (**D**) the 3D-printed model with supports and (**E**) the model presented in the field for photography.

5. Results

Observation Sheet 1 gave the results shown in Figure 9. Regarding the observation of the intense movement of the hands, arm, and body during the creation of the model, a very high level was found in the experimental group (4.8) compared to the control group, which was only moderate (2.9). The second observation that focused on the creation of shapes and volumes only with the intention of inquiry resulted in a very high level (4.7)



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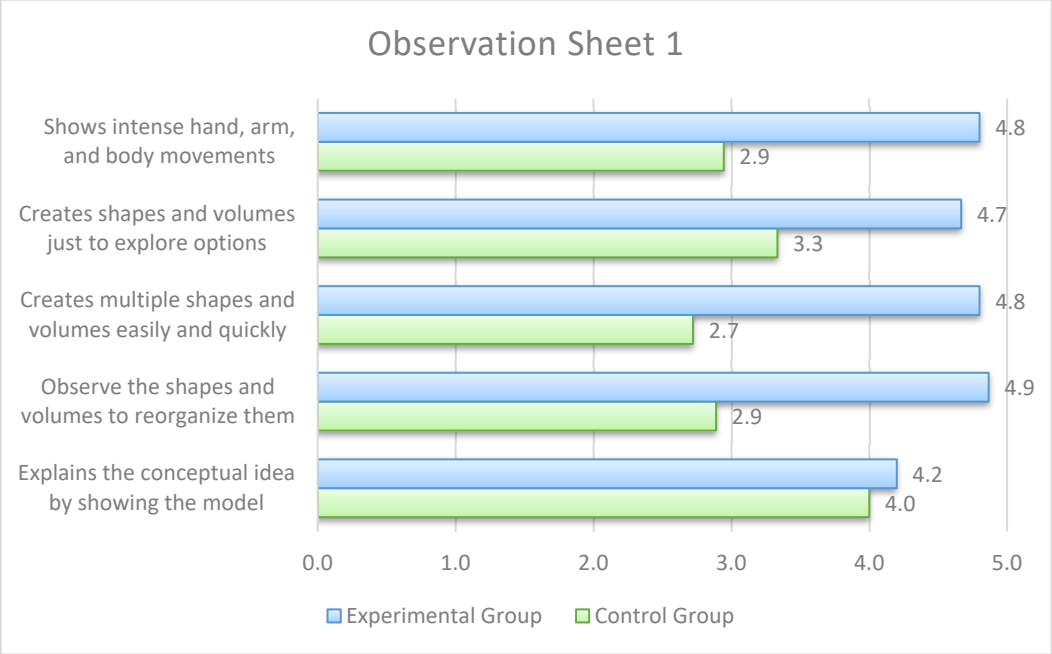


Figure 9. Values obtained in both groups with the application of Observation Sheet 1.

The results of Observation Sheet 2, which focused on the final model as a product, can be seen in Figure 10. Regarding the three-dimensional complexity of the model that needs to be understood by moving and observing the object, it has been found that the printed models have been more complex, which required more manipulation and observation (4.7) compared to the manual models that have been simpler (3.5). As for the materiality of the model, those of the experimental group have induced a little more to be touched and to be observed with lights and shadows than those of the control group (4.5 vs. 4.1). Finally, the printed models ended up exhibiting greater abstraction and beauty as autonomous objects (4.3) than the hand models (3.9).

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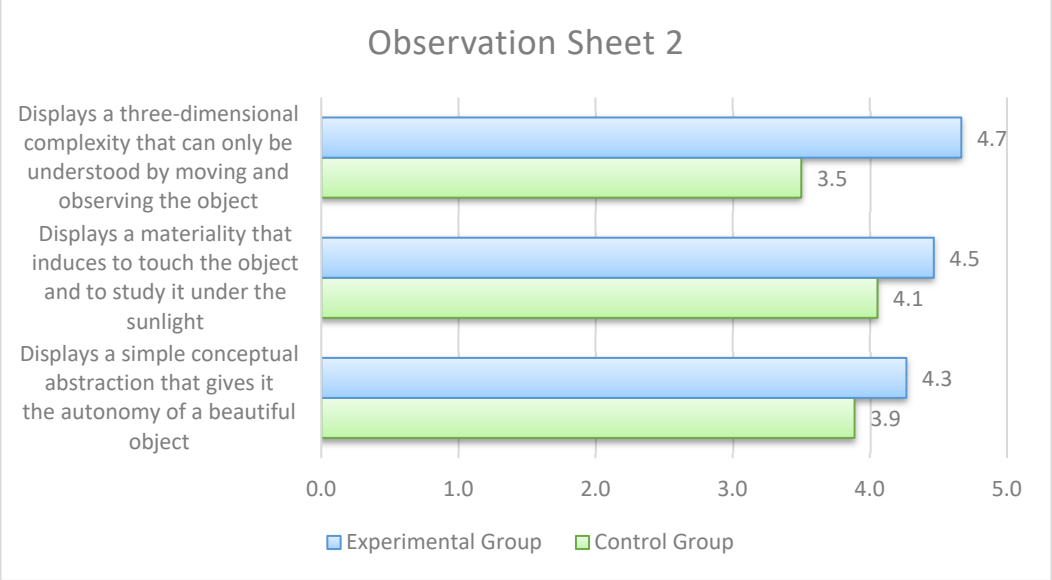


Figure 10. Values obtained in both groups with the application of Observation Sheet 2.

6. Discussion

Regarding the results obtained, this research validates the first hypothesis proposed. That is to say, the incorporation of the IVR in the process of the ideation and configuration of the first architectural idea through the modeling of a virtual conceptual model has shown not only similar characteristics and conditions as the same traditional process of building physical conceptual models but has also shown some important advantages.

In terms of the phenomenological condition, that is, the intense bodily experience that occurs throughout the creative process, it is in the virtual environment that a greater linkage of the creative process with bodily experience and movement has been generated. This assertion aligns with those who argue that this environment generates meaningful experiences [33] that challenge the phenomenological idea that the sense of bodily presence is anchored only to the physical body [34]. It should be pointed out that only body movement was recorded on the observation sheet; however, despite the fact that this was not a previously established variable, gestures and body expressions of astonishment and admiration, but also of reflection, judgement, and satisfaction, were observed with great incidence in the experimental group. This leads us to think about future research with brain–computer interface devices or others that allow data collection to be translated into more objective data. On the other hand, the complementation of the use of 3DP in the experimental group has completed the intense and corporal experience when they received their 3D-printed pieces to make the final adjustment, arrange them on the field, and take photographs under the sun. All this has generated a haptic link between the body and the hand with the created object [22], making the whole process a phenomenological experience.

Regarding the characteristics of the idea generation process, the interpretations are as follows. The first characteristic refers to the fact that modeling should be indecisive and slow, exploring, inquiring, and reflecting on the shapes. In the virtual environment, it has been easy to create free strokes and geometric shapes following the movement of the hands, and it has also been easy to modify them. Therefore, this inquiry and exploration have been very productive compared to those carried out manually because the construction demanded more time or became difficult when it came to complex shapes. Something similar happened with the second characteristic, which refers to the second moment in which, once the shapes have been explored, multiple variants begin to be created quickly. The virtual environment has fostered the easy copying, derivation, and modification of alternatives compared to the few manually generated alternatives. These two characteristics demonstrate that the limitations of design media can restrict thinking by influencing the

way problems are explored and answered [27]. Regarding the third characteristic referring to the perception of the objects created to advance in the process of the materialization of the idea, a significant difference has been found. The virtual environment allows for scaling the objects so as to perceive them as a small sculptural object or as a very large building with the possibility of walking through it and even feeling spatial sensations [35]. This important quality allowed for a rapid readjustment of the objects, triggering a process of instantaneous reflection and feedback [22] that did not occur as intensely in the control group. Finally, the fourth characteristic that refers to the final modeling that allows for confronting the three-dimensional idea with others—in this case, the professor—has not shown significant differences. Despite this, the greater three-dimensional complexity of the virtual models has meant that the students use the model much more, moving it and rotating it to explain the conceptual ideas, as opposed to the manual models that, due to their three-dimensional simplicity, have not been manipulated much in the confrontation.

An important finding not initially anticipated relates to the length of time the creative process took. When the members of the control group were assigned the same time as the experimental group (60 min) to create the model, they had to be assigned 30 min more to finish the task because the models were very unfinished. Since the experimental group had completed the task the day before, it was no longer possible to equalize the times.

As for the second hypothesis, this research also validates it. The incorporation of 3DP in the materialization of the first architectural idea has helped to produce physical models that not only have similar characteristics as the manually produced conceptual models but are also superior in some respects. Regarding the finished and presented model, a better result was found in the three evaluated criteria in the models created in IVR and printed in 3D. In terms of the three-dimensionality and complexity of the shapes of the models, the models of the experimental group showed superiority over those of the control group due to the easy modeling of almost any form in IVR and their easy materialization with 3DP. In terms of materiality, it has been observed that the materiality of the white filament used has not been surprising in the printed models, but it has been enough to induce touch and manipulation to have a haptic experience superior to the models made with white cardboard. The use of other materials such as translucent resins for 3D printing or filaments finished with various materials remains to be explored. Finally, conceptual abstraction has behaved very similarly in both groups, but the better completion of the printed models, their complexity, and their materiality have conferred a status of a small conceptual sculpture over the manual modeling.

Two unanticipated findings were found in the analysis of the completed models. The first is related to the terrain models. Since the immediate context allows us to understand the spatial relationships of the designed object [36], the experimental group, having the terrain model present all the time, modeled on the basis of it and obtained more relevant proposals. This was not the case with the control group, which made little use of the terrain model in the modeling process, obtaining mostly models superimposed on the intervention terrain. The second is related to the quality of the models produced. It was found that the 3D-printed models of the experimental group showed greater accuracy and detail in complex three-dimensional shapes compared to the manual models of the control group. This was mainly due to the ability of the 3D-printing technology to handle complex geometries with high precision.

The weaknesses of the modeling process in IVR are as follows. First, there is the partial availability of hardware and software that is not available in every university or office. Unequal accessibility to these technologies can create a gap in professional training and practice, and these ethical concerns must be addressed to integrate these technologies in a sustainable and equitable manner. There is also the cybersickness, which involves symptoms similar to motion sickness, with nausea and light-headedness as a result of prolonged use [37]. Finally, there is a lack of the software for creating materials and textures (only colors can be assigned), as with other software such as Tilt Brush. This limits the conceptual ideas based on materiality.

The weaknesses of 3D-printed models are their difficulty to be modified and transformed after printing compared to models built with cardboard. This affects thedisposable and modifiable quality of conceptual models arriving, after many iterations, at a final answer. A second weakness is the choice of material to make the model. The impossibility of using any material other than the printing filaments limits the choice of materials that, by their connotations or meanings, can better express a conceptual idea [14]. The time demanded by 3D printing is time subtracted from the designer for reflection [22], but it is also a useful time for reflection on other aspects of design. Finally, as an emerging technology such as IVR, there is the ethical consideration of unequal accessibility to these technologies. This, in developing countries, may further widen the gap in professional training and practice.

The research was conducted with a relatively small group of students, which limits the generalizability of the results. A larger sample size could provide more robust and representative results. Another important limitation is that the assessment of the creative process and the final models was conducted using Likert scales, which may be subject to the subjectivity of the observers. This potential observer bias may have affected the assessments and thus the conclusions. To mitigate this bias, future studies will implement more objective assessment methods, such as additional quantitative and qualitative analyses, and the use of a wider range of measurement tools. Finally, the research was conducted over a relatively short period of time, which may not be sufficient to capture all aspects of the impact of IVR and 3DP on the creative process in the long term.

The findings are in line with existing literature suggesting that digital technologies such as IVR and 3DP can significantly improve the architectural design process [7,38]. The integration of these technologies not only facilitates the rapid creation and modification of conceptual models but also improves the spatial and tactile understanding of architectural ideas. The implications for the teaching and practice of architecture are significant. Incorporating IVR and 3DP into academic curricula can enrich the educational experience for students, providing them with advanced skills and a greater connection to the creative process. For professionals, the adoption of these technologies could significantly improve the efficiency and quality of architectural projects.

Despite the multiple advantages and the few disadvantages found, an integration of traditional techniques with digital tools that allow for broader, versatile, fluid, and creative processes is considered as the best alternative [39]. Regardless of the technological means used, the cognitive processes that have throughout history generated brilliant architectural ideas should never be altered.

7. Conclusions

The results of the comparison of two groups of architecture students ideating and configuring their first ideas of a small architectural project through conceptual models allow for concluding that the incorporation and complementation of the IVR and 3DP in that cognitive process have not only not affected it but have favored it over its similar one using manual models both in the process and in the final result.

First, the intense phenomenological experience generated in the virtual environment, reflected in the students' body movement and expression, highlights a deeper connection to the creative process, including a greater connection to the creative process compared to students who did not use technologies. Furthermore, in the second moment, the haptic link with the 3D-printed object becomes tangible and direct since the pieces are taken by hand to assemble the model, place it on the cardboard terrain, and make the study for taking pictures under the sunlight. Both moments complement each other and constitute a phenomenological experience essential to generating architectural ideas that match or surpass the experience of the traditional process.

Regarding the four characteristics of the creative process of idea generation, it is concluded that in the first three, the use of IVR has fostered the cognitive process with respect to the group that materialized their ideas by building models manually. That is to

say, the inquiry and reflection of shapes, the multiplication of alternatives and variants, and the perception of the shapes created to make derivations or corrections have been better developed in the virtual environment. In terms of the last characteristic, the difference has been irrelevant. The confrontation of the idea in front of the professor and using the physical modeling have been very similar.

Regarding the evaluation of the final models, it is concluded that due to the easy physical materialization of the models created in IVR, the models of the experimental group have stood out in their three-dimensional complexity, which has led to their more detailed observation. As for the representation of the materiality of the object, they have been very similar since they all used only white cardboard or filament. Despite this, the texture and the finishing of the 3D printing have led to a more direct manipulation and tactile experience. Finally, the conceptual abstraction has also been very similar, with the small difference that the models printed because of their complexity have stood out as small sculptural objects.

The implications of this research are significant for the field of architectural education and professional practice. The validation of IVR and 3DP as effective tools in the architectural ideation and configuration process suggests that their integration into academic curricula could enrich students' educational experience, providing them with advanced skills and a greater connection to the creative process and spatial compression. The ease of exploring and materializing complex ideas in a virtual environment, followed by their physical realization through 3D printing, can foster greater innovation and creativity in architectural design. For professionals, the adoption of these technologies could significantly improve the efficiency and quality of architectural projects. However, a balanced combination of traditional and digital techniques is recommended to ensure a holistic creative process that does not rely exclusively on technologies but uses them as complementary tools that enhance the skills and knowledge acquired.

Future research could explore the long-term impact of these technologies on the architectural design process and their application in wider professional contexts. In addition, studies could be developed to evaluate the effectiveness of both technologies complemented at other, more advanced stages of the architectural design process, with larger samples and with groups with greater age and experience in both design and IVR use to determine whether age and experience influence the use of these new digital tools. And given the incursion of artificial intelligence (AI) as a powerful tool in architectural design capable of autonomously generating images and three-dimensional models, the combination of IVR, 3DP, and AI could further revolutionize the field, allowing architects to explore a wider range of innovative ideas and solutions. Future studies should investigate how the integration of these technologies can optimize the architectural design process and their practical applications in education and the professional field.

The integration and complementarity of IVR and 3DP have proven to influence the way design problems are explored and the way architectural thinking is realized. Their complementarity with traditional analogue procedures can turn the design process into a complete cycle that encourages the generative generation of architectural ideas with the potential to transform the way architects design.

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PONENCIA EN CONGRESO INTERNACIONAL 1

Virtual Reality and 3D Printing in Architectural Design. Case study: the Conceptual Model.

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Abstract

Two disruptive technologies have had an important approach to the field of Architecture. The first is Virtual Reality which has shown significant advantages in the visualization, simulation, and evaluation of architectural designs. The second is Digital Fabrication and more specifically 3D printing which has shown strength in rapid prototyping of previously unbuildable forms. This research argues that the use of immersive virtual reality tools complemented with 3D printing tools in the process of creating a conceptual idea can be an advantageous alternative to the traditional architectural design workshop. To demonstrate this hypothesis, the design process of conceptual models has been addressed from two approaches, the first one has developed the traditional and artisanal methods and the second one has introduced immersive virtual reality and 3D printing. The experimentation has been carried out with two groups of students of the subject Architectural Design 1 of the Faculty of Architecture and Urbanism. The results have been compared in five criteria, multiple solutions, compositional principles, shapes and volumes, relationship with the environment and communication of the idea. It is concluded that the complementarity of both technologies does not alter the cognitive processes of architectural ideation and, on the contrary, it offers important advantages over the traditional and artisanal way of creating conceptual models.

Keywords
Architecture, Digital Fabrication, 3D Printing, Virtual Reality, Architectural Design, Conceptual Model

1. Introduction

The teaching of architectural design is traditionally done in design workshops where theory and creativity are linked in a manual work. For this, an efficient didactic strategy in the training of future architects is done through drawings and models. These traditional methods of teaching design develop manual skills, and in turn develop creative skills in the design process from a critical, experimental, and collaborative environment. However, since the 1980s, the development of computer technology has made increasing incursion in the different phases of the design process and in the different levels of design, displacing manual craftsmanship. The model as a mechanism for representing architecture has remained throughout history, but with the emergence of the digital model, it has been strongly displaced. And although there is a hybridization between both systems nowadays [1], digital models and lately virtual models have not been able to displace the model in terms of its function of three-dimensional approximation in the configuration phases of the project idea, and the generative function itself, understood as a kind of three-dimensional sketch, which enables the ideation of the formal structure itself through physical manipulation [2].

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The purpose of this research is to compare the use of traditional manual and handmade methods, versus methods that incorporate technological tools such as virtual reality and digital fabrication in the approach of an initial architectural concept through small conceptual models. From both approaches, a conceptual model was designed and built that allowed the student to carry out a volumetric study of the architectural project. This research argues that the complementarity of these two disruptive technologies does not alter the cognitive processes of architectural ideation performed through the creation of a conceptual model and on the contrary, they offer many advantages compared to manual and handmade creation.

2. Literature review

2.1 The conceptual model in architectural design

Although the architectural design process is not linear, it is recognized that it has different stages or phases. After the preliminary phase of analysis or known as pre-design, the schematic design phase follows, which is the most complex because it requires the participation of various cognitive processes such as critical thinking, imagination, and creativity. This phase, also known as ideation, is critical in the whole process, both for teaching and learning. It establishes a design concept or an abstract idea to solve the design problem, which is the most relevant part of the narrative of the design. This design concept must be expressed visually through shapes and it has traditionally been the drawing the most efficient and quickest way to make such ideas and concepts visible [3]. But when the three-dimensional complexity of the shape exceeds the possibilities of manual drawing, which is more recurrent in new students, the model is shown as the ideal tool that allows the manipulation of complex shapes and geometries [2]. Unlike the presentation or relief model, the conceptual or configuration model is a working artifact that could be compared to the sketch. This "three-dimensional sketch" incorporated as a strategy in the design workshop allows an important approach to the concept as a complex volumetric object [1].

The pedagogical strategy of using small conceptual models to complement the conception drawings has the following characteristics and advantages: They are three-dimensional synthesized expressions of the conceptual idea. They share with the conception drawing an expressive synthesis that makes them instruments of knowledge of the ideas underlying the architectural form [4]. They have scale and proportion which allows to perceive the relationships between its different parts and to have an idea of the human scale. “Full of excitement, I move to models. Then models absorb all the energy, and so they require information about scale and relationships which cannot be fully perceived on drawings” [5]. They have a materiality that was assumed and decided according to the scale and forms. These models take on technical problems such as the choice of material because they constitute in themselves a "project" that turns them into autonomous and abstract objects [4]. They react to light as a real building does, which makes it possible to study the volumes and their shadows under the sun. A model allows the space represented there, to scale, to react truthfully when placed under the sun “A model (...) allows the space represented therein, to scale, to react in a truthful way when it is put under the sun”[6]. They are easy to modify and correct to express the best three-dimensional form of the conceptual idea. "The mock-up can and should be made step by step expedient in easily manipulated material, suitable for quick modification, destruction, and correction" [7]. They generate a haptic link between the hand and the material. The materiality of the model allows a direct experience of touch, learning the value of haptic, textures and materials [8]. They allow the reflection of the relationships between the created volumes. With the model the light is seen because the shadow is detected, the emptiness is perceived because the fullness is detected, the remoteness is understood by the observed proximity. "In the elaboration there is reflection of the dialectics of all the elements, there is an intellectual exercise" [8]. They achieve a better maturation of the idea because of the time required for its execution. The participation of the hand in the models makes

time a moment of maturation of the architectural project. The hand and the time will be guarantee of a reflected, thought, projected result [8]. And they allow rapid and comparative learning. The model has a traditional didactic capacity in the teaching of architecture because of its easy execution in the early stages of learning and because of its small size, easy handling and collective comparability [4].

2.2 Architectural design education and digitalization

Teaching in architectural design has undergone a deep transformation in the era of digitalization. In recent years, digital design seems to be a dominant phenomenon. Therefore, digitization in architectural education is and remains a controversial process [9]. Recent studies indicate that the introduction of computer-aided design tools has revolutionized the way students approach architectural projects [10, 11]. In this sense, these technologies allow for greater accuracy and efficiency in the conceptualization and representation of designs. In addition, teaching has become more accessible thanks to the proliferation of online resources, such as courses and tutorials [12].

While change has been exponential since the 1960s, it is not difficult to assimilate architecture without the digital part. In this way, digital design theory tends to acquire a presence in the academic discourse in order to create theoretical bases for new design processes that transform traditional education models, as well as architectural projects [9]. This evolution in architectural education has led to more interaction between students and a more focused approach to the development of practical skills and creativity.

Furthermore, it is relevant to highlight that the various responses to digitalization have shown the need to analyze the teaching of design and the profile of the future professional of students [13]. Specific studies indicate that the specific quality of architecture should push architects to conceptualize a dimension of architectural research with good feedback between research and practice, as already happens in other professions [14, 15].

2.3 Architectural Design and Digital Fabrication

Since the beginning of this century, digital fabrication laboratories (FabLab) have been implemented as centers of innovation, entrepreneurship and as allies to personal design and production [16]. Its definition indicates the digitization of manufacturing processes, the term is broad, ranging from the technical to the social, where a range of tools and concepts converge, from nanometer precision to machines capable of self-replication, to programming languages for digital manufacturing in virtual reality [17]. Digital fabrication creates finished parts from computer-designed models based on manufacturing processes [18] that open the way to flexibility and productivity in industry.

Digital fabrication laboratories are essential elements in contemporary education and scientific research. Digital fabrication, which includes technologies such as 3D printing among others, has revolutionized the way researchers prototype and produce components, accelerating the development process. These labs allow students to apply that knowledge in the creation of real prototypes. Several researches highlight the importance of this combination in training practical skills and preparing students to solve real or everyday problems [19]. In addition, the availability of online resources and open source software have democratized access to digital fabrication tools, expanding learning opportunities worldwide [20].

The integration of digital fabrication techniques into architectural design processes is a major challenge to create a digital building culture but is of enormous impact since traditional construction techniques and complex forms difficult to implement in the past are challenged [21]. On the other hand, 3D Printing can favor a better communication of ideas in the design process among participants generating a collaborative approach is the generation of innovative and sustainable design processes [22].

2.4 Architectural Design and Virtual Reality

Virtual laboratories have gained relevance in science education due to their ability to provide hands-on experiences through digital environments [23]. Several studies indicate that virtual laboratories allow students to explore scientific concepts in a safe and repeatable manner [24, 25]. Virtual design refers to the creation and manipulation of three-dimensional objects and spaces in digital environments [26]. In addition, digital design tools are fundamental to the creation and editing of graphic and architectural content since they provide a range of options for conceptualization and representation of designs.

These methodologies and tools have expanded the creative possibilities. Therefore, several authors [27, 28] point out that virtual reality and 3D rendering have raised the quality of presentations, which is crucial for conveying design ideas effectively.

Virtual models allow architects and designers to visually explore a project before it is built, which can be valuable for decision making and communication with clients. Various research has highlighted the effectiveness of virtual models in architectural design evaluation [26, 15, 29]. On the other hand, traditional architectural models are physical mock-ups made by hand with materials such as cardboard, wood or foam. Research indicates that traditional models can be more useful for evaluating tactile and scale aspects, but are less efficient in the evaluation of light and views, compared to virtual models [30]. It should be noted that virtual and traditional models are valuable tools in the architectural design process, each with their own advantages and disadvantages. The choice between the two depends on the specific project objectives and representation needs. Therefore, combining both approaches can provide a more complete and effective understanding of an architectural design.

3. Purpose of the research

The purpose of this research is to determine the impact of the adoption of emerging technologies on architectural design processes. Specifically in the early stages of architectural design where the cognitive processes of critical thinking, creativity and imagination must maintain their natural flows without mediations that alter or distort such processes. To determine this impact, a case study has been carried out with new architecture students in the creation of conceptual models. In this case study, a group that has developed traditional, artisanal methods of creating and constructing conceptual models has been compared with another group that has developed a method that has incorporated immersive virtual reality with haptic controls and 3D printing. By comparing the two methods, results can be obtained that will help architects and designers make more informed decisions about when and how to use each approach based on their specific goals and the needs of each project. These results can contribute to the improvement of the design process and decision making in architecture.

4. Methodology

The methodological design to determine the advantages and disadvantages of innovation in the teaching and learning strategies of architectural design in the elaboration of a conceptual model was based on the case study of students in the first cycle of architecture. For this purpose, a comparison of two experimental groups was made. Each group consisted of students enrolled in Architectural Design Workshop 1 at the Faculty of Architecture and Urbanism of the Universidad Nacional de San Agustín de Arequipa in Peru. This subject is of a theoretical-practical nature and its main competence is the approach to knowledge and experimentation of form and space in the design process. Within this process, it is the phase of conceptual ideation of the first forms that requires the greatest contribution of critical thinking, creativity, and imagination on the part of the student, and it is in this phase that this research has focused its analysis. The case study for this research was the final practical work of the subject, which consisted of the design of a small boat landing and viewpoint located on the banks of the Chili River in the city of Arequipa. The

students conducted an analysis of the site, the user and the activity to define an architectural program for three spaces. The students then had to define a conceptualization and a first three-dimensional solution through a conceptual model. The time allotted for the conceptual ideation process was five days.

The experimentation was carried out with the 33 students enrolled in group B of that subject. The group was divided equally according to their previous grades and randomly, so that their previous learning would not be a variable that would distort the experimentation. Group 1 consisted of 15 students who were assigned to work in the virtual reality and digital fabrication laboratory and Group 2 consisted of 18 students who worked in the conventional design workshop classroom.

Table 1
Characteristics of student groups

Group	Amount	Characteristics	Workspace
01	15 students	7 women y 8 men	Digital fabrication and virtual reality laboratory
02	18 students	13 women y 5 men	Classroom - Architectural design workshop

The students in Group 1 worked in a differentiated manner as follows. On the first day they had training in the handling of the HTC Vive HMD and Google's "Blocks" software. This application allows creating 3D objects using simple geometric shapes, a color palette, and a set of helper tools. This session ended with each participant using the equipment and software for 20 minutes (Figure 1). On days 2 and 3 they did work in the design workshop classroom. On the fourth day, according to the previously established schedule and for 45 minutes they used the hardware and software to create their three-dimensional proposal in the virtual environment (figure 1). Immediately after finishing the three-dimensional conceptual model, the file was exported. The file was processed with the free Ultimaker Cura software to be sent to three Creality 3D printers in the Digital Design and Fabrication Lab (Figure 2). On the fifth day, the 15 students in this group were given the printed pieces for assembly and presentation together with the students in Group 2. Group 2 students worked independently in the workshop, applying the traditional strategies of the design workshop, and making a model with cardboard, cardboard, and other materials.

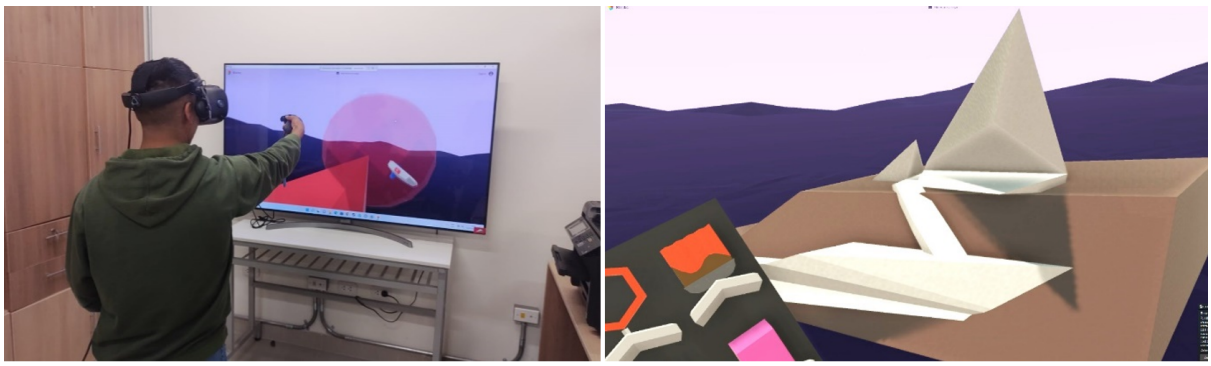


Figure 1: On the left is one of the students with the HMD and haptic controller creating his model. On the right the Google Blocks application interface.

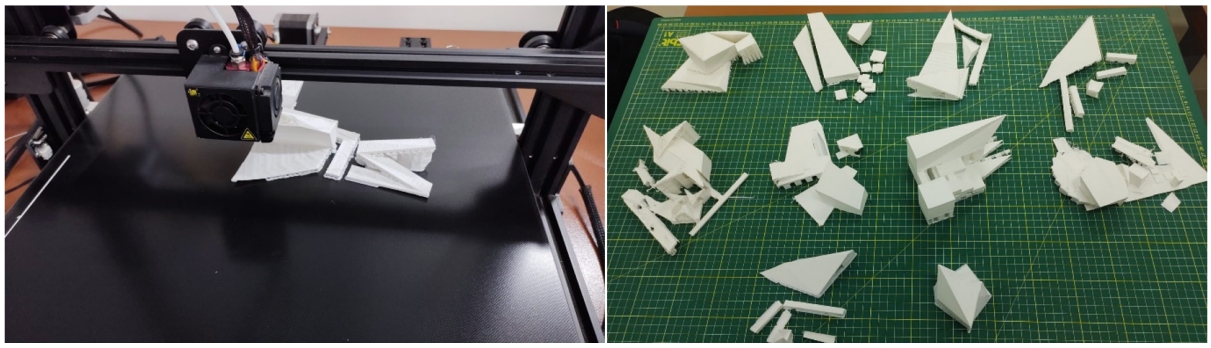


Figure 2: On the left, the 3D printing process. On the right the printed parts ready to be assembled.

The comparison of the conceptual models was carried out using the following evaluation instrument based on five criteria: (i) multiple solutions, (ii) compositional principles, (iii) shapes and volumes, (iv) relationship with the environment and (v) communication of the idea.

Table 2
Instrument for evaluation and comparison of the conceptual models

Criteria	Description
Multiple solutions	Development of several models exploring all possibilities or solutions to find the best idea.
Compositional principles	Application of compositional principles such as unity, balance, direction, center of interest.
Shapes and volumes	Creation of solutions with new and ingenious forms in response to the main idea of the proposal.
Relationship with the environment	Integration of the volumetry to the idealized slope of the terrain and orientation towards the surrounding visuals.
Communication of the idea	Communication of the idea through the finalized conceptual model.

5. Results

Regarding the first comparison criterion, multiple solutions, it was found to be quick and easy to create several alternatives in the immersive environment. Most of the students created between two and five virtual models. On the other hand, the creation of hand-made models did not allow this multiplicity. The delay in the construction of a model, even a schematic one, prevented students from creating more than one. Only in the few cases in which the construction of the model did not respond to the student's idea, they created a second model (Figure 3).

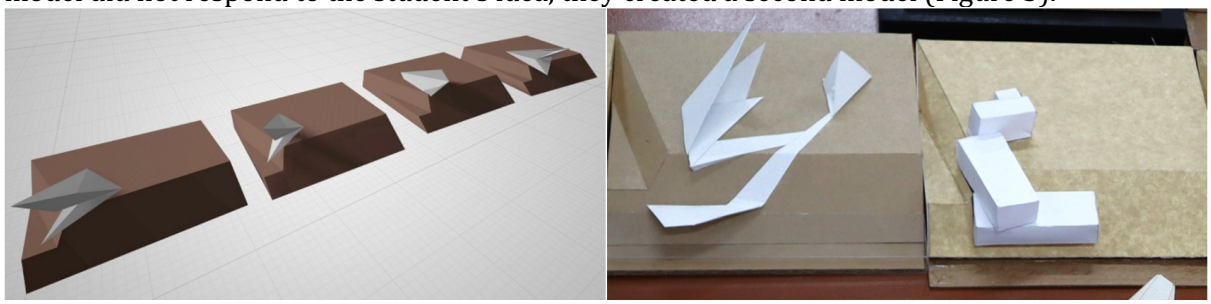


Figure 3: Multiple solutions: on the left the multiple IVR solutions, on the right the unique handcrafted solutions.

For the second criterion, called compositional principles, it was observed that the virtual models presented a greater development of the conceptual idea and therefore a greater presence of compositional criteria. The compositional criteria that were evidenced were rhythm, repetition, balance, unity, and movement. On the other hand, the manual models showed simpler solutions with basic compositional principles such as unity and symmetry (Figure 4).

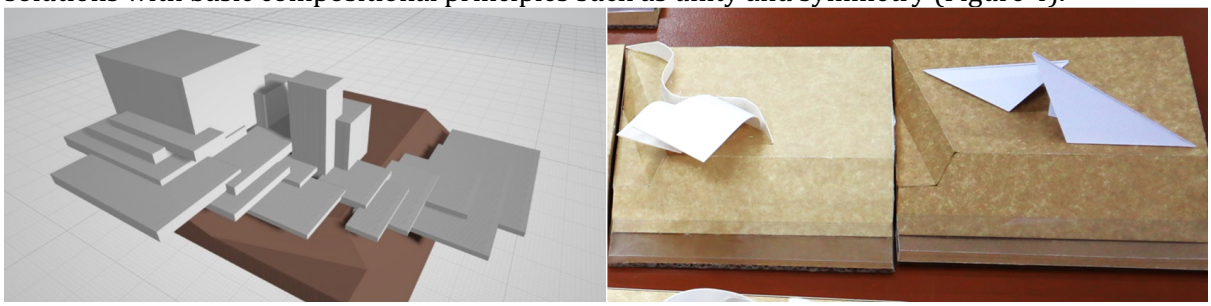


Figure 4: Composition principles: on the left a model in IVR, on the right two handmade models.

For the criterion of shapes and volumes, we found in the virtual models the predominant use of polyhedral volumes such as cubes, parallelepipeds, and pyramids. Despite this, most of them were complex volumes with inclinations, deformations, intersections, etc. On the other hand, in the manual models, curved shapes were used in addition to polyhedral shapes (Figure 5).

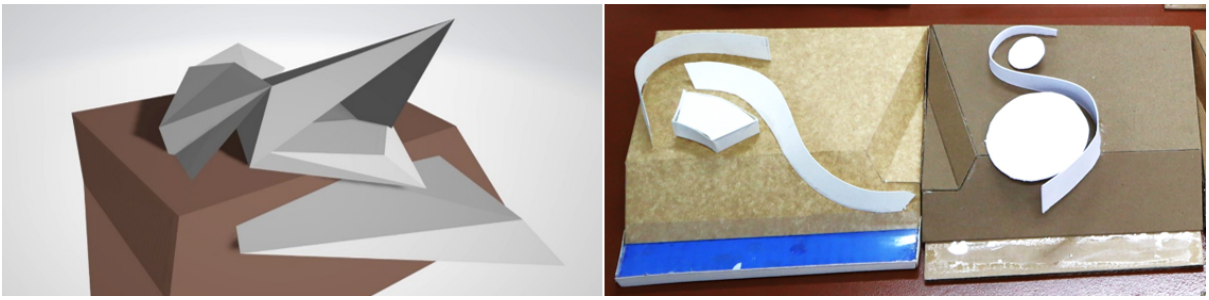


Figure 5: Shapes and volumes: on the left a complex polyhedral model in IVR, on the right two simple curved models.

In Figure 6, relationship with the environment, it was observed that the manual models mostly present a limited relationship with the site (specifically with the slope). In several works it was observed that the proposal simply overlaps superficially with the terrain. On the other hand, in the virtual models, the responses use the slope in favor, constituting a better response as a pier and consistent with the topography of the site (Figure 6).

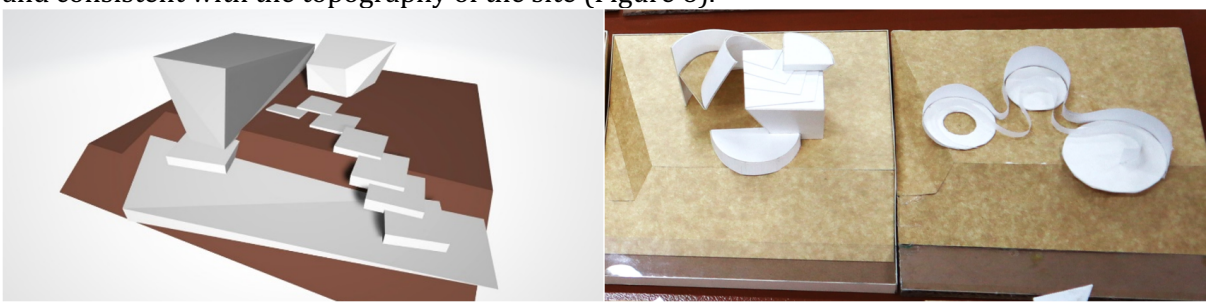


Figure 6: Relationship with the environment: on the left a model using the slope in IVR, on the right three handmade model with little adaptation to the slope.

Finally, for the criterion comparing the communication of the idea, the responses from both groups presented a variety of characteristics. In the case of the virtual models, which were then materialized with 3D printing, they showed the same physical qualities as the manually produced models. On the other hand, it has been found that printed models in general present a more complete conceptual idea than manual models that have been shown to be unfinished or

incomplete. It has also been found that the 3D printed mockups present a greater three-dimensional development, unlike the manual models that have shown conceptual ideas more thought out in two dimensions, usually in plan (Figure 7).

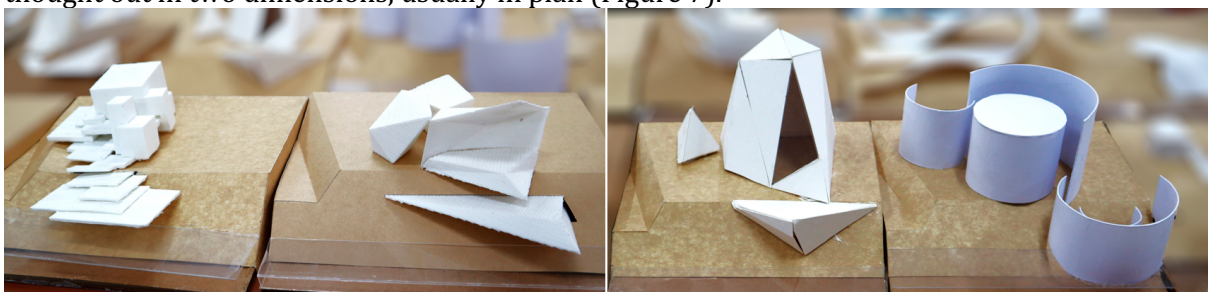


Figure 7: Idea communication: on the left a model created in IVR and 3D printed, on the right the handmade model.

Three findings were found outside the comparison criteria. The first one has to deal with the execution time of the models. The execution of the models first created in a virtual environment and then printed in 3D was much shorter than those created manually. In the first case, such construction has only been reduced to the assembly of the pieces on the base terrain. The second finding is related to the previous one. By having the pieces of the models printed in 3D, the students in the process of assembling them have been able to have that ideal haptic linkage that is conferred to the manual model and that has also allowed the students to make final adjustments of proximity (Figure 8). The last finding is that the printed models are very difficult to modify unlike the manual models built with cardboard.

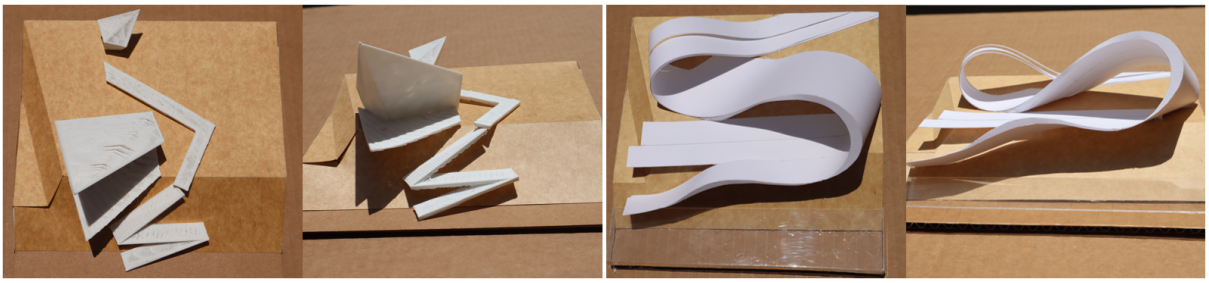


Figure 8: Idea communication: on the left the a model created in IVR and 3D printed, on the right a handmade model. Both models studied under the sunlight

6. Discussion

The first disruptive technology used to develop the conceptual model was immersive virtual reality. The immersive environment provided by this medium added to the interaction and the benefits of Google Blocks software has shown to have the following advantages compared to the creation of handmade models. It allows the quick and easy creation of polyhedral shapes as well as free forms (curves) in direct relation to the movement of the hands. This form is very similar to traditional drawing where thinking, sight and hand movement are linked with a pencil on a sheet of paper, but this time with three-dimensional strokes. This form of creation generates a haptic link between the body and the hand with the created object [8], a characteristic that digital models created in other ways do not have. Therefore, the processes of critical thinking and creativity are not affected by the mediation of this technology. It allows the creation of many solutions and their variants achieving a quick arrangement for the application of more compositional principles. At the same time, the easy and direct modification of the object has generated a process of instant reflection and feedback, a necessary feature in conceptual models [7, 8]. It allows a better perception of the three-dimensional idea due to the possibility of rotating around the object and giving it different scales. This is one of the most compelling advantages that cannot be achieved in other digital media [29]. Finally, it facilitates the creation of a conceptual model in a reduced time compared to the traditional handmade way. On the other hand, it has

been found as disadvantages the intangibility of the object that distances it from a real and direct haptic experience of manipulation of shapes and materials and that, in addition, does not allow to experience the behavior of the model under natural light. The unavailability of software to create materials (only colors can be assigned) limits any conceptual idea based on materiality. Finally, virtuality does not allow having the model in front of the student permanently for reflection and feedback processes, except for the exported three-dimensional models capable of being viewed on cell phones, tablets, or PCs.

The second technology applied was digital fabrication. In this case the use of 3D printing with FDM technology has proven to have the following advantages. It has favored the materialization of any shape previously created in virtual reality. This workflow has been very simple since the exported virtual reality file was recognized by the software to laminate the 3D models for subsequent printing. This material creation of the conceptual model made it possible to solve the disadvantages of the virtual model, that is, its intangibility, its immateriality and its permanent physical presence [1, 4]. Although the printing of the 15 models (on three printers at the same time) took 7 hours, this time was not charged to the student's work. This can also be considered a disadvantage if it is considered crucial that the time spent in the construction of the model allows for maturation and reflection [8]. By printing the conceptual model in several parts, it allowed the student not only the haptic experience of manipulating it for final assembly, but also the possibility of making readjustments based on direct perception [1, 8]. The printed model, like the handmade ones, also allowed to perceive its scale and proportion and the reaction of the object under sunlight [1, 8] The disadvantages found are the impossibility of materializing the models with any material other than the printing filaments, as it happens in traditional models with cardboard, micas, sticks or others. In addition, it has been found that it is difficult to modify the model once printed, becoming almost a finished sculpture.

The inclusion of digital tools in the methodology of the architectural design process, from the early years of training promotes openness to new models and ways of dealing with design, which complement the traditional physical models to give better results in the academic performance of students. In this context, it is important to include digital fabrication and virtual reality laboratories within the methodology of the architectural design process to explore other attitudes and qualities in university students in addition to the aforementioned.

7. Conclusions

After carrying out a case study to determine the advantages and disadvantages of using immersive virtual reality and 3D printing in the creation of conceptual models by first year architecture students, the following conclusions were reached:

The qualities that immersive virtual reality has such as immersion, presence, and interaction, added to the easy creation of objects with haptic controls that are achieved with the Google Blocks application allow: (a) To create very quickly and easily multiple responses in the inquiry and search for forms that materialize the main idea. (b) Manipulate, transform, and copy objects in a simple way to test and verify arrangements and composition criteria. (c) Create a very wide diversity of shapes, from simple polyhedral shapes, through curves, to more complex and free shapes with the simple movement of the hands. Moreover, these forms can become more complex with manipulation. (d) To better understand the three-dimensionality of the proposal by the possibility of perceiving the model from different angles, different scales, and different points of the observer. (e) To propose ideas relevant to the place due to the pertinence of creating the model always over the idealized terrain.

On the other hand, the qualities of 3D printing, such as the materialization of almost any three-dimensional shape, low costs and accessibility and automation, as well as its compatibility with the files exported by the IVR application, allow: (f) To reduce the effective time of the student for the manufacture of the model, giving more time to cognitive processes. (g) Achieve a haptic link with the student from the moment of grabbing the printed pieces to assemble the model and arrange them on the cardboard terrain. (g) Perceive the relationships of the volumes to scale,

proportion and proximity to make adjustments at the time of presenting the model. (h) Study the interaction of the model with natural light to determine a sun exposure study and the impact of the sun's rays and shadows.

Therefore, from the proposed methodology it is concluded that the complementary introduction of these two disruptive technologies in the processes of ideation and creation of a conceptual model does not alter the cognitive processes of architectural ideation; on the contrary, they provide important advantages that may be the indication of the rupture of some paradigms of the teaching-learning process of architectural design.

The use of other software for artistic creation in conjunction with other digital fabrication techniques is proposed as future research, always looking for innovations in traditional strategies in the methodology of architectural design.

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PONENCIA EN CONGRESO INTERNACIONAL 2

Immersive Virtual Reality applied to Architectural Conception Drawing: novices vs. experts.

The creation of architectural ideas is a key competence that the architecture students must acquire, which is achieved through hand drawing as well as the development of creativity and Spatial Skills throughout their studies. This research argues that architectural conception drawing mediated by Immersive Virtual Reality (IVR) enhances both capabilities and reduces differences between new and senior students in architecture. To demonstrate the hypothesis, a convenience sample of 28 students from Universidad Nacional de San Agustín de Arequipa participated in an experiment. Both groups drew an architectural idea using HMD and Tilt Brush software. Prior to this the level of creativity and Spatial Skills was evaluated using three standardized tests, and their IVR conception drawings were evaluated using two grade sheets. The results show that novices, despite having a lower average in creativity, stand out in fluency and experts in elaboration when creating in IVR. In the measurement of the levels of Spatial Skills, a very slight difference is observed, but novices develop better the three-dimensionality of the object in IVR. In conclusion, the utilization of IVR enables easy visualization and manipulation of three-dimensional drawings and enhances the achievement of creative ideas through conception drawing while minimizing the differences in Spatial Skills and creativity levels between novices and experts previously measured with standardized tests.

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Keywords
Immersive Virtual Reality; Conception Drawing, Graphic Ideation, Tilt Brush, HMD, Architecture, Design.

1. Introduction

The construction of ideas in architecture is closely connected to drawings and the act of drawing. The drawing of ideas is considered a fundamental competency that architecture student must acquire. Traditionally, this competence is developed through hand drawing with pencil on paper, is achieved with practice in drawing and design workshops and with the development of the cognitive capacities of creativity and Spatial Skills (SS) throughout their academic journey. This research argues that drawing architectural ideas mediated by Immersive Virtual Reality (IVR) not only promotes creativity and the three-dimensional development of ideas, but also has the potential to minimize the disparities in these cognitive abilities between freshmen and seniors in architecture.

1.1. Creativity and the drawing

Four stages are recognized in the creative process: preparation, incubation, insight and verification. In preparation, data is collected and related ideas are sought. In incubation, the prepared material is elaborated and organized. Insight occurs when existing ideas are combined to form complex mental structures. In verification, the value of the idea is evaluated and its complete form is elaborated [1]. The creative process requires not only the conception of an idea but also the development of a complete response. In architectural design, the creative process employs methods such as drawing, which deploys the ability to design and develop visual language [2]. Techniques such as computer-assisted drawing have also been incorporated, which have made it possible to recognize the importance of the technologic support. For the drawing method, the freehand technique shows in tune with the movement of the hands on the paper and the stroke created, being that the movements of the hand feed creativity through several mechanisms of the nervous system [3]. Therefore, in the creative process, the method, the instrument and the technique must be taken into account, since they can limit or enhance creativity in the architectural design process.

1.2. Spatial Skills and the drawing

Spatial Capacity can be defined as the capacity to generate, retain, retrieve and mentally manipulate well-structured visual images and their parts in two- and three-dimensional space [4]. Among the three components of this cognitive ability is the Spatial Skill (SS) which can be measured with standardized psychometric tests. This research will use Carroll's proposal [5] to measure it, which identifies two subcomponents: spatial visualization and mental rotation. SS are important in architecture for representing spatial ideas successfully and therefore for the creation of spaces and learning experiences [6]. Some authors link SS to the creativity needed for architectural design [7] by demonstrating that individuals with high SS excel in designing complex forms, while those with medium and low SS excel in simple additive approaches.

1.3. Conception Drawing

The process of generating an idea involves a "front-end" approach, in which partial and rudimentary representations are produced, evaluated, transformed, modified, refined and replaced by others, until their creator is satisfied with the results [8]. This active representational process gives rise to a special type of drawing that is known as “conception drawing” which was first introduced by Boudon and Deshayes [9]. They defined it as the drawing to conceive, grope, adjust and rectify, thus a reality-generating drawing, a conjectural and formative drawing of an architectural object that still exists only virtually [10]. Conception drawings are graphic expressions that act by concentrating abundant conceptual load and high symbolic codification that support extensive ideas, lines of action, or tentative proofs. They are configured as guidelines for subsequent actions, not being able to outline a definitive solution due to their low graphic codification, but they do generate discourses to achieve architectural responses [11].

1.4. Immersive virtual reality in the design process

IVR offers different possibilities to explore and express ideas in the design process compared to traditional methods [12]. It serves as a valuable tool for experiencing spaces through the creation of a strong sense of presence [13]. It allows immediate design feedback [14] and investigates the impact of spatial stimuli and the perception of architectural space [15]. Moreover, IVR strengthens experiential learning by allowing constructivism with first-person experiences and creating a sense of immersion, enabling students not only observe but also interact with their environment as a means of learning [16]. Also contributes to motivate students in the acquisition of knowledge [17], facilitates communication in the process of a design project and efficiently supports participatory design in decision making [18].

2. Materials and Methods

The methodological process is based on the correlation between creativity and SS in the creation of ideas through concept drawing in IVR (figure 1). To measure these aspects, three input instruments and two output instruments were utilized. The first input instrument was the Torrance Test of Creative Thinking (TTCT) which evaluated the level of creativity through drawings. This test assesses the components of originality, fluency, flexibility, and elaboration. Fluency measures the number of responses, flexibility measures the variety of responses, originality of the novel and unconventional responses, and elaboration measures the amount of detail. The test has a maximum running time of 30 minutes [19]. The second input instrument was the Mental Rotation Test (MRT) to measure the spatial rotation of objects through the recognition of blocks in three-dimensional perspective with different orientations [20]. The third input instrument was the Differential Aptitude Test: Spatial Relationships (DAT-SR) which evaluated spatial visualization recognizing two-dimensional figures and mentally constructing a three-dimensional mental image from them [21].

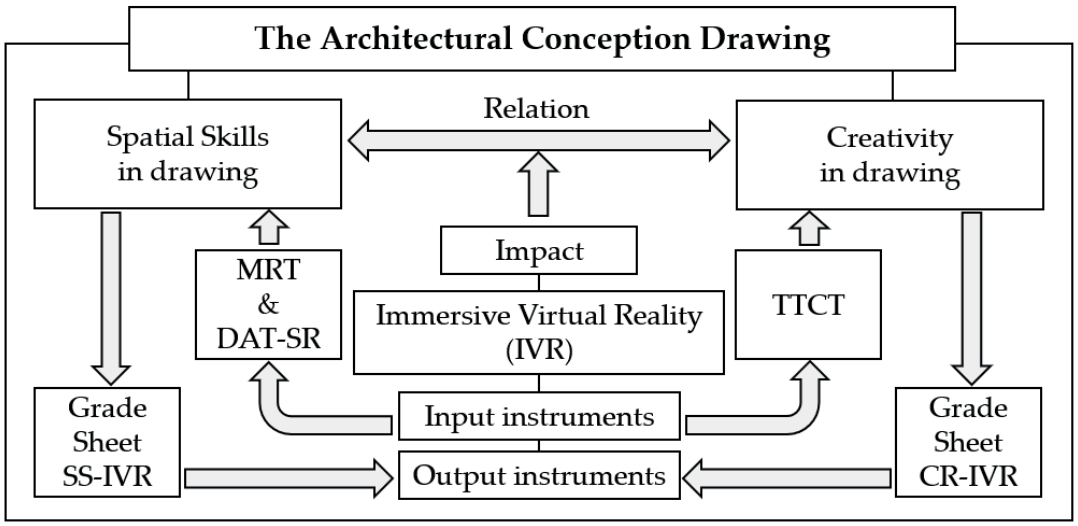


Figure 1. Conceptual relationship of the literature review and methodological process

The first output instrument was a grade sheet (CR-IVR) that assessed the creativity of the designed object in IVR taking the same four criteria of the TTCT (table 1). Some examples of the evaluated objects can be seen in figure 3.

Table 1. Grade sheet to assess the creativity of the designed object in IVR (CR- IVR)

N°	Items	Points
1	**Originality**: novel and unconventional designed objects are shown	10
2	**Elaboration**: many details that embellish and improve the designed object are shown	10
3	**Fluency**: a large number of designed objects are shown.	10
4	**Flexibility**: a high variety of designed objects are shown	10
	Total	**40**

The second output instrument was also a grade sheet (SS-IVR) that evaluated the three-dimensionality of the same object based on four criteria (table 2): three-dimensionality that evaluates if the object is developed in all its dimensions and is not worked by flat faces; complexity, that measures if the object shows a high level of complexity without affecting its understanding and unity; depth, that evaluates if the object was created with mastery of depth perception; and scale, that evaluates if the object was constructed considering its perception at different scales. Some examples of the evaluated objects can be seen in figure 3.

Table 2. Grade sheet to assess the three-dimensionality of the designed object in IVR (SS- IVR)

N°	Items	Points
1	**Three-dimensionality:** the object shows a development in all its sides and dimensions and is not only worked by flat faces	10
2	**Complexity:** the object shows a high level of complexity without affecting its understanding and unity	10
3	**Depth:** the object is constructed with a mastery of depth despite not having a physical support	10
4	**Scale:** the object is constructed looking for its perception with the change of scales (smaller and bigger)	10
	Total	**40**

For the experiment, 28 students from the architecture program of the Universidad Nacional de San Agustín de Arequipa in Perú were recruited. For the selection of the participants, a convenience sampling was carried out, seeking that the participants fit archetype 1 "novices": students who attended the first year of studies and who passed the subjects in architectural drawing and architectural design. And archetype 2 "experts": students who attended four years of the course and who passed all the subjects related to graphic expression and eight subjects of architectural design. A Google Forms questionnaire was used for recruitment, which also collected information on specific conditions such as color blindness, epilepsy, dizziness, nausea and migraine. These conditions also restricted participation in the experiment. Only 14 out of 80 first-year students and 14 out of 60 senior students met the conditions and agreed to participate in the experiment. The average ages of the novice and expert participants were 20.08 and 23.43 years respectively.
After recruitment and the signing of a consent form to participate in the research, two sessions were

scheduled. In the first session the three input instruments were applied for one hour, then proceeded for 15 minutes to the explanation and handling of the HTC Vive HMDs and Google's software for artistic drawing Tilt Brush. The first session ended with each participant using the equipment and software for 20 minutes. At the end of this session each participant was given the poem "El Viento" by Peruvian writer José María Eguren. No explanation was given beyond reading, understanding, and recognizing the feelings and sensations that this text generated.

The second session began with the explanation of the design theme: to generate an architectural idea for a "Livable Sculpture" that would allow them to experience the sensations of the poem studied. It was emphasized that the goal was not to produce a precise and finalized proposal but to develop an idea that could be further refined later. They were also asked to record the whole ideation process. In the IVR environment, participants were given 25 minutes to create three-dimensional drawings of their initial ideas. This was followed by a five-minute break to drink high-electrolyte fluid. They then continued for another 25 minutes to resume initial drawings, ending attempts, and finalize the idea. Figure 2 shows the students' IVR drawing process and the result obtained.



Figure 2. The students creating their designs with de
HMD HTC Vive and de Tilt Brush software and the obtained results.

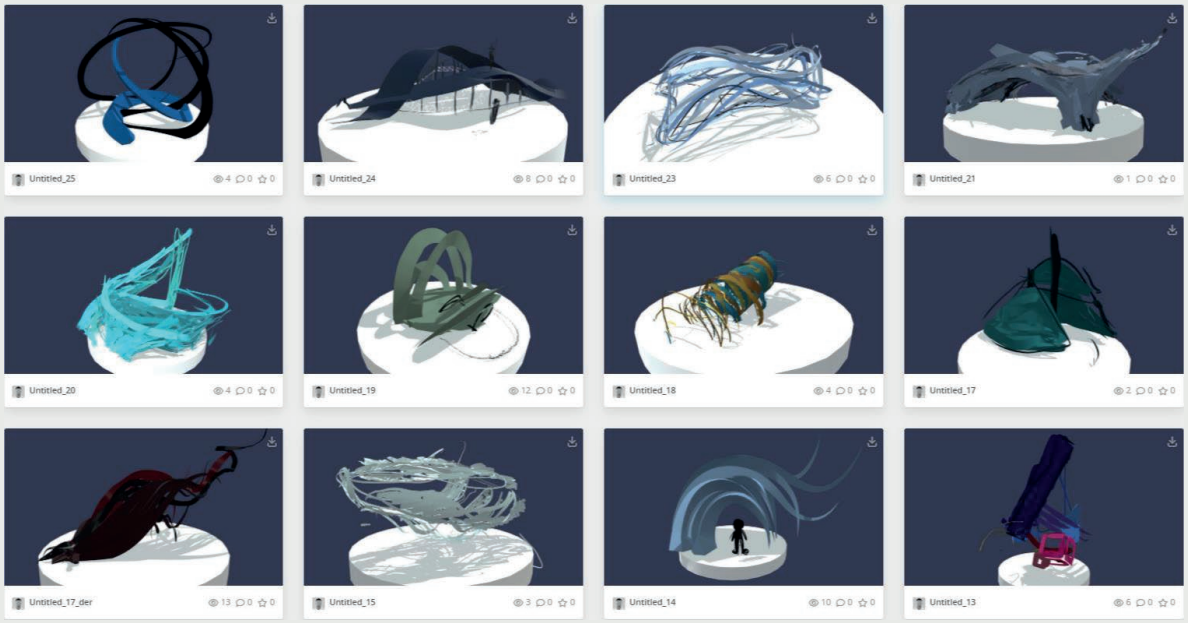


Figure 3. Some examples of designs made by the students (available at https://sketchfab.com/johnbel/collections/ivr-b8be915b5d6949dbafec60a2c7a3cac3)

3. Results

The evaluation of creativity levels measured using TTCT shows on average a slight superiority in favor of the experts. In the disaggregate, novices stand out in originality and fluency in comparison with the expert who stand out in flexibility and elaboration (table 3).

Table 3. Test averages and scores obtained from the evaluation of the IVR designed object.

	TTCT					Creativity Score (CR-R)					DAT -SR	MRT	Spatial Skill Score (SS-R)
	Originality	Elaboration	Fluency	Flexibility	**Total**	Originality	Elaboration	Fluency	Flexibility	**Total**			
Novices (n=14)	42.57	8.79	19.50	10.29	**78.45**	6.29	5.71	8.29	5.43	**25.71**	**40.37**	**24.04**	**34.14**
Experts (n=14)	39.99	9.13	18.71	10.63	**81.14**	6.14	6.71	3.86	4.43	**21.14**	**40.86**	**23.14**	**32.71**
Max score					255					40	50	40	40

This trend is even more pronounced in the evaluation with CR-IVR, where novices, in addition to standing out in originality and flexibility, stand out significantly in fluency. As for the measurement of the SS levels, there is a very slight difference between the DAT-SR and the MRT, however, when evaluating the three-dimensionality of the designed objects, novices demonstrated a greater advantage (table 3).

For a better comparison of the TTCT values (maximum score 255) and the values of creativity evaluated

with CR-IVR (maximum score 40), the TTCT values have been scaled to a maximum of 40. Figure 4 illustrates a correlation between the TTCT scores and the results of the CR-IVR. The comparison reveals that despite having a higher average TTCT score, the experts did not achieve as creative responses in IVR as the novices did. In novices the curve of TTCT values is steeper than the curve of IVR design results. This result suggests that the differences in creativity are narrowing in IVR context. Conversely, for the experts the curve of the results is steeper than that of TTCT. This shows that the more creative ones obtained a more creative design in IVR, and the less creative ones did not take advantage of the tool and obtained less creative designs.

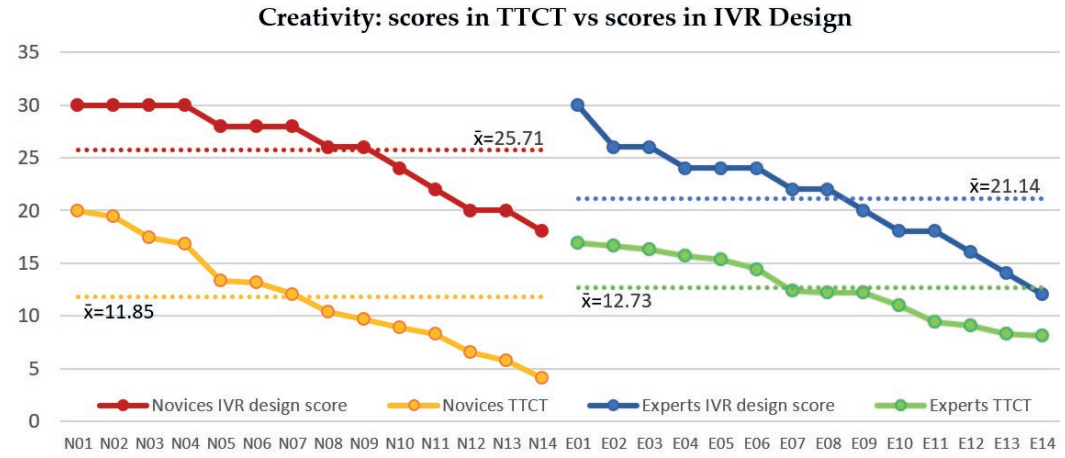


Figure 4. The evaluation of the creativity level using the TTCT and the CR-IVR (grade sheet in IVR)

The SS results evaluated with the DAT-SR compared to the SS-IVR scores show that there is a correlation between the spatial visualization levels and the mastery and outcome of the three dimensions of the designed object. Another result found in both groups is that the slope of the SS-IVR trend line is smoother than the slope of the DAT-SR test. See figure 5 for the flatter Novices and Experts IVR design score (SS-IVR) curves than the steeper Novices and Experts MRT curves. This result shows that the IVR environment reduces spatial visualization cognitive differences by making participants better understand and master the three dimensions. With the MRT there is also a correlation between the level of spatial rotation and the three-dimensionality of the final object.

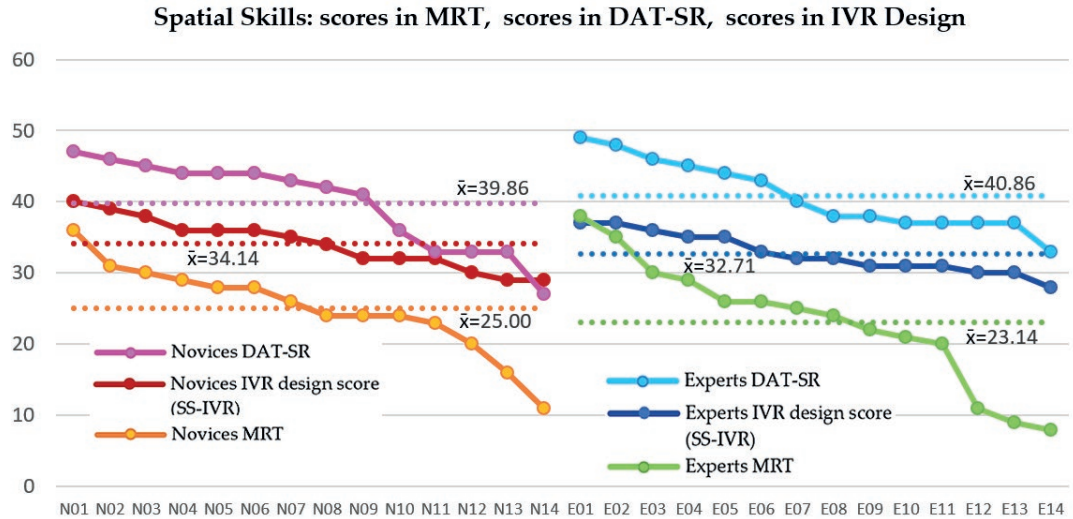


Figure 5. The evaluation of the SS levels using DAT-SR, MRT and the SS-IVR (grade sheet in IVR)

In this case, it is a little steeper the curves of the values obtained in the MRT than the SS-IVR. Figure 5 also shows that students with lower values in the MRT (see the right end of the curves) achieve much better levels of three-dimensionality of the designed object in IVR.

4. Discussion

IVR offers different possibilities to explore and express ideas in the drawing and design process compared to traditional methods due to immersion, presence and immediate design feedback [14]. These benefits have been reflected in this research by introducing IVR as a tool for architectural conception drawing. It has been found that using HMDs with haptic controls on both hands and the use of the artistic application Tilt Brush, students have shown greater creativity in CR-IVR than their TTCT values. IVR has enhanced creativity particularly in the fluency and elaboration components in both novices and experts. But it has been fluency which has been enhanced with more emphasis in the novices probably since in the first year the design process itself is studied in great detail and applied to small architectural objects. In contrast, experts learn over the years that almost any idea is good if it can be developed properly, which may be limiting their level of fluency but further developing their elaboration component. This has been the case in the experimentation; the experts have slightly outperformed the novices in the elaboration of their ideas in IVR.

Although expressing creative ideas does not require high SS levels, for Architectural Conception Drawing which involves the creation of a three-dimensional object, this cognitive skill is required to achieve complex three-dimensional responses rather than simple additive forms [7]. IVR has enabled novices and experts both to develop a highly complex three-dimensional concept drawing. In IVR it is possible to directly visualize and manipulate the objects that are being created, and it is exactly the skills which are measured in DAT-SR and MRT. It is clear that both groups have taken advantage of the benefits of the IVR to execute conception drawings with mastery of three-dimensionality, complexity, depth, and scale.

This research has an exploratory scope with an experimental design. A methodology was designed with a non-probabilistic sampling therefore it is not intended to generalize the results to the total population under study. However, the findings of this research show clear evidence of an imminent paradigm change in the conception drawing in architecture. For future research, it is suggested to design with probability sampling, control groups and longitudinal designs to determine more significant relationships in this area of knowledge.

5. Conclusions

This research concludes that an IVR environment using HMDs with haptic controls and the Tilt Brush artistic drawing application is the optimal tool to visualize and directly manipulate three-dimensional drawings and to achieve creative ideas through the conception drawing of a small architectural space. This conclusion is reached after an experimentation carried out with 28 students from the Universidad Nacional de San Agustín de Arequipa in Peru, 14 novices and 14 experts after being evaluated with three input instruments (TTCT, DAT-SR and MRT) and two output instruments (CR-IVR and SS-IVR). The IVR environment is favorable for fostering all four components of creativity through conception drawings. However, two components are most favored: fluency in novices and elaboration in experts since easy, real-time, freehand drawing in IVR is unrestricted by space, technique, or mental mastery of three-dimensionality. Also, the IVR environment is favorable for visualizing and directly manipulating the objects being created in such a way as to achieve conception drawings with mastery of three-dimensionality, complexity, depth, and scale. This has been more exploited by the novices but both groups have shown a mastery in the skill of generating and

manipulating complex and well-structured three-dimensional objects over their measurements with DAT-SR and MRT. It is considered as a future work to carry out an experimentation with control groups and in different time intervals to obtain more conclusive results.

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